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The temperature impact on the electricity demand

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SAGGI

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THE TEMPERATURE IMPACT ON THE ELECTRICITY DEMAND*

ABSTRACT

La temperatura influenza la domanda di energia elettrica.
La domanda di energia elettrica aumenta in estate e inverno a causa del cambiamento climatico ma con intensità diverse. In estate, infatti, la domanda cresce più velocemente rispetto all'inverno perché diversi sono i metodi di riscaldamento e raffreddamento.
Questo lavoro si propone di esaminare il legame tra la temperatura e la domanda di energia elettrica.

The temperature has a significant impact on electricity demand.
The electricity demand in summer and winter increases due to climate change but with different slope, precisely steeper in summer than in winter because of the availability of different methods of heating and cooling This paper proposes to examine the relationship between electricity demand and temperature.

PAROLE CHIAVE

Temperatura – domanda di elettricità

Temperature – electricity demand

1. The unusual behavior of power prices can be explained based on some properties of electricity. Electricity is in fact a very special commodity: except hydroelectric power, it cannot be stored and must be generated at the instant it is consumed.

The interaction between demand and supply of electricity is very peculiar: the demand is highly inelastic and very sensitive to the temperature and weather conditions; the generation process, i.e. the supply of electricity, is assured by generators with low marginal costs to cover the base load, as hydroelectric plants, nuclear power plants, and coal units. To meet peaks in the demand, emergency units (oil and gas fired plants) with high marginal costs are to be put on the operation.

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* Saggio sottoposto a referaggio secondo il sistema del doppio cieco.

Supply curves exhibit therefore a time variable kink after which offer prices rise almost vertically[1].

Whenever the load (demand) crosses the offer curve in the rapidly raising part of the curve, electricity prices may assume very high values

Electricity plays an important role in economic development in many countries. It is well known that its price is determined according to the rule of supply and demand and, also, electricity demand in the countries shows a seasonal pattern.
Few studies have been proposed to emphasize the relationship demand-temperature, look for example T. Ahmed et al[2], proposed a multiple linear regression analysis to establish a correlation between electricity demand and the historical climatic. G.Franco[3]and Hekkenberg[4], for example, show that it can be represented in the form of "U" shaped curve .

In general, we note, in agreement with the observed data, that in the summer the demand for electricity is higher than in winter because to keep warm, you can use alternative forms of energy.

As Huisman[5], rightly, pointed out in one of his works, power consumption depends on temperature, precisely heating in winters and air-conditioning in summers and shocks in supply or demand are due to shocks in temperature.

We also observe that the temperature influence power prices and the variance of the same.

Several previous studies such as SM.Howden[6], R. Huisman[5], T.Ahmed[2] have observed, analyzed the relationship between the demand and the temperature and proved that the demand may change if the temperature changes.

However, few studies have been reported in the literature about the impact of climate change on electricity demand. At this end, this paper wants to explain, starting

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[1] R. Huisman, *The influence of temperature on spike probability in day-ahead power prices*, in *Energy Economics*, 30, 2008, pp. 2697-2704.
[2] T. Ahmed, K.M. Muttaqi, A.P. Agalgaonkar, *Climate change impacts on electricity demand in the State of New South Wales*, Australia, Applied Energy 98, 2012, pp. 376-383.
[3] G. Franco, A. Sanstad, *Climate change and electricity demand in California*, in *Climate Change*, 87, 2008, pp. 139-151.
[4] M. Hekkenberg, R.M.J. Benders, H.C. Moll, A.J.M. Schoot Uiterkamp, *Indications for a changing electricity demand pattern: the temperature dependence of electricity demand in the Netherlands*, in *Energy Policy*, 37, 2009, pp. 1542-1551.
[5] R. Huisman, R. Mahieu, *Regime jumps in electricity prices*, in *Energy Economics*, 25, 2003, pp. 423-434.
[6] S.M. Howden, S. Crimp, *Effect of climate and climate change on electricity demand in Australia*, CSIRO Sustainable Ecosystem, 2001.

with the relationship between the temperature and the demand and then with the interplay by the supply and the demand, the impact of the climate change on the power prices.

The impact of temperature on the demand has been studied by Huisman[7], Ahmed[8],. Hekkenberg[9] .

Electricity demand shows a clear seasonal pattern. The temperature has a significant impact on electricity demand. To take into account this god, we aim to study the relation between demand and the temperature and to determine the electricity price as the interaction between supply and demand.

Previous studies have found the relationship between demand and the temperature and how the demand may change under varying weather conditions.

This paper is organized as follows:

In the next section, we model the temperature, then we explain the proposed methodology, and obtain the main equation of the dynamics of power prices.

2. Modelling temperature: temperature are not deterministic, so to taking in account the strong seasonal variation in the temperature, in this model we suppose that it is the sum between a deterministic component $f(t)$ and a stochastic component $T(t)$. $T(t)$ can be described by the following stochastic differential equation:

$$dT(t) = -\mu\, T(t)dt + \sigma\, dW(t) \qquad 1$$

where $\mu \in R,\ \mu > 0,\ \sigma \in R, \sigma > 0$ and W is a standard Brownian motion.

