A Dynamic Electricity Tariff survey for Smart Grid in South KOREA

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ABSTRACT

In this paper, an analysis for consumer perception of the level of electricity price, the amount of household electricity consumption and consumer perception on dynamic electricity pricing system in South Korea are investigated. A survey was conducted between July 24 and August 17, 2015 and then for the preference analysis, Binary Logistic Model is applied for the acceptance, Ordered Probit Model is applied. The major findings say that the less they have monthly income, the more satisfied dynamic pricing. In dynamic electricity tariff, real time pricing is most preferred dynamic pricing system and it reaches about 40% of respondents.

Keywords: Dynamic Electricity Tariff, Smart Grid, Binary Logistic Model, Ordered Probit Model.

1. INTRODUCTION

Worldwide interest is being focused on Smart-grid due to the restrictions on greenhouse gases emission for prevention of global warming and the demand for improving energy efficiency. Electricity tariff can play an important role in smart grid by decreasing electricity usage, helping energy efficiency, and demand-side management. According to the electricity tariff structure, electric customers to reduce their electricity usage in a given time period or shift that usage to another time period in response to a price signal.

There are a variety of electricity tariff type and incentives to promote energy conservation, including time-of-day tariffs, seasonal tariffs in areas where seasonal demand fluctuation is evident, and compensation for users who avoid peak hour consumption. Under a time-of-day tariff, electricity consumed during peak hours is charged at a higher rate than electricity consumed during off-peak hours. This tariff encourages consumers to use electricity prudently during peak hours. But these electricity tariff structure does not show the current electricity usage and cost information. For that reason, time-based or dynamic pricing is designed and consumers has better information about the cost of electricity. It allows that consumers can schedule their electricity usage during periods of low cost rates. Time-of-day electricity rate structures do not reflect the cost difference of supplying electricity in peak versus off-peak hours. Therefore, the customer has no market incentive to adjust their pattern of electricity consumption. As an example of market incentive, peak-time rebates can incentivize consumers to reduce their load during peak hours or when the reliability of the grid is at stake. [1][2]

There is various type of dynamic electricity pricing methods: Time of Use (TOU) pricing, Critical Peak Pricing(CPP), Real Time Pricing(RTP) and Peak Time Rebate(PTR). Before applying dynamic electricity tariff, how consumers respond to dynamic electricity pricing methods and identify the most promising mechanisms suitable for wide-scale deployment.

This study develops an approach to dynamic pricing in support of Electricity Tariff Design in South Korea. Most residential electricity customers in South Korea are on a graduating pricing system, meaning when they use electricity, it costs different based on their consumption amount. This study mainly investigated consumer perception of the level of electricity price, the amount of household electricity consumption and consumer perception on dynamic electricity pricing system. For data collection, a survey was conducted for 1,000 consumers who live in Seoul, Korea between July 24 and August 17, 2015. To analyze for the preference, Binary Logistic Model is applied and for the acceptance, Ordered Probit Model is used.

This paper is composed as follows. Chapter 2 shows the dynamic electricity tariff system and electricity tariff of South Korea. Chapter 3. explains the methodology for analysis of consumer preferences. Chapter 4. mentions the questionnaire survey method and collected data. Chapter 5. illustrates the results estimated by using the surveyed questionnaire. Lastly, Chapter 6. presents conclusion of this Study.

2. DYNAMIC ELECTRICITY TARIFF

Time-based or dynamic pricing refers to the provision of a service or commodity in which the price depends on the time when the service is provided or the commodity is delivered. The rationale of dynamic time-varying pricing is to reflect changes (expected or observed) in supply and demand over time and their impact on costs. Time-based pricing includes: (i) fixed time-of use rates for electricity and public transport, (ii) dynamic pricing reflecting current supply-demand situation; or (iii) differentiated offers for delivery of a commodity depending on the date of delivery.

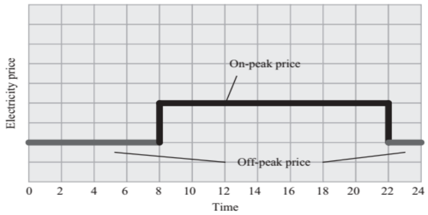

Figure 1. Time of Use Pricing

Fig 1. Shows Time of use (TOU) pricing, Under TOU pricing, the electricity prices are rates set for specific hourly time periods on an advance or forward basis. Prices paid for energy consumed during these periods are pre-established and known to consumers in advance, thus allowing them to vary their usage in response to these prices and manage their energy costs by shifting usage to a lower cost period or reducing their consumption overall.

