CHAPTER 18

ELECTRICITY FUTURES

Paolo Falbo, Daniele Felletti and Silvana Stefani

Abstract: This chapter describes forwards and futures for electricity currently traded in Europe and other markets. Due to the non-storability of electricity, spot prices are highly dependent on local supply and demand conditions, business activity, and weather conditions. Seasonality is also very strong during the day (peak versus off-peak hours), during the week, and during cold and hot seasons. As a consequence, liquidity is low and the day-to-day volatility is much higher than in financial markets. Electricity futures and forwards may help generators, consumers, and marketers to manage volatility, but they also introduce risks of their own. The vast literature shows the elusive behavior of the so-called risk premia. We evaluate the *ex post* performance of monthly base load futures contracts on the Italian market in 2008–2013. We propose and test a linear approximation of the risk premium with respect to the time to maturity.

Keywords:

Introduction

Electricity is a flow rather than a stock commodity: it is produced and consumed instantaneously and continuously. Once generated, electricity cannot be stored. These peculiar characteristics make pricing of futures and forwards one of the most interesting and challenging questions among all the financial markets. Since the cost-of-carry approach as a non-arbitrage condition cannot be applied here, it is recognized that pricing futures and forwards is not feasible with the classical and accepted models that are currently applied to commodities and financial products. On the other hand, inelastic demand and uncertainty in supply, combined with non-storability, make electricity the most volatile traded "commodity". Thus, the mechanism behind future price formation is of utmost importance, since all electricity market participants are well aware of the importance and necessity of risk management. Understanding the nature of the deviation of future prices from expected spot prices (the so-called risk premium) is particularly crucial, but so far rather elusive. The question is still open. The literature on futures and forwards and their relationship with the underlying electricity spot is quite vast and will be shortly reviewed here.

The classical approach on commodity futures prices is described in Fama and French (1987). It is related to *the theory of storage* and is linked to the cost of convenience of holding inventories. In the theory of storage, traders can offset their position in forwards by holding long or short inventory in the underlying commodity. Therefore, the prices for delivery at a future time period depend on the current price of the commodity accrued by the convenience yield that accounts for the expected additional value of inventory. An alternative approach to modeling forward and futures prices is based on *expectation theory*. The forward price of a commodity is modeled as the expected spot price of the underlying commodity during the delivery period plus a risk premium that should compensate producers for swapping uncertainty against fixed prices (also called hedging pressure). Although it is argued that these two theories are not mutually exclusive, nevertheless the expectation theory is the starting point for many electricity forward price models. In fact, since electricity is not storable, it makes sense to rely on expectation theory instead of the theory of storage. Bessembinder and Lemmon (2002) develop an equilibrium model for electricity forward prices based on the assumptions that both the supply and demand sides are risk averse and that electricity cannot be stored. The forward power price becomes/serves as a downward biased predictor of the future spot price if expected power demand is low and demand risk is moderate. The revealed market premia should emerge as the net hedging costs from the different risk aversion of generators and retailers in the spot market. Furthermore, the difference between the forward price and the realized spot price (which is the standard way of defining risk premia) decreases with the anticipated variance of spot prices and increases with the anticipated skewness of spot prices. In addition, because electricity is a derived commodity in the sense that market prices are often set by technologies that convert gas or coal into power, it is an open question whether much of the premia in power may actually be related to fuel inventory. Lucia and Torrò (2011) empirically analyze the relationship between futures and spot prices for short-term futures contracts in the Nordic Power Exchange. They find positive, significant evidence of a deviation from futures and underlying spots, the significance and the size of it varying seasonally and with the level of hydro reservoirs. Douglas and Popova (2008) and Bloys van Traslong and Huisman (2010) find some evidence in favor of a relation between the electricity forward premium and gas storage inventories. Huisman and Kilic (2012) examine to what extent electricity futures price contain expected risk premium or have power to forecast spot prices and whether this might be dependent on the type of electricity supply. They find time varying risk premia in the Dutch market and not in Nordpool, so they conclude that the same model cannot be applied to all electricity markets. Botterud *et al.* (2010) analyze spot and futures prices for Nordpool, and find that futures prices tend to be higher than spot prices. They argue that differences between the supply and demand in term of risk preferences and the ability to take advantage of short-term price variations can contribute to explain the observed relation between futures and spot prices. Bunn and Chen (2013) focus on the problem of estimating *ex post* the *ex ante* premium for risk. They propose a model taking into account various sources of risk such as statistical risk, fundamental risk, and behavioral risk. Pietz (2009) analyzes futures prices in the German market EEX from an *ex post* perspective and finds evidence of significant positive risk premia in 1 month and 3 month futures. The chapter also discusses the significance of *ex ante* with respect to *ex post* risk premia.

Our work contributes to the existing literature on futures in electricity markets by analyzing empirically the deviation of futures prices from observed spot prices. The analysis is carried on the Italian forward base load monthly contracts (2008–2012). The results show the presence of an aggregate positive risk premium. However, case by case, a clear non-convergence of futures to the underlying spot prices (or average of them) is shown. Moreover, a positive variance of the payoff is found at delivery.

The results highlight the peculiarities of the electricity market and show how more research should be done on modeling futures, since most of the rules valid for the other financial and commodity markets do not hold here.

A brief description of spot electricity markets is given in the second section. The peculiarities of forward/futures electricity markets are described in the third section. The empirical analysis is carried out in the fourth section. Conclusions are in the fifth section.

Electricity Markets

The restructuring process of the electricity sector in many countries worldwide has been accompanied by the opening of competitive spot electricity markets. Prior to deregulation, electricity prices were relatively steady. After deregulation and introducing competition in wholesale and retail electricity markets, electricity prices have been among the most volatile of any traded commodity.

