# Electricity Demand and Price Analysis in California Using Possibility Regression Model

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***Abstract*** **— In this paper, we analyze the prices of electricity power market in California[1]. Firstly, we discuss the 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 price fluctuation 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 suggest that the demand increasing expectation of the market participant which is formed by temperature fluctuation induced the price volatility. We show that the relationship between the price volatility and the temperature fluctuation is affected by temperature fluctuation for previous few days.**

## I. INTRODUCTION

Electricity market in California had opened for April 1998 to March 2001. That 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[2]. Generally, the market price is determined by the balance of supply and demand. In the electricity market, its demand depends on the temperature, thus the climate has influence on electricity prices. In the California Power Exchange (CalPx) fluctuation, however the behavior of prices data was improper, especially year 1999. The objective of this paper is to analyze the relationship of the temperature and electricity demand, and furthermore to predict the electricity prices.

## II.PRICE MODEL OF ELECTRICITY IN CALIFOLNIA

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

### *A. Electricity Demand Model in California*

Based on the maximum temperature, the electricity demand is forecasted. It is a conventional idea. So our discussion starts at this idea. Fig. 1 shows a correlation of the maximum temperature/day and maximum electricity demand in San Francisco. Where the maximum demand *D* increases proportionally to the approximate square of the maximum temperature *Temp*. Thus we used the 2nd order polynomial applied to *D-Temp* model (eq.(1)). The parameters of equation (1) were determined by the method of least squares. We obtained the following parameters.

$$D = 12.11 \cdot Temp^2 - 18.33 \cdot Temp + 22167 \tag{1}$$

$D$ : *Maximum Demand* [MWh]

$Temp$ : *Maximum Temperature* [deg. C]

Furthermore, we can find out that the change of the temperature is a periodical pattern throughout the year. Thus we use a following periodical model (eq. (2)) as a seasonal model in California,

$$Temp = A_0 + A_1 \cdot \sin(2\pi d / T) + A_2 \cdot \cos(2\pi d / T) \tag{2}$$

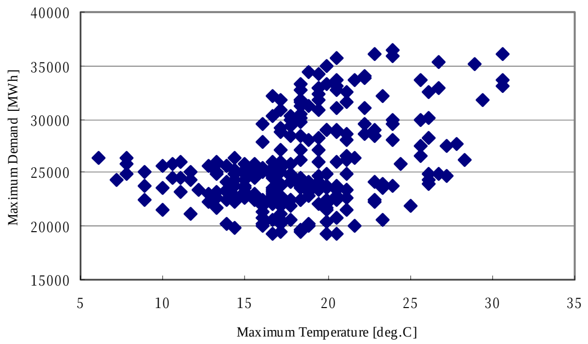


Fig. 1. Correlation between maximum temperature and demand (San Francisco).

where the parameters $A_0$, $A_1$, and $A_2$ are determined by fuzzy (possibility) regression analysis, thus left-hand variable *Temp* is also fuzzy number which is expressed by 2 parameters, namely $A_i$<$a_i$, $c_i$>, where $a_i$ is most likely value of the regression parameter, where $c_i$ is the possible maximum spread from $a_i$ to higher and lower values of parameter. We obtained the following values of $A_0$, $A_1$, and $A_2$, respectively.

$A_0$ : <18.55, 8.06>
$A_1$ : <5.1, 0.0>
$A_2$ : <-3.05, 0.66>

This model may be likened to the climate of the California (especially San Francisco). Fig. 2 shows possibility range of the maximum temperature.

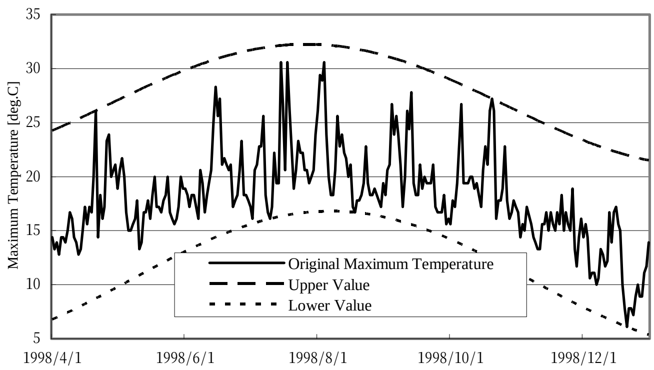


Fig.2. Result of the possibility regression analysis.

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

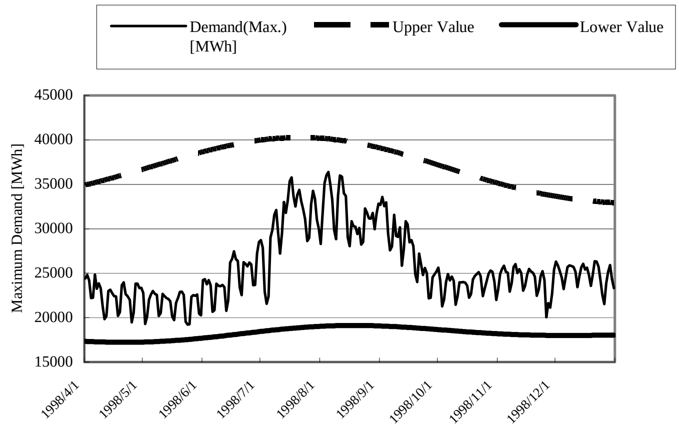


Fig. 3. Possibility of the maximum electricity demand.