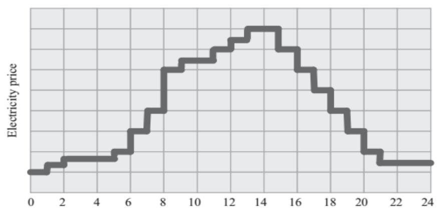

Figure 2. Real Time Pricing

Fig 2. Explains Real time pricing (RTP), electricity prices may change hourly, or even sub-hourly, with price signals provided to the user shortly in advance, reflecting the utility's cost of generating and/or purchasing electricity at the wholesale level RTP defines hourly or half-hourly prices corresponding to changes in the intra-day or day-ahead cost of electricity generation and delivery. For RTP, one option is 'one-part' pricing, in which all use is priced at the hourly or spot price. Another approach is 'two-part' pricing. Two-part RTP tariff designs include a historical baseline of customer use, added to hourly prices only for marginal use above or below the baseline.

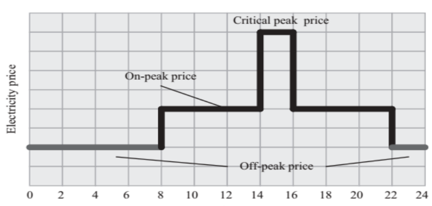

Figure 3. Critical Peak Pricing

Fig 3. illustrates Critical peak pricing (CPP), TOU prices are in effect except for certain critical peak days when prices may reflect the exceptionally high costs of generating and/or purchasing electricity at the wholesale level.[3]

Customers thus see market prices only at the margin. CPP uses real-time price at major system peaks. The CPP prices are restricted to a small number of hours per year, where electrical prices are much higher than normal peak prices, and their timing is unknown ahead of being called.

In general, electricity tariff is a different as a season and usage hour. Table 1. is the electricity price from Korea Electric Power COoperation (KEPCO). Most residential electricity customers in South Korea are on a graduating pricing system, meaning when they use electricity, it costs different based on their consumption amount. Currently, it is composed of 6 levels and the cost level 6 is 11.7 times more than level 1.

Table 1. Electricity rates table, Korea

Demand charge (won/household)		Energy charge (won/kWh)	
1 ~ 100kWh	410	1 ~ 100kWh	60.7
101 ~ 200kWh	910	101 ~ 200kWh	125.9
201 ~ 300kWh	1,600	201 ~ 300kWh	187.9
301 ~ 400kWh	3,850	301 ~ 400kWh	280.6
401 ~ 500kWh	7,300	401 ~ 500kWh	417.7
500kWh ~	12,940	500kWh ~	709.5

3. METHODOLOGY

For the preference analysis, this paper uses a binary logistic Model. In statistics, logistic regression or logit model is a regression model where the dependent variable is categorical. The binary logistic model is used to estimate the probability of a binary response based on one or more predictor or independent variables.

Logistic regression measures the relationship between the categorical dependent variable and one or more independent variables by estimating probabilities using a logistic function, which is the cumulative logistic distribution. The model of logistic regression, however, is based on quite different assumptions from those of linear regression. The predicted values are probabilities and are therefore restricted to (0,1) through the logistic distribution function because logistic regression predicts the probability of particular outcomes.[4][5]

The simple logistic model has the form

$$\text{logit}(Y) = natural\ \log(odds) = \ln\left(\frac{\pi}{1-\pi}\right) = \alpha + \beta X. \qquad (1)$$

$$\pi = Probability(Y = \text{outcome of interest} \mid X = x,\ a\ specific\ value\ of\ X) = \frac{e^{\alpha+\beta x}}{1+e^{\alpha+\beta x}}, \qquad (2)$$

where π is the probability of the outcome of interest or event, α is the Y intercept, β is the regression coefficient, and e = 2.71828 is the base of the system of natural logarithms. X can be categorical or continuous, but Y is always categorical.

According to Eq (1), the relationship between logit (Y) and X is linear. Yet, according to Eq (2), the relationship between the probability of Y and X is nonlinear. For this reason, the natural log transformation of the odds in Eq (1) is necessary to make the relationship between a categorical outcome variable and its predictor linear. The value of the coefficient β determines the direction of the relationship between X and the logit of Y. When β is greater than zero, larger (or smaller) X values are associated with larger (or smaller) logits of Y. Conversely, if β is less than zero, larger (or smaller) X values are associated with smaller (or larger) logits of Y.