The debate over information efficiency of different kinds of financial markets have developed extensively. Electricity markets have remained outside of this debate for a long period of time, since their liberalization has arrived in a relatively recent period (both in the U.S. and EU countries), with respect to other more traditional commodity markets. Some empirical analyses have proved that power markets have greatly improved their efficiency after liberalization (see for example, Mansur and White, 2012). Turning more specifically to electricity futures markets, the literature is less developed. An example is the work of Feng *et al.* (2007) focusing on the Nordpool futures market in North Europe.

Electricity prices are usually divided into baseload and peakload prices, according to the time of the day. In the United States, peak hours usually occur in the afternoon, especially during the summer months when the air conditioning load is high. During this time, many workplaces are still open and consuming power. Peak hours can also occur in the evening after work hours, when household appliances are heavily used. Baseload (off peak) and peak hours vary across countries, according to the demand profile. Baseload plants are used during baseload hours and produce energy at a constant rate, usually at a low cost relative to other production facilities available to the system. Examples of baseload plants using non-renewable fuels include nuclear and coal-fired plants. Peak power plants are power plants that generally run only under peak demand for electricity. Because they supply power only occasionally, the electricity is supplied at a much higher price per kilowatt hour than base load power. Peak plants are generally gas turbines that burn natural gas.

Even though power production and transmission capacity has been extended over the years and transmission of power between countries has become more common, electricity markets are local. Prices can vary substantially across countries, also according to the input used for production. In France, baseload production is provided by nuclear plants, among the cheapest sources of energy; in Nordic countries, hydroelectric plants produce most of the electricity needed. Poland and Germany use coal, Italy oil and gas. Since 2006, the spectacular growth of renewable production (essentially Photovoltaic (PV) and wind), has changed the scenario. Prices have decreased both in peak hours (due to PV) and in off peak hours (due to wind).

Electricity markets include the Day-Ahead market for selling and buying power for the following day, the Adjustment Market for input/output adjustment based on outcomes on the Day-Ahead market, and the Dispatching Services Market for the physical balance in real time of the volumes of energy are fed into and withdrawn from the system. In this chapter, like in the current literature, we will refer to the Day-Ahead market. In the Day-Ahead market, which is considered as the electricity spot market, the mechanism to fix market electricity spot prices is regulated by a uniform auction. Electricity producers submit bids for each generating unit. The price/capacity bids are used to construct a 'merit order' of generating units, i.e., a market supply curve, subject to transmission costs and constraints. The intersection of the market supply curve with estimated demand determines the 'system marginal price' (SMP), i.e., the spot price, for each hour. Price formation is usually taken as the offer of the most expensive plant needed at that time. Thus, the highest marginal cost generator makes the price.

A peculiar characteristic of electricity is non-storability; it cannot be stored in warehouses like the great majority of commodities, and at any moment demand has to be met by electricity produced at the same time. So, electricity prices are primarily driven by spot demand and supply. Price fluctuations are the result of marginal cost fluctuations. As far as the demand is concerned, demand for electricity fluctuates daily, according to peak or off-peak hours, day and night. Demand is highly local. Spain has a different demand profile than Germany. North Italy has a different demand profile than South Italy. Moreover, electricity demand in the short-term market is fairly inelastic and cannot be met by/through clearing the inventory. Therefore, unexpected demand shocks due, for example, to extreme weather conditions (particularly cold or hot days) or additional need of power (typically Christmas holidays), cause an upward shift in the demand-supply curve.

From the side of supply, production costs vary substantially between different types of installation: at one extreme, wind, sun and hydropower are practically at zero cost with gas turbines at the other end of the scale. As soon as demand increases, more expensive plants enter into production and unexpected outages or disruption in transmission make the supply-demand curve shift upwards and prices jump. As a result, sudden jumps in prices (spikes) can occur. The "storage limitation" problem causes a highly volatile day-to-day behavior of the spot prices, far more volatile than in financial markets. Seasonality is also very strong, during the day (peak versus off-peak hours), during the week, during cold and hot seasons. To give an idea, in "ordinary" financial series volatility is about 10–20% of average prices, in commodities this figure can reach 80–100%,

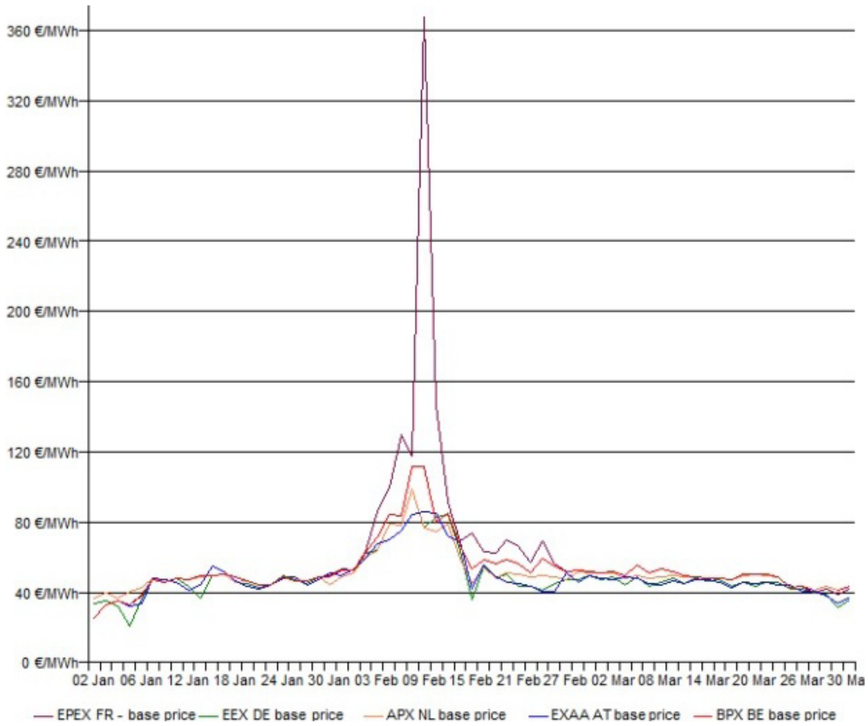

Figure 18.1. AT, BE, DE, FR, NL — Daily baseload prices 2012.

and in some electricity prices it is 300–450%. Many models have been proposed to capture the specifics of spot prices by taking into account seasonality, high volatility, mean reversion: see for example Mayer *et al.* (2011), Geman and Roncoroni (2006), Geman (2005), Deng (2000), Eydeland and Geman (1999), and Wolak (1997). The matter is still open. In Figure 18.1, daily baseload prices for Center Western Europe (Austria, Belgium, Germany, France, and the Netherlands) are reported (Year 2012, EU 2012). In February 11, a spike occurred in the EPEX Market, bringing the price to over 360€MWh.

