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Paper:

Electricity Demand and Price Analysis in California Using Possibility Regression Model

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In this paper, the authors analyze the prices of electricity spot market in California. Firstly, we discuss the relation between annual demand of electricity and the temperature in California. We identify the electricity demand is related to temperature using possibility regression analysis. Then we show the fluctuation of electricity price is influenced by the demand. In the early summer season of 1998, the relationship between temperature and electricity price in California was simple. However, in the mid summer season in 1998, the price volatility of the electricity goes on increasing. Secondly we show that the expectation (speculative buying) of the market participant which is formed by temperature fluctuation induced the price volatility. We show that the price volatility is affected by temperature fluctuation for a previous few days.

Keywords: possibility regression analysis, fuzzy number, spot price of deregulated electricity market, forecasting

1. Introduction

Electricity spot market in California had been opened from April 1998 to March 2001 [1], [2]. That spot market has opened for only 3 years (1998, 1999 and 2000). In the year 2001, the market has closed by reason of its structural defect [3].

Generally, the market price is determined by the balance of supply and demand. In the same way the price of electricity spot market in California was determined in the California Power Exchange (CalPx) where the electricity supplier and the electricity buyer participated in the auction. The auction mechanism was sealed bid auction, that the market participants had to forecast the other market participants' bidding price in order to maximize their profit. Therefore they needed to forecast exactly the electricity demand [4]. In the electricity market, the demand generally depends on the temperature, therefore the climate has usually influence on electricity prices. However the price fluctuation of electricity in CalPx was strange [5].

The objective of this paper is to analyze the relationship of temperature and electricity demand, and furthermore to predict the behavior of electricity prices (in a period of high temperature).

2. Price Model of Electricity in California

In the well-balanced market, the spot price of electricity is determined by the demand and supply. In the days of the beginning of the California Power Exchange (on April, 1998), the market price depended on the demand. The electric power supplier, in order to maximize profit, needs to do an accurate estimate of electricity demand. Based on the prediction of the demands, the electricity prices are determined.

2.1. Electricity Demand Model in California Based on Climate Model Using Possibility Regression Analysis

Based on the maximum temperature, the electricity demand is generally forecasted. It is a conventional idea. Our discussion starts at this ordinary idea. **Fig.1** shows a correlation of the maximum temperature/day and maximum electricity demand in California [6]. Here, as the maximum temperature/day, we used either of higher one among temperature of San Francisco and temperature of Los Angeles. Electricity demand receives influence by temperature and the date and time. We think that temperature also influences a sudden rise of a demand among other things. The maximum demand (D) increases in proportion to square of the maximum temperature (Temp), approximately. Thus we used the 2nd polynomial to D-Temp model (eq.(1)). The parameters of following equation (1) were determined by the least squares.

$$D = (23.06)Temp^2 + (-442.73)Temp + 24098.2. \quad (1)$$

D :Maximum Demand [MW]
Temp :Maximum Temperature [deg. C]

Furthermore, we can find out that the change of the temperature is a periodical pattern throughout the year.

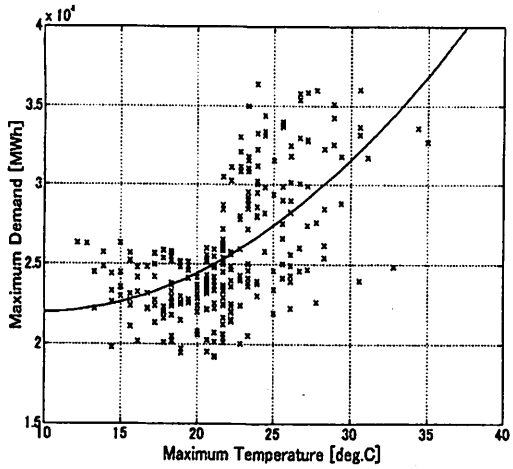

Fig. 1. Correlation between maximum temperature and electricity demand (California: Max{San Francisco, Los Angeles }).

