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Estimating daily peak load using symmetrical doubly linear adaptive-fuzzy regression model

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Abstract. One appropriate and efficient model to estimate daily peak load is using fuzzy regression models. In this article, two types of fuzzy regression models named linear fuzzy regression and doubly linear adaptive-fuzzy regression are worked on. We will demonstrate by a practical example that the variance of doubly linear adaptive-fuzzy regression model is always lower than the variance of linear fuzzy model.

Keywords: daily peak load, linear fuzzy regression, doubly linear regression, daily peak load estimation

1. INTRODUCTION

Vague or applied data have wide applications in different fields such as trust ability, marketing, quality control, photo identification, etc. one problem about vague data is personal interpretations or varied identification terms (terms like enough, good, sufficiently … which receive different interpretations). In fact, in many cases, their true meanings are not understood precisely; therefore, we can only interpret them personally. Actually, we can only perceive only a series of approximate descriptions or the spread of their concepts. For instance, to understand the influence of a text characters on its comprehension, it is recommended to use [ ]; here the result of this test depend on the person's perspective, age, environment, personal reasons, and the person's attempt to understand the text. Therefore, some factors are embedded in [ ] as they might not be expressive in the text. It means that this symbol is the best-describing one out of these agents; of course, these agents are fuzzy products (Joung, 1996). In fuzzy data analysis, an analysis shows a relationship between fuzzy data and crisp (non-fuzzy) counterpart of dependent variables, and one or several independent fuzzy variables. An important issue here is left and right spread of a fuzzy number. Also, one analysis can be done through linear-fuzzy regression technique on these spreads. In this article, two models of regression called linear fuzzy regression and doubly linear adaptive-fuzzy regression model, which has smaller variance compared to linear fuzzy regression model, are introduced.

The structure of the article is as follows: first, some explanations about fuzzy mathematics and fuzzy numbers involved in this article (i. e. triangular fuzzy numbers) are given. Then, both regression models are described; and at last, a practical illustration is presented and estimated through both regression models.

2. FUZZY MATHEMATICS

Classical mathematics is an appropriate tool if we deal with the world of dual values. In dual-value world, the value of each predicate is shown by either of the two values of 'true' or 'false', or in mathematical language by $\{0,1\}$.

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However, human thinking developments and advances in science and technology necessitates a need for more appropriate scientific tools for describing more complex concepts of human life and environment; concepts which cannot be shown by conventional mathematics, which is founded on dual value criteria.

Fuzzy mathematics responds to this need; the need for multiple values for concepts instead of dual values for concepts; the need for describing the world realities as they are, instead of describing them an frameworks where they don't fit in.

Principles and basics of science argues that any thing is either true or false, while every thing is not so if we consider relativeness of things. A state of "uncertainty" verifies about real phenomena. Maybe, the basic mistake of science is this fact: something that makes sense in certain cases is generalized to every phenomena. In fact, science describes fuzzy world in a non-fuzzy way.

1.2. MEMBERSHIP FUNCTION AND MEMBERSHIP DEGREE

Suppose set X . We say $\tilde{A}$ is a fuzzy subset of X if

$$\tilde{A} : X \longrightarrow [0\,,1] \tag{1}$$

is a function.

The amount which is given to x in this relation is known as x's membership degree. $\widetilde{A}$ fuzzy set can also be shown as $\widetilde{A} = \left\{\left(x, \widetilde{A}(x)\right) \middle| x \in X\right\}$.