Summing up, Table 18.1 describes synthetically the major differences between electricity and financial markets (Falbo *et al.*, 2010a).

All these specific peculiarities make electricity markets hard to model.

Table 18.1. Main differences between financial markets and electricity markets.

Issue	In financial markets	In electricity markets
Maturity of market	Several decades	Relatively new
Market activity (liquidity)	High	Low
Impact of storage	Low	High
Impact of meteorological events	Low	Very high
Impact of seasonality	Low	Very high
Impact of economic cycles	High	High

Futures and Forward Markets

Electricity suppliers face two sources of risk: uncertainty of spot prices and uncertainty of production costs. Risk management can be a serious challenge for electricity companies, mainly of small size, because of price volatility and production risks. Power generation companies seek certainty in their costs and revenues through hedging practices, contracting, and active trading. Power marketers sell to both utilities and retail consumers, often through fixed medium term bilateral contracts in which they face the risk of buying back electricity to the spot market. Utilities managers buy electricity and sell it to consumers; they often buy at fixed prices and face the risk of buying at prices higher than the current price at the moment of delivery. Furthermore, a traditional and explicit goal of utility regulation has been to stabilize retail prices, even though nowadays electricity prices are volatile. This constraint introduces a further source of uncertainty for producers and marketers, since there is no flexibility to adjust costs to final selling prices. The entire sector, from generators to consumers, faces risk. Uncontrolled exposure to market price risks can lead to devastating consequences for market participants. The California electricity crisis of 2000/2001 is largely attributed to the fact that the major utilities were not properly hedged through long-term supply contracts. Furthermore, lessons learned from the financial markets suggest that financial derivatives, when well understood and properly utilized, are beneficial to the sharing and controlling of undesired risks through properly structured hedging strategies (Deng and Oren, 2006). For these reasons, derivative instruments to hedge against volatility are essential in the electricity markets. In particular, electricity futures and forwards may help generators, consumers and marketers to manage volatility, but they also introduce risks of their own. Among other sources of risk, in Falbo *et al.* (2010a), the perverse effect on hedging strategies of a poorly designed spot price index is described. A usual way to hedge against price uncertainty in electricity markets is signing forwards. In fact, less than 5% of the whole of European electricity is traded on the spot markets (Wu *et al.*, 2002; Routledge *et al.*, 2000). Since forwards allow for the sale of production in advance at a given price, but do not hedge against fuel cost volatility, the total risk can be reduced by selling also in the spot market (Falbo *et al.*, 2010b).

New York Mercantile Exchange (NYMEX) issued the first electricity futures contracts in March 1996, the California–Oregon Border (COB) and Palo Verde (PV) futures contracts. Currently, futures contracts are traded in almost all electricity markets in Europe and the United States. German/Austrian and French futures are traded in the EEX market. The Nordic Power Exchange (Nord Pool), the first multinational exchange for electricity trading, has existed since January 1996. Spot and futures contracts are traded here. Finally, the Singapore Exchange (SGX) is developing Asia's first electricity futures market with a targeted launch by end-2014.

Futures and forward contracts

Also for electricity markets, as well as in many other cases, futures and forward contracts are basically the same. They consist of an agreement between two parties on fixing a price for the delivery of a given quantity of electricity over an established period of time.

The relevant differences between forward and futures contracts are related to the exchange place (futures are traded on institutional exchanges while forwards are traded in no central place and their prices are made publicly available through brokers' circuits), the presence of a clearing house and of a mandatory margin (futures have them, forwards do not), the delivery of the underlying asset (futures are almost always settled by cash, forwards most of the time by physical delivery), the standardization of the maturities and the lengths of the delivery periods (futures are subject to standardization, forwards are not), and the typical size of the contract (futures are usually expressed in units equal to 1 MWh, forwards usually adopt multiples of 5 MWh).

A consequence of non-storability of electricity is that the only possible delivery is through a supply over a period of time. Indeed, the entire lifecycle of a standard futures/forward contract on electricity can be divided in a *trading period* and a *delivery period*. Differently from the classical case, the convergence of futures price to spot does not hold here. At the end of the trading period futures prices expire, yet the spot price continues evolving during the entire delivery period. Figure 18.2 synthesizes the relevant dates and periods required to model a futures contract.

Parties can open positions on forward and futures contracts only before the delivery period. At maturity (T), that is, at the end of the delivery period H, contracts expire. If physical delivery was agreed, the seller fulfills his obligation by supplying the due quantity of energy. If cash settlement was agreed, payoff calculation is possible, and the corresponding payment concludes the contract.

Delivery periods H usually last either a month, a quarter, or a year. Any period H contains a variable number of hours, depending on the calendar. We use the number of hours to measure the length of a period, so, for example, delivery period of February 2012 had length $\#(H = \text{Feb-2012}) = 29{*}24 = 696$, while $\#(H = \text{Feb-2013}) = 28{*}24 = 672$.