Thus we use a following periodical model (eq. (2)) as a seasonal model of California.

$$Temp = A_0 + A_1 \cdot \sin(2\pi d/T) + A_2 \cdot \cos(2\pi d/T)\ . \quad (2)$$

In equation (2), the parameters A_0, A_1, and A_2 are determined by fuzzy (possibility) regression analysis [7]. The parameters A_0, A_1, and A_2 are determined by fuzzy (possibility) regression analysis. Thus variable Temp (left-hand side) is a fuzzy number which is also expressed by 2 parameters, namely A_i<a_0, c_i >. Where a_0 is a center value of a fuzzy set. c_i is a deviation of fuzzy set.

We do the following linear conversion in order to determine parameters a_0, c_0, a_1, c_1, a_2, and c_2,

$$Temp = A_0 + A_1 \cdot X_1 + A_2 \cdot X_2, \ \ldots\ldots\ldots\ldots\ (3)$$

where X_1, X_2 are $\sin(2\pi d/T)$, $\cos(2\pi d/T)$, respectively.

Then we solve the following linear programming problem:

$$\text{Minimize} \sum_{i=1}^{n} (c_0 + c_1 x_i + c_2 x_i)$$

Subject to:

$$a_0 + a_1 x_1 + a_2 x_2 - (c_0 + c_1 x_1 + c_2 x_1) \le Temp_1$$

$$a_0 + a_1 x_2 + a_2 x_2 - (c_0 + c_1 x_2 + c_2 x_2) \le Temp_2$$

$$\cdots$$

$$a_0 + a_1 x_n + a_2 x_n - (c_0 + c_1 x_n + c_2 x_n) \le Temp_n$$

$$a_0 + a_1 x_1 + a_2 x_1 + (c_0 + c_1 x_1 + c_2 x_1) \ge Temp_1$$

$$a_0 + a_1 x_2 + a_2 x_2 + (c_0 + c_1 x_2 + c_2 x_2) \ge Temp_2$$

$$\cdots$$

$$a_0 + a_1 x_n + a_2 x_n + (c_0 + c_1 x_n + c_2 x_n) \ge Temp_n$$

and:

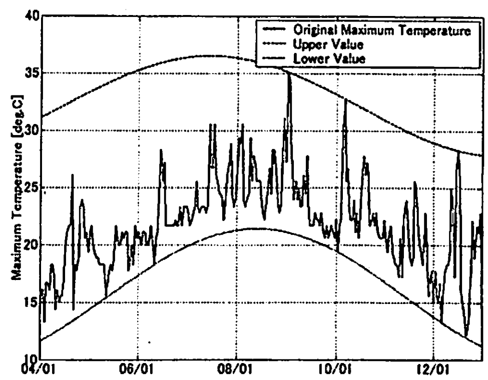

Fig. 2. Result of the possibility regression analysis.

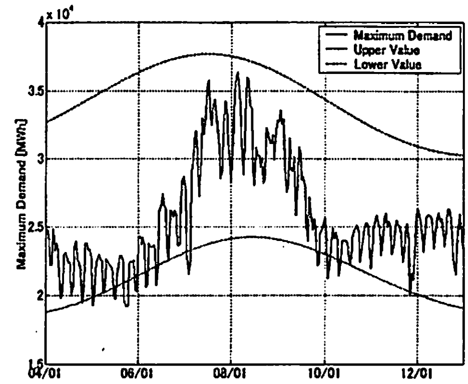

Fig. 3. possibility domain of the maximum electricity demand.

$$c_0, c_1, c_2 \ge 0 . \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4)$$

After the above optimization, we obtained the following values of A_0, A_1, and A_2, respectively.

A_0 : <23.87, 8.28>

A_1 : <4.24, 0.0>

A_2 : <-2.55, 1.43>

This model may be compared to the climate of the California (the climate that we watched from electricity demand). **Fig.2** shows possibility range of the maximum temperature through the year.

Based on equation (1) and (2), we estimated the possibility range of the electricity demand as shown in **Fig.3**, all the year round.