The temperature cannot, for example, rise day after day for a long time. This means that our model should not allow the temperature to deviate from its mean value for more than short periods of time. Namely, the stochastic process describing the temperature has a mean-reverting property.

3. Demand temperature relation: the relation between electricity demand and the temperature is found to be 'U' shaped function. In particular, for low temperatures, the curve is less steep than for the highest temperatures due to the possibility to use alternative forms of energy.

We suppose that the electricity demand function is given by:

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[7] R. Huisman, R. Mahieu, *Regime jumps in electricity prices*, in *Energy Economics*, 25, 2003, pp. 423-434.

[8] T. Ahmed, K.M. Muttaqi, A.P. Agalgaonkar, *Climate change impacts on electricity demand in the State of New South Wales*, Australia, Applied Energy 98, 2012, pp. 376-383.

[9] M. Hekkenberg, R.M.J. Benders, H.C. Moll, A.J.M. Schoot Uiterkamp, *Indications for a changing electricity demand pattern: the temperature dependence of electricity demand in the Netherlands*, in *Energy Policy*, 37, 2009, pp. 1542-1551.

$$D(t,T(t)) = \begin{cases} \alpha_1(f(t)-\eta)^2+\beta+\gamma\big(T(t)\big)^2 & f(t)<\eta \\ \alpha_2(f(t)-\eta)^2+\beta+\ \gamma(T(t))^2 & f(t)>\eta \end{cases} \qquad 2$$

with $0<\alpha_1<\alpha_2$, $T(t)$ is the temperature, η is the temperature values in which the demand is minimum and β is the point at which $f_T(t)=\ \eta$ and therefore (it proves) the minimum point $m(\eta,\beta)$of the considered function (2) is the point of the base load power prices.

We assume that $0<\alpha_1<\alpha_2$ to emphasize that in winter we can warm up with an alternative form of energy while in summer, the conditioners use almost exclusively electricity which is why we often find ourselves in front of the black-out.

It will be useful later to consider the differential of the demand function.

At this end, we study equation 2 and we put:

$$g(t) = \begin{cases} \alpha_1(f(t)-\eta)^2+\ \beta & f(t)<\eta \\ \alpha_2(f(t)-\eta)^2+\ \beta & f(t)>\eta \end{cases}$$

and

$$x\big(T(t)\big)=\gamma T(t)^2;$$

From which it is easily checked that

$$D(t,T(t))=g(t)+x(T(t)$$

and so:

$$dx\big(T(t)\big)=2\gamma T(t)dT(t)+\gamma\sigma^2 d(\big(T(t)\big)^2)$$

from 1 we have:

$$dx\big(T(t)\big)=2\gamma T(t)[-\mu\, T(t)dt+\ \sigma\, dW(t)]+\gamma\sigma^2 dt$$

so it is:

$$dx\big(T(t)\big) = [-2\mu\, x(T(t)) + \gamma\sigma^2]\, dt + 2\,\sigma\,\sqrt{\gamma}\ \sqrt{x(T(t))}\ dW(t).$$

We get a dynamic for $x\big(T(t)\big)$ namely the square root process of Cox et al.[10]

The purpose of the paper is to propose a quantitative model as analytical tool to examine the effect of temperature change on the electricity demand of the market.
In this paper we propose a model in which the dynamics of power prices is determined by the relation between temperature $T(t)$ and electricity demand $D(t, T(t))$.
We postulate that the dynamics of $K(t)$[11] can be viewed as the sum of two components: a predictable component $h(t)$ deterministic and unpredictable movements of the prices thus stochastic component $k(t)$.

$$K(t) = h(t) + k(t)$$

$k(t)$ has the following stochastic

$$dk(t) = \begin{cases} -\rho_0 k(t)dt \quad + \phi_0 d\, W_0^k(t) \\ -\rho_0 k(t)dt\ + \phi_1 dW_1^k(t) + \tilde{\theta}\, dN(t) \end{cases}$$

where $\rho_0 \in R, \rho_0 > 0,\ \phi_0 \in R, \phi_0 > 0$ e $\phi_1 \in R, \phi_1 > 0,\ W_0$ and W_1 are independent Brownian motions and $N(t)$ is a Poisson process[12] with constant intensity λ.

4. The model and main result: we assume that the dynamics of power prices is determined by the interplay between demand and supply as follow:

$$P(t, T_t) = h_0 exp\left[\frac{D(t, T(t)) - K(t)}{h_1}\right]$$

We consider its natural logarithm so we have:

$$\log P(t, T_t) = \log h_0 + \frac{g(t) - h(t)}{h_1} + \frac{x\big(T(t)\big) - k(t)}{h_1}$$

[10] J.C. Cox, J.E. Ingersoll, S.A. Ross, *A theory of the term structure of interest rates,* in *Econometrica*, 53, 1985, pp. 385-407.
[11] C. Mari, *Random movements of power prices in competitive markets: a hybrid model approach,* in *Journal of Energy Markets*, 1, 2008, pp. 87-103.
[12] I. Karatzas, S. Sherve, *Methods of mathematical finance, second edition*, Springer Verlag, New York, 1998.