It is also of major relevance to notice that futures and forwards should not be regarded as derivative contracts. The major argument

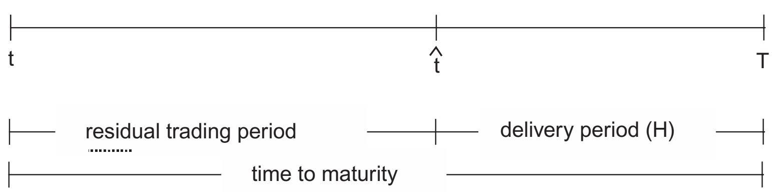

Figure 18.2. Time framework.

to support this view is again the technical impossibility to store any significant quantity of this commodity. When the storage of the underlying asset is not possible, arbitrage opportunities are ruled out and therefore nothing can enforce futures prices to coincide with the spot price (adjusted for the interest rate and time to maturity). Futures prices of electricity are subject only to the equilibrium between demand and offer as a standard primary asset.

We name the spot index price of electricity of day t as p_t. We assume that it is calculated as an arithmetic average of the 24 hourly prices:

$$p_t = \frac{1}{24}\sum_{h=1}^{24} p_{t,h}. \tag{18.1}$$

The arithmetic average is the standard way to calculate the daily index price in most electricity markets worldwide, even though exceptions exist (see on this topic Falbo *et al.*, 2010a). Another relevant index in the electricity markets is the peak load index, which is calculated over peak hours, usually between 9 a.m. to 8 p.m., only for the working days.

The price fixed in a futures contract for delivery of 1 MWh on period H agreed on day t is referred to as *futures price* and it is labeled as $f_{t,H}$. As already mentioned, in most cases in a futures contract at the end of the trading period the parties agree not to settle their contract through physical delivery, but prefer a cash settlement. In both cases the profit/loss is calculated as the difference between the average electricity price and $f_{t,H}$ observed during H. In particular, letting the *ex post* average price of electricity of period H, $\bar{p}_H$, be equal to:

$$\bar{p}_H = \frac{1}{\#(H)}\sum(t,h) \in H p_{t,h} \tag{18.2}$$

the payoff of a futures contract signed in t for period H is

$$y_{\tau,H} = y_{T(H)-t,H} = \bar{p}_H - f_{t,H},$$

where $\tau = T(H)-t$ is the time to maturity, that is the number of days between the last delivery date of period H (i.e. $T(H)$) and t. τ can never be less than the length of H. Such a payoff is sometimes referred in the literature as the risk premium, even though we do not agree on such a definition. Indeed, in absence of a meaningful hypothesis to differentiate the buyers from the sellers, from a financial point of view, in a futures contract both parties have a symmetric position with no explicit risk transfer from one party to the other.

Empirical Analysis

In this section, after some preliminary data description, we introduce and estimate a simple linear model of the risk premium. Furthermore, we develop a modified version of the Lo and Mackinlay variance ratio test to verify if futures prices follow a Brownian motion.

Data

In this analysis we analyze the time series of the real-time forward contracts observed in Italy during the periods from January 2008 up to November 2013. The forward electricity market in Italy captures by far a larger quota of the total volume of the contracts for delivery than the futures market organized by GME (the Italian Exchange Authority for electricity) and IDEX (the electricity futures market organized by the Italian Stock Exchange).

Real time quotations are accessible through a brokerage trading platform, where the bids of producers and retailers are collected and shared.

The values of $y_{t,H}$ have been calculated on a daily basis. In particular, $f_{t,H}$ have been identified with the latest quotation of day t, as long as a deal (at least) occurred in t.

Figure 18.3 shows several trajectories of the premium process calculated *ex post* for the (monthly) delivery periods from Jan-2012 to Nov-2013.

We can distinguish different cases. The expected behavior of these trajectories under the hypothesis of symmetric risk aversion, are those of Jan-2012 (2012_M01 in the figure; it matches immediately the price and moves around it) and Jul-2012 (similar to Jan-2012 but with a larger volatility). Dec-2012, Feb-2013, and Nov-2013 are

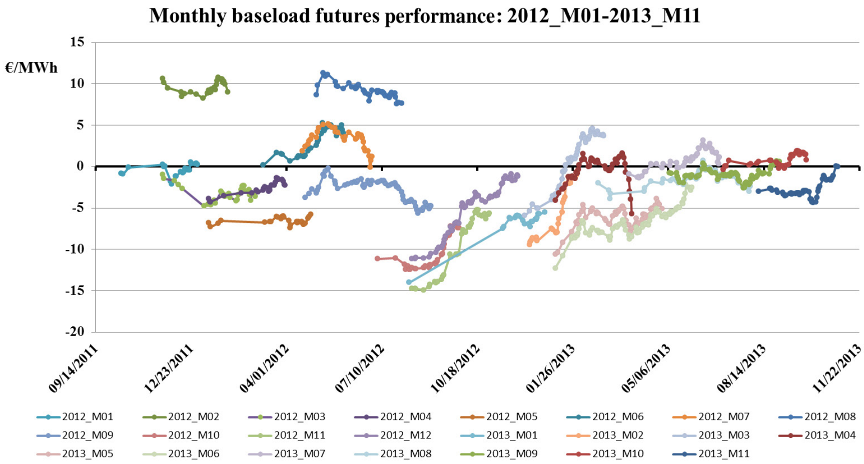

Figure 18.3. Trajectories of the payoff of monthly base load futures on Italian market from 2012_M01 to 2013_M11.

also "regular", that is, they start far from zero but approach the correct value as the trading period finishes. However, the trajectory of Mar-2013 shows a clear trend, so that the trajectory crosses the target. Then there are contracts that never match the target, like Feb-2012 and Aug-2012 (typically this is due to unexpectedly high spot prices during the delivery period). Finally there are cases, like Sep-2012, of a diverging trend moving the trajectory far from 0, and totally odd cases like Apr-2013.

Are futures prices unbiased estimates of spot electricity prices?