2.2. Relation between Temperature and Electricity Price

In this section, we discuss the fluctuation of prices of electric power market. **Fig.4** shows the relationship of the electricity spot prices in CalPx and the maximum temperature, in California in 1998. Dashed line and solid line show the maximum temperature/day and the spot prices

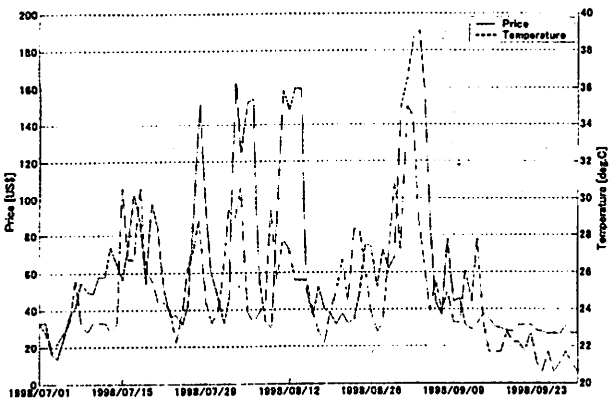

Fig. 4. The relation between price and temperature.

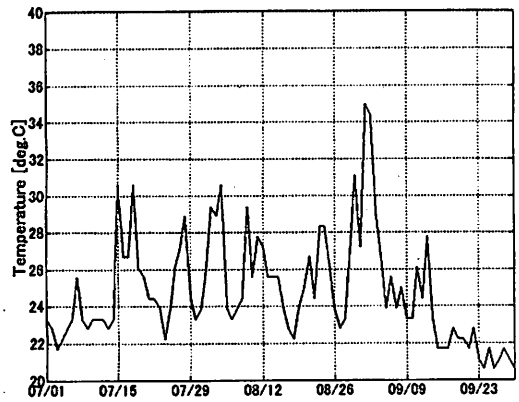

Fig. 5. Maximum temperature/day in California.

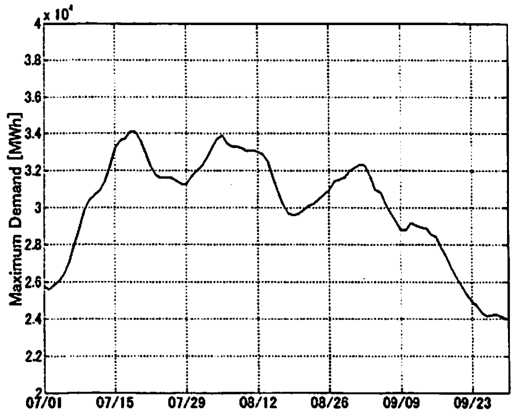

Fig. 6. Moving average of maximum demand/day.

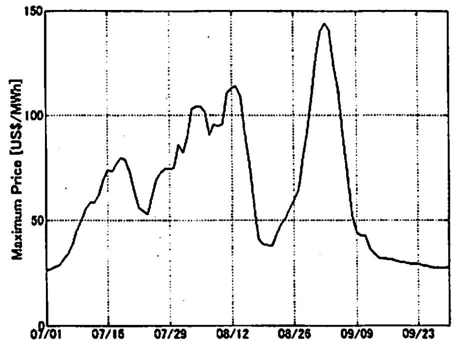

Fig. 7. Moving average of maximum prices/day in CalPx.

of the electricity respectively. There are three peeks of the high temperature, i.e. 15th July and 18th July and 4th Aug.

Figure 5 shows the maximum temperature/day of California. **Figs.6** and 7 show respectively the moving average of maximum demand/day and maximum prices/day, in order to except the weekly pattern.

When the maximum temperature was on the rise, the maximum demand was upward tendency. Because of a law of supply and demand, the price has gone up. The change of the demand appeared in the beginning of summer. However once temperature has gone up, the electricity demand is keeping the high value, it does not go down soon. After such a period, when a high temperature is expected, the prices rise up higher than an earlier occasion. We think that these prices are speculative.

We consider that this speculation is produced by the market participants because of their profit maximization activity.

2.3. Forecasting Model of The Electricity Prices

The characteristics of electricity price data of CalPx are following.