1.3. Example

Suppose $A = \{1,2,3\}$ and $X = \{1,2,3,4,5\}$. As such, characterizing function of A is as follows:

$$\chi_A(x) = \begin{cases} 1 & x = 1,2,3 \\ 0 & x = 4,5 \end{cases}$$

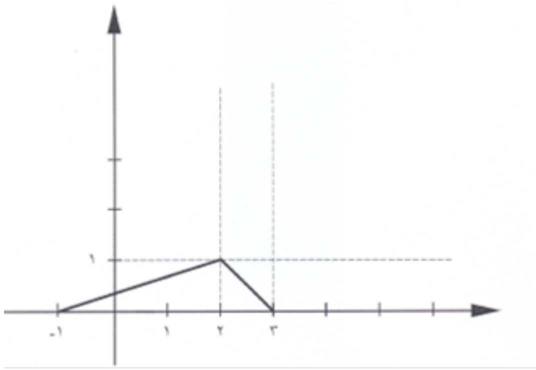
Which shows that 1, 2, and 3 are members of A and 4 and 5 are not. Now, membership function can be defined as follows, as a generalization of characterizing function.

1.4. Membership Function

Membership function of a triangular fuzzy number is defined as below:

$$\tilde{A}(x) = \begin{cases} \frac{x-a+l_a}{l_a} & a - l_a < x \le a \\ \frac{x-a+r_a}{r_a} & a < x \le a + r_a \\ 0 & else \end{cases} \tag{2}$$

In which l_a is called left spread of "a" and r_a is called the right spread of it. As can be understood from the term 'triangular fuzzy', the graphic picture of these numbers are the shape of a triangle. For instance, the triangular fuzzy number of $l_a = 3$، $a = 2$ and $r_a = 1$ is as follows:



Graph 1. for triangle fuzzy number of $l_a = 3$ ، $a = 2$ and $r_a = 1$

3. FUZZY REGRESSION

As for every regression technique, the purpose of fuzzy regression is determining a function relation between the dependent variable with a set of independent variables. Both of the numbers can be crisp, or the independent variable can be crisp while the dependent variable a fuzzy number. In this article, we present two models of linear fuzzy regression and doubly linear adaptive-fuzzy regression model. The advantage of doubly linear adaptive-fuzzy regression model over linear regression is that its variance is lower. In continuation, the two models are presented together with a practical example of using them about peak load.

Linear fuzzy regression model is as follows:

$$Y_i = A_0 + A_1 x_{i1} + \cdots + A_p x_{ip} \quad , \; i = 1, \dots, n \tag{3}$$

In which x_{ij} are real numbers and $Y_i = [c_i - s_i, c_i + s_i]$ is a triangular fuzzy number with the center of c_i and the spread of s_i . Parameters of linear fuzzy regression are shown as $A_m = [a_m - r_m, a_m + r_m]$ or membership function ofY_i. Based on this, we define:

$$Y_{Li} = c_i - s_i \quad , \quad Y_{Ri} = c_i + s_i$$

$$\hat{Y}_{Li} = \hat{L}_0 + \hat{L}_1 x_{i1} + \cdots + \hat{L}_p x_{ip} \quad , Y_{Ri} = \hat{R}_0 + \hat{R}_1 x_{i1} + \cdots + \hat{R}_p x_{ip} \quad , \quad i = 1, \dots, n$$

$$\hat{A}_m = [\hat{a}_m - \hat{r}_m, \hat{a}_m + \hat{r}_m] \quad , \quad \hat{a}_m = \frac{\hat{L}_m + \hat{R}_m}{2} \quad , \quad \hat{r}_m = \frac{|\hat{R}_m - \hat{L}_m|}{2}$$

(4)

According to the above-mentioned relations we define:

$$\hat{a} = (\acute{x}x)^{-1}\acute{x}c \qquad , \qquad \hat{r} = (\acute{x}x)^{-1}\acute{x} \tag{5}$$

In this relation, x is a matrix of n*(k+1), and c is centers' vectors, and s is input spreads or p sizes.