Let us observe some preliminary evidence. In Figure 18.4, each candle summarizes the series of futures prices for each monthly contract H. According to candlestick graphs, black candles represent the case of a trajectory where

$$y_{\hat{t}} < y_{t_0},$$

i.e.,

$$f_{\hat{t},H} > f_{t_0,H},$$

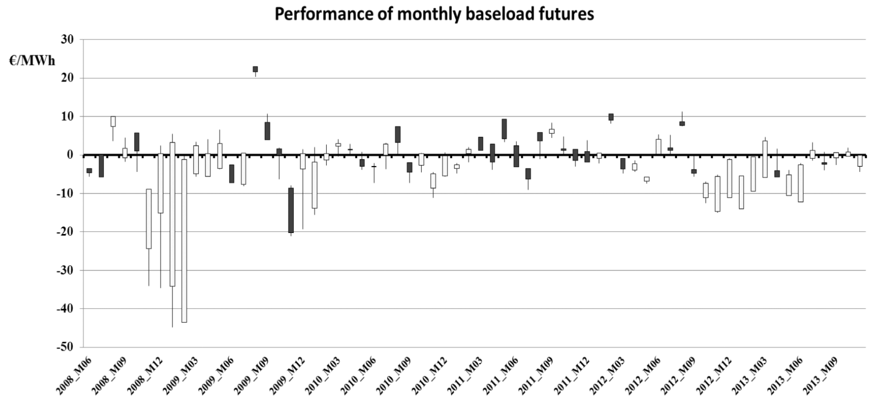

Figure 18.4. This candlestick plot represents the performance of baseload monthly futures. Black candle stands for closing futures price higher than the starting value (the opposite applies for the white color). In our case the starting date varies from case to case; the closing date is typically in $\hat{t}$.

where t_0 is the starting day of futures trading while the opposite applies to white color. The surprising cases are therefore represented by the black candles lying below zero, and the white ones lying above, since in both cases we are faced with trajectories which kept diverging away from zero during their trading period. These contracts, which are not a few, forecasted the spot price better at large time to maturities than at the end of the trading period.

Figures 18.5 and 18.6 show the y_τ values for the H periods analyzed here. In particular, Figure 18.5 focuses on monthly periods, while Figure 18.6 shows quarterly periods. Overall these two figures show that future prices do not match the spot price and that their uncertainty persists over time. This is particularly true for monthly contracts.

Observing the values of y_τ separately for each period H, it is apparent that futures prices tend not to be good forecasts of $\bar{p}_H$. However we must also consider the average behavior of y_τ, that is, the process of the payoff resulting from the average payoff of over all the future contracts.

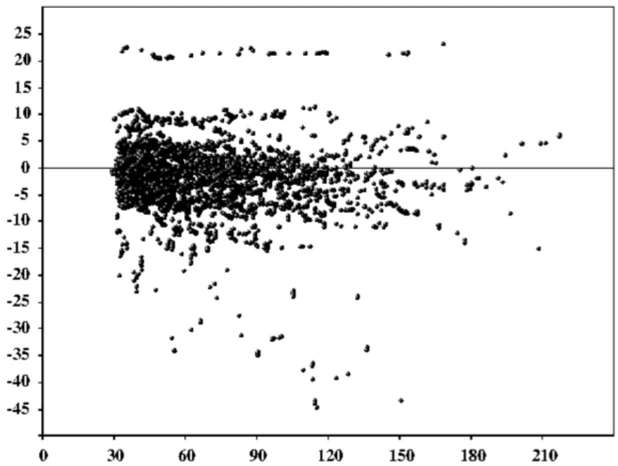

Figure 18.5. y_t values (€/MWh) of monthly baseload contracts on Italian market from Jun-2008 to Oct-2013 versus the time to maturity (days).

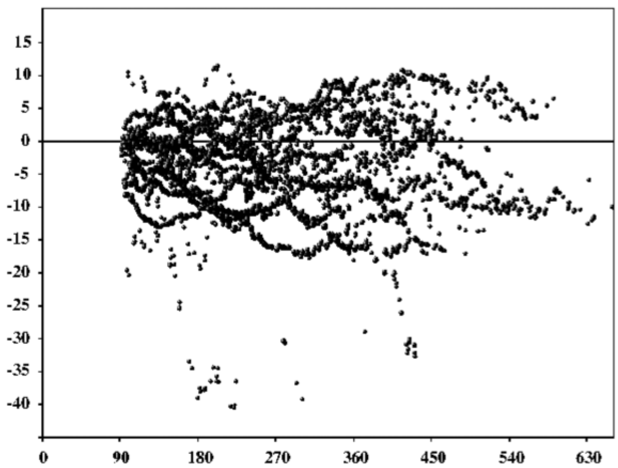

Figure 18.6. Performance (€/MWh) of quarterly baseload contracts on Italian market from Q4 2008 to Q3 2013 versus time to maturity (days).

Under the hypothesis that producers, retailers, and consumers of electricity have similar risk aversion and similar individual diversification opportunities, futures contracts on electricity should be fixed at a price reflecting unbiased estimates of future spot prices. Indeed both parties in a futures contract turn a future random payoff into a fixed one in a perfectly symmetric way. In competitive markets the buyer and the seller will agree to fix a price which lets them be indifferent with respect to the distribution of the future profit/losses (i.e., the distribution of $y_{\tau,H}$). Under the previous symmetry hypothesis the expected value of $y_{\tau,H}$ should be zero for both, that is to say

$$f_{t,H} = E[\bar{p}_H]. \tag{18.3}$$

Equation (18.3) tells us that futures prices are expected to be unbiased estimates of spot prices of electricity. To develop a test on such implication, we assume that futures prices follow a standard Brownian process with no drift:

$$df_{t,H} = \sigma_f dW_t. \tag{18.4}$$

Several empirical analyses tend to show that future prices do not have a significant trend. In Equation (18.4), we implicitly assume that futures prices follow the same stochastic process independently from the delivery period H.