1) When temperature is going up (we need air conditioner), the electricity price is also going up. The cause of price rising is the increase of electricity demand.
2) Electricity price has a period of one week that is a period of social activity. This period is observed through the year.
3) The price rises only by a sign of temperature increases, after having recorded a very high temperature once. **(Fig.4)**
4) A low price of electricity does not always depend on a change of temperature. **(Fig.8)**

We consider above-mentioned characteristics and build a model of electricity price.

Firstly we express electricity price $P(t)$ of time t by periodic function of equation (5).

$$P(t) = P_0(Temp) + \sum_{k=1} P_k(Temp)\sin(\frac{2\pi}{T_k}t + \varphi_k(Temp)) \quad \cdots\cdots (5)$$

Where, $P_0(Temp)$ is a DC component, $P_k(Temp)$ is amplitude, $\frac{2\pi}{T_k}$ is a frequency, and $\varphi_k(Temp)$ is a phase, respectively. Here, $\frac{2\pi}{T_k}$ is inversely-proportional to the social activity period of a week or to a seasonal change of a year. The equation (5) is shown as the equivalent equation (6), to make it easy to do the processing of least square method and regression analysis later.

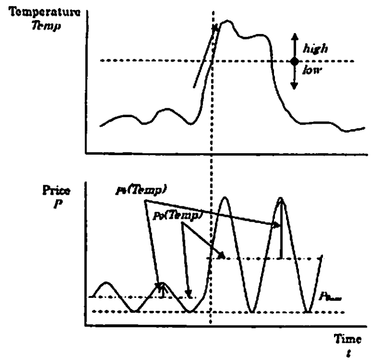

Fig. 8. Relationship between temperature and electricity price.

$$P(t) = P_0(Temp) + \sum_{k=1} PA_k(Temp)\sin(\frac{2\pi}{T_k}t)$$

$$+ \sum_{k=1} PB_k(Temp)\cos(\frac{2\pi}{T_k}t), \quad \cdots\cdots\cdots (6)$$

where,

$$P_0(x) = PB_0(Temp),$$

$$P_k(Temp) = \sqrt{PA_k(Temp)^2 + PB_k(Temp)^2},$$

$$\varphi_k(Temp) = \tan^{-1}\frac{PA_k(Temp)}{PB_k(Temp)},$$

respectively. In order to express the model of only a short term of the summer, we used the 1st order periodic function of eq. (7).

$$P'(t) = PB_0(Temp) + PA_1(Temp)\sin(\frac{2\pi}{T_1}t)$$

$$+ PB_1(Temp)\cos(\frac{2\pi}{T_1}t) \quad \cdots\cdots\cdots\cdots (7)$$

Here, we consider, "Why has electricity price risen suddenly once again?" The following causes can be considered.

1) If it is too hot, an air-conditioner becomes necessary.
2) A sudden rise of temperature becomes a trigger of an electric price rise.

Because these conditions are things on the basis of sensitivity of a human being, we decide to use fuzzy model described by the following rule.

R_1 : IF *Temp* is *low*

THEN $P = <26.9, 7.39> (Temp)$

$$+ <4.18, 2.61> (Temp) \sin(\frac{2\pi}{T_1}t)$$

$$+ <5.51, 0.0> (Temp) \cos(\frac{2\pi}{T_1}t)$$

$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (8)$$

Table 1. IF-THEN rules.

	Temp	$\frac{dTemp}{dt}$
Rule 1	Low	—
Rule 2	High	Large
Rule 3*	High	Not large

*It is generally necessary, but we do not use it in this case.

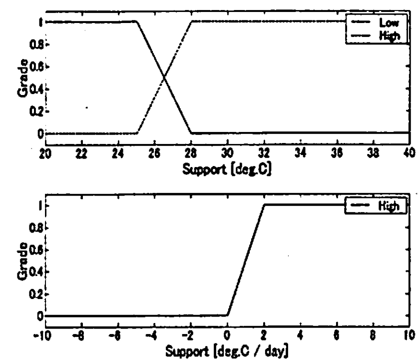

Fig. 9. Fuzzy sets representing "Low", "High", and "Large".