*B. The Relation* between *Temperature and Electricity Price*

In this section, we discuss the fluctuation of prices of electricity power market. Fig.4 shows the prices in CalPx and maximum temperature in San Francisco in 1998. Dashed line and solid line show maximum temperature/day and prices of the electricity, respectively. There are three peaks of the high temperature, i.e. 15th, 18th, July, and 4th Aug.

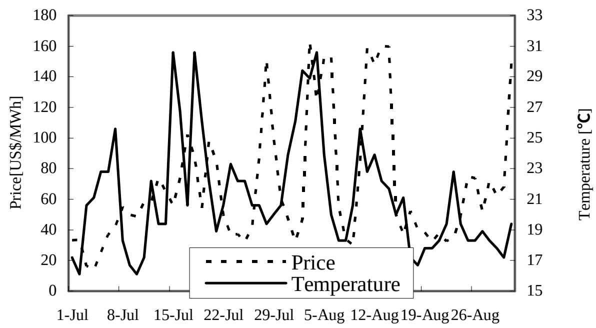


Fig. 4. The relation between price and temperature.

Fig.5 shows the maximum temperature/day in San Francisco. Fig. 6 and 7 show the moving average of maximum demand/day of the electricity and maximum prices/day in CalPx, respectively, in order to expect 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. These changes in demands appeared in the beginning of summer. However once temperature has gone up, demand has kept the high average, not gone down quickly. After that, when the high temperature is expected, the prices go up higher than on an earlier occasion. We understand that its price is speculative.

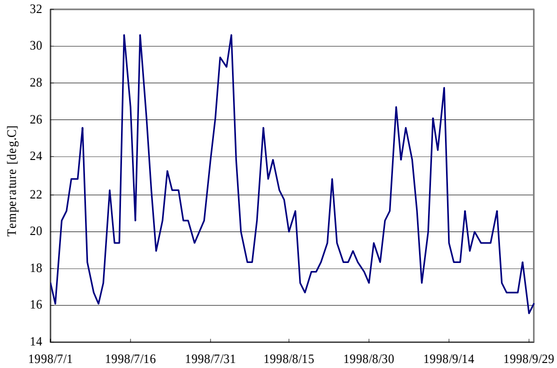


Fig.5. Maximum temperature/day in San Francisco

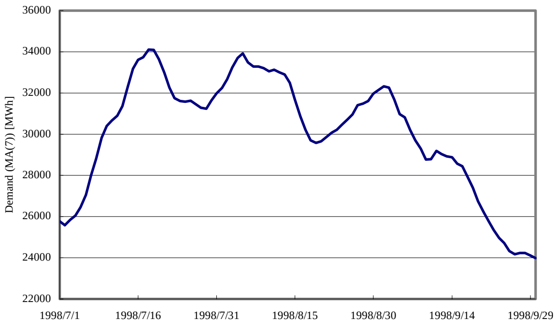


Fig.6. Moving average of maximum demand/day.

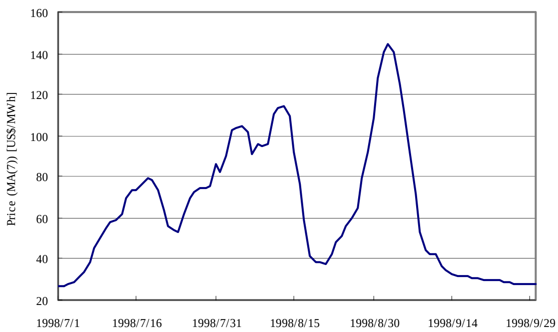


Fig.7. Moving average of maximum prices/day in CalPx.

*C. Forecasting Model of The Electricity Prices*

The electricity price data of CalPx show the following characteristics.

1) When temperature is going up and we need air conditioner, the electricity price is also rising up. The reason 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 in the year.
3) A price rises only by the sign that temperature increases after having recorded the highest temperature once. (See Fig. 4)
4) A low price of electricity price does not always depend on a change of temperature. (See 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 period function of equation (3).

$$P(t) = P_0(Temp) + \sum_{k=1} P_k(Temp)\sin(\omega_k t + \varphi_k(Temp)) \quad (3)$$

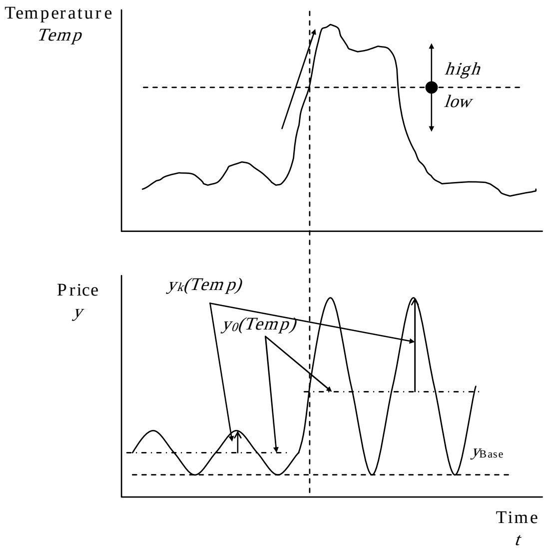


Fig. 8. Relationship between temperature and electricity price.