We consider the following simple linear model for the payoff of a futures contract H:

$$E_t[\bar{p}_H] - f_{t,H} = r_H(T(H) - t) + b_H, \tag{18.5}$$

where b_H is a idiosyncratic random variable with zero expected value and r_H is a constant which reflects the risk premium of the futures prices. Observe that in the absence of any difference in the risk aversion between buyers and sellers, no risk premium should establish in the market, and Equation (18.5) coincides with Equation (18.3). Assuming that the expectation of $\bar{p}_H$ at time t coincides with its *ex post* realization, the empirical model of Equation (18.5) is

$$y_{\tau,H} = r_H(T(H) - t) + b_H + \epsilon_t.$$

Table 18.2. Regression results for all the futures contracts.

Coefficient	#cases	#cases $\neq 0$ significantly	Mean	Std. deviation
r_H	66	20	−0.0419	0.109
b_H	66	15	0.916	6.774

Table 18.2 reports the regression results obtained for all the futures contracts analyzed here.

As the table shows, in the majority of cases (40 out of 66) the estimate of parameter r_H is not significantly different from zero, as well as b_H (51 out of 66). At the same time b_H is not different from zero on average, as can be observed by comparing its mean with the standard deviation. Notice that b_H was indeed assumed as a zero mean random variable. The payoffs of futures contracts observed case by case look like trajectories with no trend (in most cases), exactly as Figure 18.3 shows.

Let us however consider the aggregate version of Equation (18.5), that is aggregating it over the H. In this way, we obtain the market equation of the expected payoff:

$$E_H[E_t[\bar{p}_H]] - E_H[f_{t,H}] = r(T - t), \tag{18.6}$$

where r is a coefficient reflecting the risk premium for the market overall. In particular, we should expect that r is zero if there is no significant different risk aversion between buyers and sellers. Again in Equation (18.6), we assume that the expectation of $\bar{p}_H$ at time t coincides with its *ex post* realization. In such a case the resulting empirical model for the overall market is:

$$E_H[\bar{p}_H - f_{t,H}] = E_H[y_\tau] = r(T - t) + b + e_t, \tag{18.7}$$

where b is expected to be not significantly different from zero and e_t is an error term. Figure 18.7 shows the resulting regression line of Equation (18.7), where data have been grouped into time intervals

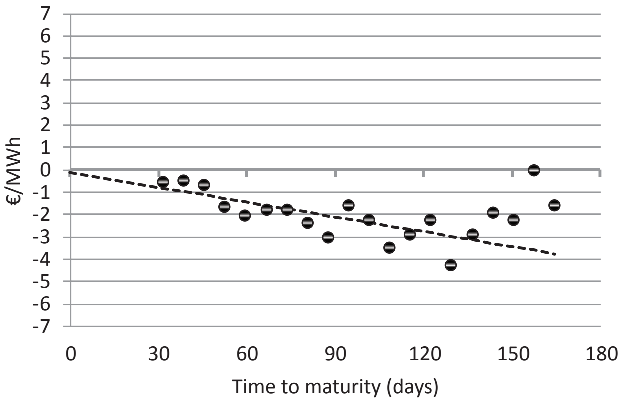

Figure 18.7. Average performance of monthly baseload contracts on Italian market versus time to maturity.

Table 18.3. Aggregated regression results.

Coefficient	Estimate	Standard error	t-Student value	$Pr > (t)$
r	-0.02207	0.0047	-4.67	0.0002
b	-0.1129	0.3633	-0.31	0.7594
$Std(y_t)$	0.0332	0.00745	4.46	0.0003
Intercept	3.95252	0.5723	6.91	<0.0001

of one week. As it was expected the regression line in Figure 18.7 shows that $E[y_\tau]$ tends to zero as $\tau \to 0$.

The estimated values of the regression of Equation (18.7) are summarized in the following Table 18.3.

Such a result confirms the empirical findings of the literature that there is a positive risk premium embedded in futures prices (recall that the negative value of the coefficient r is due to the fact that y_t is defined here as $\bar{p}_H - f_{t,H}$), so that they tend to over-estimate the spot price, with the over-estimation increasing linearly with the time to maturity. However, at the same time, we have already observed that this result does not hold observing futures contracts case by case. At the same time b is not significantly different from zero, as it was expected.

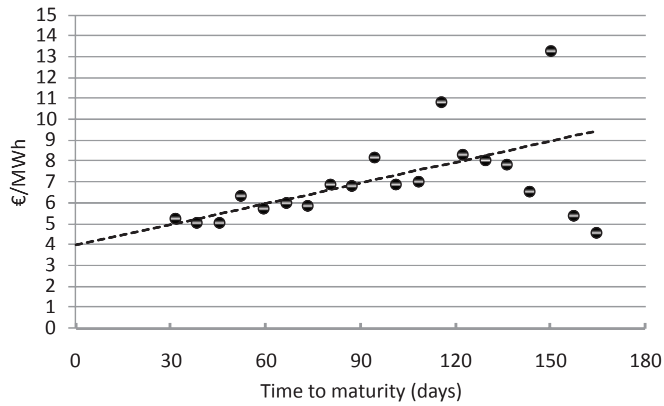

Figure 18.8. Standard deviation of the payoff of monthly baseload futures on Italian market versus time to maturity.

We next consider how the standard deviation of y_τ changes with respect to the time to maturity (see Figure 18.8), when grouping the observations in time intervals of one week.

As far as the standard deviation is concerned, a linear dependence on the maturity is found. Table 18.3 summarizes the estimation results obtained by regressing the standard deviation of y_τ with respect to the time to maturity over all the contracts. The results shown in Table 18.3 has been obtained considering the time to maturity with at least 10 observations.

It is relevant to observe that the intercept is significantly greater than zero. This means that there is a significant residual volatility of about 3.95 €/MWh. Indeed, such a residual volatility can be attributed to the variance of b (idiosyncratic error) and to that of e_t (the model error).