R_2 : IF *Temp* is *high*

AND $\frac{dTemp}{dt}$ is *high*

THEN $P = <82.1, 39.5> (Temp)$

$$+ <6.86, 9.66> (Temp) sin(\frac{2\pi}{T_1}t)$$

$$+ <22.5, 7.02> (Temp)\cos(\frac{2\pi}{T_1}t)$$

$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (9)$$

R_3 : IF *Temp* is *high*

AND $\frac{dTemp}{dt}$ is *not high*

THEN $P = PB_0(Temp) + PA_1(Temp)\sin(\frac{2\pi}{T_1}t)$

$$+ PB_1(Temp)\cos(\frac{2\pi}{T_1}t)$$

$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (10)$$

These fuzzy rules show that the market participants bid the electricity price in the spot market. Rule 1 shows that market participants expect that the temperature is low, and does not change rapidly. Rule 2 shows that market participants expect that the temperature is high, and is going up suddenly. In other words, they bid the high price. This model forecasts the price volatility by this rule. Rule 3 shows that temperature is high and constant. It is gener-

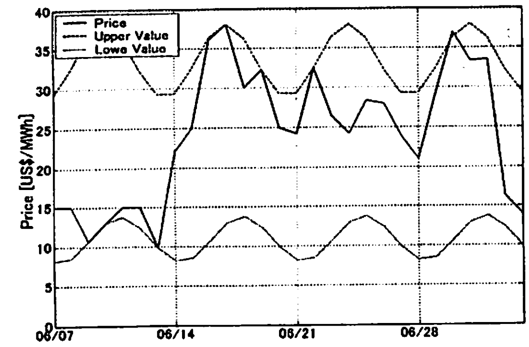

Fig.10. The forecast of the electricity spot prices, when temperature is not much high.

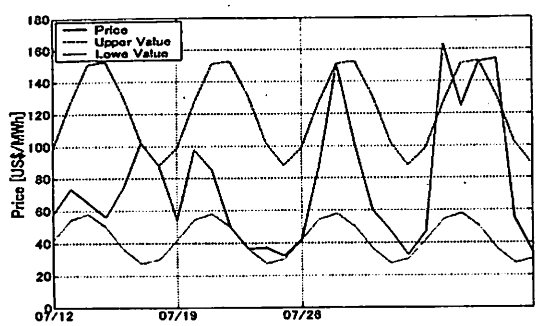

Fig.11. The forecast of the electricity spot prices, while temperature rises up.

ally necessary, but we do not use it in this case. We use the following membership functions for the temperature and the temperature change (i.e. "Low", "High", and "Large") as shown in **Fig.9**.
where

$$\text{Low} = \{1/20, 1/25, 0/28, 0/30\},$$

$$\text{High} = \{0/20, 0/25, 1/28, 1/40\},$$

$$\text{Large} = \{0/-20, 0/0, 1/5, 1/20\}.$$

Figure 10 shows the results of the electricity price forecast, from 28-June to 5-July, when temperature is not so high. Parameters of this model are determined using the first 3 weeks data (i.e., from 7-June to 21-June). Real line is the recorded original data, and dashed line shows upper fuzzy value, and dotted line shows lower fuzzy value. A domain surrounded by two lines is a possibility domain. Real data fit into the possibility domain predicted as shown in **Fig.11**. Here, model parameters are determined using first 3 weeks data (i.e., from 12-July to 1-August).

3. Conclusions

The prices of electricity power market in California have been analyzed. Firstly the annual demand of electricity and the temperature (climate) of California have been discussed. We show the relationship between the electricity demand and the temperature with possibility recurrence analysis. Then we show the price fluctuation has been influenced by the demand. However, in the summer season of 1998, the price volatility of the electricity was increasing. So we suggest that the expectation of the market participant which had been formed by temperature fluctuation induced the price volatility. Finally, we show that the relationship between the price volatility and the temperature fluctuation was affected by temperature fluctuation of the last few days. We have proposed the forecasting model of electricity market based on the profit maximization behavior of the market participant. We think that this forecasting model based on the volatility of human activity can also apply other electricity market.

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