Where, $P_0(Temp)$ is a DC component, $P_k(Temp)$ is amplitude, $\omega_k$ is a period, and $\varphi_k(Temp)$ is a phase, respectively. Here, $\omega_k$ is equal to 1 week of the social activity period or to 1 year of climate change. The equation (3) is shown as the equivalent equation (4), to make it easy to do the processing of least square method and regression analysis later.

$$P(t) = P_0(Temp) + \sum_{k=1} PA_k(Temp)\sin(\omega_k t) + \sum_{k=1} PB_k(Temp)\cos(\omega_k t), \quad (4)$$

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. We pay attention to it here in short term of the summer, so we use 1st order periodic function as eq. (5).

$$P'(t) = PB_0(Temp) + PA_1(Temp)\sin(\omega_1 t) + PB_1(Temp)\cos(\omega_1 t) \quad (5)$$

Here, we think about the reason why electricity price rises suddenly once again. The following things are thought about.

a) Because it is too hot, air-conditioning becomes necessary.

b) Electricity price became speculation for a change of temperature. Therefore price reacts to a rise of temperature sensitively.

Because these conditions are things on the basis of sensitivity of a human, we decide to use fuzzy model described by following rule (especially, eq. (7)).

$R_1$ : IF *Temp* is *low*

$$\text{THEN } P = PB_0(Temp) + PA_1(Temp)\sin(\omega_1 t) + PB_1(Temp)\cos(\omega_1 t) \quad (6)$$

$R_2$ : IF *Temp* is *high*

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

$$\text{THEN } P = PB_0(Temp) + PA_1(Temp)\sin(\omega_1 t) + PB_1(Temp)\cos(\omega_1 t) \quad (7)$$

Fig. 9 shows the results of price forecast, when temperature is not much high (from 28-Jun to 5-July). Model parameters are determined using the first 3 weeks data (i.e., from 7-Jun. to 21-Jun.). Thick real line is recorded original data, and dashed line and dotted line show upper and lower values of the possible region, respectively. As evident in the figure, the data in the forecasted period are covered by possible regions.

In the meantime, fig. 10 shows the results of price forecast, when temperature is rising up (from 2-Aug. to 8-Aug.). Here, model parameters are determined using first 3 weeks data (i.e., from 12-July to 1-Aug.). The data in the forecasted period are also covered by possible regions.

## III. CONCLUSION

The prices of electricity power market in California were analyzed. Firstly, the annual demand of electricity and the temperature in California was discussed. We identified the electricity demand has been related to temperature using possibility regression analysis. Then we showed the price fluctuation has been influenced by the demand. However in the mid summer season in 1998, the price volatility of the electricity went on increasing. So we suggested that the demand increasing expectation of the market participant which had been formed by temperature fluctuation induced the price volatility. Finally, we showed that the relationship between the price volatility and the temperature fluctuation was affected by temperature fluctuation for the last few days.

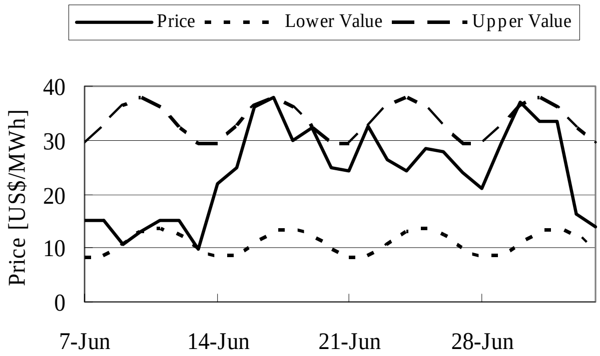


Fig. 9. The results of price forecast, when temperature is not much high (from 28-Jun to 5-July).

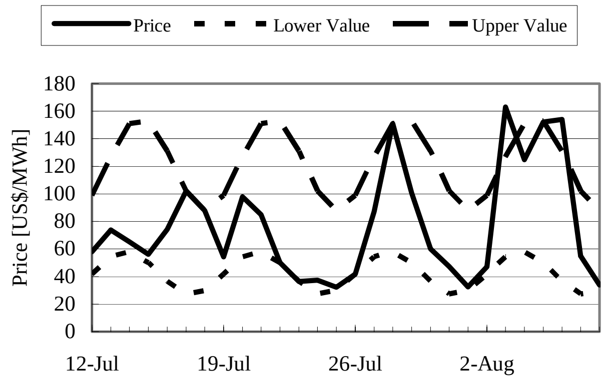


Fig. 10. The results of price forecast, when temperature rises up (from 2-Aug. to 8-Aug.).


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