Volatility of futures prices

Following the analysis of Lo and Mackinlay (1988) on the test of random walk of financial securities, we address the same test to determine if futures prices on electricity follow a standard Brownian process. The relevance of such a test is motivated by the hypothesis of efficient markets. It is well known that Brownian motion is a reference model to describe efficient markets with respect to the definition of efficiency given by Fama (1970). The independent increments of Brownian motion and its simple analytical expression are ideal to represent the evolution of nonanticipating prices, that is, prices which include all the available information and consequently cannot provide any valuable information to anticipate the future evolution of the market.

The test of Lo and Mackinlay leverages the property that the variance of an increase of a Brownian motion over an interval between time t and time $t + k$ should increase linearly with k.

The weak liquidity of the Italian futures market requires a generalization of the original test (of Lo and Mackinlay) to account for the lack of regularity of the time intervals. In particular, for a generic futures contract H and given the property of linearity of variance of Brownian motion, we have that, for every H:

$$f_{t_{j+1}} = f_{t_j+\Delta t_j} = f_{\mathrm{t_j}} + \sigma_f \sqrt{\Delta t}_j \varepsilon_{f,j}. \tag{18.9}$$

The liquidity problem (i.e., "holes" in the time series) can be avoided by simply grouping the series into irregular intervals of time and making use of the identity implied by the model in Equation (18.9). The disturbance relative to the period $[t_j, t_{j+1}]$ (which is assumed to be Gaussian with null average as a consequence of the model) is

$$\sigma_f \varepsilon_{f,j} = \frac{f_{t_{j+1}} - f_{t_j}}{\sqrt{t_{j+1} - t_j}} = \Delta f_j \sim N(0, \sigma_f). \tag{18.10}$$

Collecting the values calculated in Equation (18.10) supplies an unbiased estimate of σ_f. The following Table 18.4 shows the estimates of the volatilities for each of the periods H analyzed here.

Table 18.4. Volatility of future contracts (€/MWh/day$^{0.5}$).

	M01	M02	M03	M04	M05	M06	M07	M08	M09	M10	M11	M12
2008						0.46	1.06	0.86	0.75	1.18	2.24	2.03
2009	2.19	1.37	0.85	0.55	0.67	0.34	0.73	0.29	0.49	0.76	2.01	1.81
2010	1.32	0.66	0.48	0.37	0.40	0.46	0.52	0.42	0.38	0.25	0.46	0.32
2011	0.41	0.30	0.30	0.62	0.39	0.25	0.35	0.38	0.31	0.43	0.51	0.38
2012	0.33	0.32	0.36	0.23	0.25	0.37	0.45	0.31	0.28	0.35	0.38	0.33
2013	0.25	0.56	0.37	0.52	0.41	0.36	0.37	0.35	0.29	0.27	0.28	

Based on this we modify the Lo and Mackinlay test in the following way. We applied the test only on two consecutive time intervals (of varying length). Table 18.5 shows the confidence levels to accepting correctly the null hypothesis (i.e., that the (corrected) variance over two time intervals is two times than that observed on a single time interval). Clearly the null is accepted always with a confidence equal or more than 95%.

In the following Table 18.6 we consider the differences $\bar{p}_H - f_{\hat{t}}$ for the different contracts H. Given the volatility estimates calculated in Table 18.4, for each H we evaluated the probabilities that those differences are sampled from a normal distribution with parameters 0 and σ.

So, the volatility measured over the single contracts appears perfectly compatible with a Brownian motion.

On the contrary, y_t shows a variance which is not perfectly linear with time. In particular, Figure 18.8 shows an affine growth of the variance with respect to the time to maturity, with a value equal to about 4.31€^{2}/MWh^2 at $\tau = 0$. Such a residual variance is possible because arbitrage does not hold on electricity markets. Such a result is useful for shedding some light on the process of the spot prices of electricity, in particular on the process underlying $\bar{p}_H$. Indeed, the fact that when the time to maturity tends to zero, the variance of y_t does not become null implies that the residual variance originates from $\bar{p}_H$.

Table 18.5. Confidence to accept the null (i.e., variance grows linearly with the time lag) according to Lo–Mackinlay test.

	M01	M02	M03	M04	M05	M06	M07	M08	M09	M10	M11	M12
2008						98.9%	99.3%	99.5%	99.1%	96.9%	98.4%	99.6%
2009	97.4%	95.9%	99.4%	99.8%	98.7%	98.6%	98.8%	98.2%	99.0%	98.2%	98.7%	100%
2010	98.8%	98.1%	99.7%	99.0%	97.7%	99.4%	99.9%	99.8%	99.3%	99.2%	98.1%	99.9%
2011	97.9%	98.0%	99.4%	99.4%	99.2%	99.3%	99.7%	99.0%	99.5%	98.6%	99.2%	99.4%
2012	99.6%	99.7%	99.4%	99.3%	99.2%	99.4%	99.4%	99.7%	99.8%	99.9%	99.7%	99.7%
2013	99.8%	98.9%	99.9%	99.5%	99.7%	100%	99.1%	99.7%	100%	99.9%	99.8%	

Table 18.6. Confidence of the future contract price jump during the delivery period.

	M01	M02	M03	M04	M05	M06	M07	M08	M09	M10	M11	M12
2008						7.9%	36.7%	**4.4%**	69.5%	87.9%	48.6%	97.6%
2009	79.7%	87.8%	62.7%	90.8%	45.0%	**0.0%**	90.4%	**0.0%**	16.2%	98.7%	8.1%	97.1%
2010	80.8%	92.4%	30.8%	48.2%	19.5%	26.8%	33.2%	19.1%	**3.5%**	84.5%	6.3%	90.6%
2011	28.3%	37.5%	51.3%	58.7%	6.0%	**3.0%**	**0.2%**	10.3%	**0.0%**	62.4%	63.1%	39.9%
2012	81.2%	**0.0%**	8.7%	8.2%	**0.0%**	5.4%	64.0%	**0.0%**	**0.3%**	**0.0%**	**0.8%**	54.2%
2013	**0.0%**	86.2%	8.1%	5.9%	**2.9%**	21.6%	59.4%	23.2%	70.2%	61.2%	99.1%	