3.1. Doubly linear adaptive-fuzzy regression model

Doubly linear adaptive-fuzzy regression model is based on two linear models. One of them is nuclear regression which is examined based on the centers of fuzzy numbers, and the other is dispersed regression model, which works based on left and right spreads of fuzzy numbers. This regression model is defined as follows:

$$c = c^* + \varepsilon_c \quad , \quad c^* = Xa \tag{6}$$

$$s = s^* + \varepsilon_s \qquad , \quad s^* = c^* b + 1d = Xab + 1 \tag{7}$$

Where x is a matrix of n*(p+1), "a" is a columnar vector (p+1) with regression parameters of the first model (nuclear regression model). c^* And c are vectors of central observations of triangular fuzzy numbers with (n+1) size, and s^* and s are spread vectors (left and right spreads) of triangular fuzzy number with the size of h+1. Also, 1 is a (n+1) vector whose components are all of size 1; and, finally, b and d are regression parameters for the second model (spread regression model). The above-mentioned models are based on two linear models. In the first model, inputs are from centers of fuzzy observations, and the second model which is the product of dispersions of fuzzy observations, is covered with the first model.

Observations which are predicted by variable x (equation 4) are, in fact, central observations of fuzzy number. The model presented here, is based on a possible linear relation between the size of left and right spreads on one hand, and the central estimates on the others. These cases have wide uses in real world. In fact, what was said, is similar to dependence of the centers and right and left spreads (for instance, indefiniteness and fuzziness can be considered as the dependence size of magnetism to the surrounding field).

We define:

$$a = \frac{1}{(1+b^2)}\Big((\acute{X}X)^{-1}\acute{X}(c + sb - 1bd)\Big)$$

$$b = \big(\acute{a}\acute{X}Xa\big)^{-1}(\acute{S}Xa - \acute{a}\acute{X}1d)$$

$$d = \frac{1}{n}(\acute{s}1 - \acute{a}\acute{X}1 \tag{8}$$

4. APPLICATION OF FUZZY REGRESSION ANALYSIS IN ESTIMATING DAILY PEAK LOAD

Fuzzy regression models have wide uses in estimating peak loads. All relations between output amounts – which can be peak load amounts, current load, or load or energy waste – and explanative variables of the model, can be introduced into a fuzzy regression model. For example, spread results show that energy consumption is a factor which has dependency with demand in peak. To demonstrate application of fuzzy regression method in estimating peak load, we use Feeder Fhadan data on domestic electricity subscribers in 8 days as follows:

Table 1.

day	Peak load amount (kw)	Daily energy consumption (kwH)
1st day	30.675	387.45
2nd day	26.925	369.17
3rd day	27.65	378.42
4th day	26.875	352.6
5th day	27.275	382.63
6th day	27.85	353.77
7th day	29.45	393.21
8th day	25.05	346.62

In this article, based on consumed energy, peak load amounts are calculated through two methods of linear fuzzy regression and doubly linear adaptive-fuzzy regression model. We can see that variance of doubly linear fuzzy model is less than the variance of regular linear fuzzy model.

In table 1, daily consumption amount, time, and amount of peak load in each day is shown for above feeder. Calculation results of fuzzy regression spreads are given in table 2.

Table 2. Fuzzy number spreads.

	Fuzzy number spread
1	1.51
2	1.44
3	1.48
4	1.38
5	1.49
6	1.38
7	1.53
8	1.35

At last, the estimated amount for point by means of both models are given in table 3 compared to the real amounts.

Table 3. Estimat of methods linear fuzzy regression and doubly linear adaptive-fuzzy regression model

	Real amounts	Estimate of linear fuzzy regression	Estimate of
1	30.68	28.97	28.33
2	26.93	27.62	27.69
3	27.65	28.30	28.33

4	26.88	26.4	26.54
5	27.28	28.6	28.62
6	27.85	26.5	26.62
7	29.45	29.4	29.35
8	25.05	25.96	26.13

The variance of linear fuzzy regression is 1.6, and the variance of doubly linear adaptive-fuzzy regression model is 1.19.

5. CONCLUSION

In this article, two fuzzy regression models are presented. In both models- because triangular fuzzy numbers are used (i.e. because of having spreads)- margin of safety in estimating peak amounts is higher than the regular regression. In doubly linear adaptive-fuzzy regression model, in which there exist a relationship between centers and spreads, a lower variance (or in the worst conditions an equal variance) exists compared to the linear fuzzy regression model.

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