We put then:

$$\tilde{p}\big(t,T(t)\big) = \frac{1}{h_1}\ \big[x\big(T(t)\big) - k(t)\big].$$

Therefore, to study the electricity price $K(t)$ we define a time variable kink position [13]and h_0 and h_1 are normalization parameters.

Assuming that the stochastic differential equation of $k(t)$ is the classical Ornstein–Uhlenbeck process:

$$dk(t) = -\rho_0 k(t)dt \quad + \phi_0 d\, W_0^k(t)$$

we have:

$$d\tilde{p}\big(t,T(t)\big) = \frac{1}{h_1}\Big[[-2\mu\, x(T(t)) + \gamma\sigma^2]\, dt + 2\,\sigma\sqrt{\gamma}\ \sqrt{x(T(t))}\ dW(t) + \rho_0 k(t)dt\ - \phi_0 d\, W_0^k(t)\Big]$$

that is:

$$d\tilde{p}\big(t,T(t)\big) = \frac{1}{h_1}\left[\begin{array}{c}[-2\mu\, x\big(T(t)\big) + \gamma\sigma^2]\, dt + 2\,\sigma\sqrt{\gamma}\ \sqrt{x\big(T(t)\big)}\ dW(t) \\ + \rho_0\big[x\big(T(t)\big) - h_1\tilde{p}\big(t,T(t)\big)\big]dt\ - \phi_0 d\, W_0^k(t)\end{array}\right]$$

and so:

$$d\tilde{p}\big(t,T(t)\big) = -\rho_0\tilde{p}\big(t,T(t)\big) + \frac{1}{h_1}\big[\big(\rho_0 - 2\mu\big)x\big(T(t)\big) + \gamma\sigma^2\big]\, dt + \frac{1}{h_1}\left[2\sigma\sqrt{\gamma}\sqrt{x\big(T(t)\big)}\, dW(t)\ -\ \phi_0\, d\, W_0^k(t)\right].$$

Otherwise, if the stochastic differential of $k(t)$ is given by an Ornstein–Uhlenbeck process with a jump component:

$$dk(t) = -\rho_0 k(t)dt\ + \phi_1 dW_1^k(t) + \tilde{\theta}\, dN(t)$$

[13]A kink is a position after which offer prices start rising almost exponentially in the offer curve.

we easily get:

$$d\tilde{p}\big(t,T(t)\big) = -\rho_0 \tilde{p}\big(t,T(t)\big) + \frac{1}{h_1}\big[\big(\rho_0 - 2\mu\big)x\big(T(t)\big) + \gamma\sigma^2\big]\,dt + \\ + \frac{1}{h_1}\Big[\,2\sigma\sqrt{\gamma}\,\sqrt{x(T(t))}\,dW(t) \;-\; \phi_0 d\,W_0^k(t) - \tilde{\theta}\,dN(t)\Big]$$

However, a similar specification in terms of log-price is also possible:

$$\mathrm{d}(\log P\big(t,T(t)\big)) = \frac{1}{h_1}(g'(t) - h'(t))dt - \rho_0 \tilde{p}\big(t,T(t)\big) \\ + \frac{1}{h_1}\big[\big(\rho_0 - 2\mu\big)x\big(T(t)\big) + \gamma\sigma^2\big]\,dt \\ + \frac{1}{h_1}\Big[\,2\sigma\sqrt{\gamma}\,\sqrt{x(T(t))}\,dW(t) \;-\; \phi_0 d\,W_0^k(t) - \tilde{\theta}\,dN(t)\Big]$$

We note that the stochastic process describing the price and the log-price have a mean-reverting property. We observe that the mean reversion and jumps as these are the distinguishing features of electricity prices. These features are not the result of market activity. However, their magnitude depends on varying activity in the market.
The empirical analysis can be performed to estimate the model on market data.
Data are available, for example, at www.eia.doe.gov and they are at a daily frequency without weekend days.

5. Conclusion: the results of past case studies reveal that the air temperature is the most important weather variable having an effect on electricity demand. Here we developed a model for electricity price using the relationship between electricity demand and temperature in the form of "U" shaped curve but with different slope, precisely steeper in summer than in winter because of the availability of different methods of heating and cooling.

We get a dynamics for the relationship, in particular we derive a square root process that, as we will see, it describes the market price, best of Vasicek model because we can aspect that the moderately extreme prices will be classified as base load and not spike.

The regime switches are induced by transitions between Markov states.

An empirical analysis, specifically an example of the suggested methodology application to the market, can be successfully performed. The emerging data would show the fittingness of the analysis in describing the observed phenomenon. Data are available at www.eia.doe.gov and they are given daily, without any days off.