Conclusions

In electricity markets, since storage of the underlying asset is not possible, arbitrage opportunities are ruled out and therefore nothing can force futures prices to coincide with the underlying spot price (adjusted for the interest rate and time to maturity). Consequently, risk premia show elusive behavior all over the electricity markets. We introduced and estimated a simple linear model of the risk premium. The analysis developed on the Italian case in 2008–2013 shows a possible presence of positive risk premia on an aggregate level. In particular, we found a significant risk premium of 2.2 c€/MWh/day. Such a result apparently confirms some empirical findings in the literature that there is a positive risk premium embedded in futures prices. However, the positive risk premium disappears when checking for the performance case by case of individual contracts. Moreover, the volatility of the payoffs is always positive when maturity approaches to zero and even at delivery. In particular, an affine growth of the volatility with respect to the time to maturity is found, with a value equal to about 3.95€/MWh at maturity. Furthermore, while we found evidence that futures follow a Brownian motion, the volatility of the risk premium is not compatible with it. This may give some hints for developing new models for spot prices.

References

Bessembinder, H and M Lemmon (2002). Equilibrium pricing and optimal hedging in electricity forward markets. *Journal of Finance*, 57, 1347–1382.

Bloys van Treslong and R Hiusman (2010). A comment on: Storage and the electricity forward premium. *Energy Economics*, 32, 321–324.

Botterud, A, T Kristiansen and M Ilic (2010). The relationship between spot and futures prices in the Nord pool electricity market. *Energy Economics*, 31, 967–978.

Brooks, R and AA El Keib (1998). A life-cycle view of electricity futures contracts. *Journal of Energy Finance and Development*, 3, 171–183.

Bunn, DW and D Chen (2013). The forward premium in electricity futures. *Journal of Empirical Finance*, 23, 173–186.

Commission of the European Communities (2004). Communication from the commission — inquiry pursuant to article 17 of regulation (ec) no 1-2003 into the European gas and electricity sectors. Final Report SEC.

Deng, SJ and SS Oren (2006). Electricity derivatives and risk management. *Energy*, 31, 940–953.

Deng, S (2000). Stochastic models of energy commodity prices and their applications: Mean reversion with jumps and spikes. Power PWP-073.

EU (2012). Quarterly Report on European Electricity Markets.

Eydeland, A and H Geman (1999). Fundamentals of electricity derivatives. In *Research Symposium Proceedings*, Chicago Board of Trade, 123–146.

Fabra, N and J Toro (2005). Price wars and collusion in the Spanish electricity market. *International Journal of Industrial Organization*, 23, 155–181.

Falbo, P, M Fattore and S Stefani (2010a). A new index for electricity spot prices. *Energy Policy*, 38, 2739–2750.

Falbo, P, D Felletti and S Stefani (2010b). Integrated risk management for an electricity producer. *European Journal of Operations Research*, 207, 1620–1627.

Fama, E (1970). Efficient capital markets: A review of theory and empirical work. *Journal of Finance*, 25, 383–417.

Feng, W, L Sidong and D Xuehua (2007). Empirical research on price discovery efficiency in electricity futures market. Power Engineering Society General Meeting, IEEE.

Geman, H (2005). *Commodities and Commodity Derivatives: Modelling and Pricing for Agriculturals, Metals and Energy.* Chichester: Wiley.

Geman, H and A Roncoroni (2006). Understanding the fine structure of electricity prices. *Journal of Business*, 79(6), 1225–1262.

Huisman, R and M Kilic (2012). Indirect storability, expectations and risk premiums. *Energy Economics*, 34, 892–898.

Lo, AW and C Mackinlay (1988). Stock market prices do not follow random walk: Evidence from a simple specification test. *The Review of Financial Studies*, 1, 41–66.

Lucia, J and E Schwartz (2002). Electricity prices and power derivatives: evidence from the nordic power exchange. *Review of Derivatives Research*, 5, 5–50.

Lucia, JJ and H Torrò (2011). On the risk premium in Nordic electricity futures prices. *International Review of Economics and Finance*, 20, 750–763.

Mansur, ET and MH White (2012). Market organization and efficiency in electricity markets. Working Paper. http://www.dartmouth.edu/˜mansur/papers/mansur_white_pjmaep.pdf.

Matacangay, R (2001). Market definition and dominant position abuse under the new electricity trading arrangements in England and New Wales. *Energy Policy*, 29, 337–340.

Mayer, K, T Schmid and F Weber (2011). Modeling electricity spot prices — Combining mean reversion, spikes and stochastic volatility. CEFS Working Paper.

Moulton, JS (2005). California electricity futures: The NYMEX experience. *Energy Economics*, 27, 181–194.

Nakamura, M, T Nakashima and T Niimura (2006). Electricity markets volatility: Estimates, regularity and risk management applications. *Energy Policy*, 34, 1736–1749.

Pilipovic, D (2007). *Energy Risk: Valuing and Managing Energy Derivatives*, 2nd Ed. New York, NY: McGraw-Hill.

Routledge, B, D Seppi and C Spatt (2000). Equilibrium forward prices for commodities. *The Journal of Finance*, 55(3), 1297–1338.

Shawky, HA, A Marathe and CL Barrett (2003). A first look at the empirical relation between spot and futures electricity prices in the United States. *The Journal of Futures Markets*, 23, 931–955.

Stoft, S, T Belden, C Goldman and S Pickle (1998). Primer on electricity futures and other derivatives. LBNL-41098 UC-1321.

Tanlapco, E, J Lawarrée and CC Liu (2002). Hedging with futures contracts in a deregulated electricity industry. *IEEE Transactions*, 17(3).

Wolak, F (1997). Market design and price behavior in restructured electricity markets: An international comparison. Working Paper, University of California Energy Institute.

Wu, D, P Kleindorfer and J Zhang (2002). Optimal bidding and contracting strategies for capital-intensive goods. *European Journal of Operational Research*, 137(3), 657–676.