Within the framework of inferential statistics, the null hypothesis states that β equals zero, or there is no linear relationship in the population. Rejecting such a null hypothesis implies that a linear relationship exists between X and the logit of Y. If a predictor is binary then the odds ratio is equal to e, the natural logarithm base, raised to the exponent of the slope β (e^{β}). Extending the logic of the simple logistic regression to multiple predictors, one can construct a complex logistic regression for Y as follows

$$\text{logit}(Y) = \ln\left(\frac{\pi}{1-\pi}\right) = \alpha + \beta_1 X_1 + \beta_2 X_2. \tag{3}$$

$$\pi = \text{Probability } (Y = \textit{outcome of interest} \mid X_1 = x_1, X_2 = x_2 = \frac{e^{\alpha+\beta_1 X_1+\beta_2 X_2}}{1+e^{\alpha+\beta_1 X_1+\beta_2 X_2}}, \tag{4}$$

where π is once again the probability of the event, α is the Y intercept, β_s are regression coefficients, and X_s are a set of predictors. α and β_s are typically estimated by the maximum likelihood (ML) method. The ML method is designed to maximize the likelihood of reproducing the data given the parameter estimates. Data are entered into the analysis as 0 or 1 coding for the dichotomous outcome, continuous values for continuous predictors, and dummy codings (e.g., 0 or 1) for categorical predictors.[6]

For the acceptance analysis, ordered probit model is used. The attractions of the ordered probit model are most easily appreciated by considering the consequences of analysing ordered outcomes using linear regression technique. The ordered probit model is based on the assumption that y_i^* depends linearly on x_i ,[7]

$$y_i^* = x_i{}'\beta + u_i \quad i = 1,\cdots,n \qquad u_i \sim N(0,1) \tag{5}$$

where β is a vector of parameters, not containing an intercept. These parameters will ultimately be interpretable in the same way as slope parameters in linear regression. y^* is unobserved, but the relationship between y^* and the observed variable y is

$$\begin{aligned} &y=1 \text{ if } -\infty < y^* < \kappa_1 \\ &y=2 \text{ if } \kappa_1 < y^* < \kappa_2 \\ &y=3 \text{ if } \kappa_2 < y^* < \kappa_3 \\ &\vdots \\ &y=J \text{ if } \kappa_{J-1} < y^* < \infty \end{aligned} \tag{6}$$

The parameters κ_j, $j=1,\ldots,J-1$, are known as cut-points, or sometimes threshold parameters. For the log-likelihood function, let $P_i(y)$ be the probability that the i-th respondent's response is y. This probability is

$$P_i(y) = P(\kappa_{y-1} < y_i^* < \kappa_y) = \Phi(\kappa_y - x_i{}'\beta) - \Phi(\kappa_{y-1} - x_i{}'\beta) \tag{7}$$

where $\Phi(.)$ is the standard normal cumulative distribution function. So, based on a sample (y_i , x_i , $i=1,\ldots,n$), the log-likelihood function is

$$LogL = \sum_{i=1}^{n} \ln[P_i(y_i)] = \sum_{i=1}^{n} \ln\left[\Phi(\kappa_{y_i} - x_i{}'\beta) - \Phi(\kappa_{y_i-1} - x_i{}'\beta)\right] \tag{8}$$

4. SURVEY AND DATA

The sample data was collected through questionnaire among 1,000 households that currently residing in Seoul between July 24 and August 17, 2015. The survey was carried out by this study and a face-to face interview is used to improve the reliability of the survey. For the survey, we created 3 divisions and questionnaire. Those are general information of respondents, Acceptance and Preference of Dynamic Electricity Tariff and Generals of Electricity Tariff. Table 2. shows the survey structure.

Table 2. Survey structure

Division	Area of analysis	Questionnaire
General information of respondents	Details of respondents	Monthly Income
		Residential Area
		Number of Residents
		Residential Type
Acceptance and Preference of Dynamic Electricity Tariff	Acceptance	Interest of Electricity Tariff
		Select of Dynamic Electricity Tariff
	Preference	Preference of Dynamic Electricity Tariff
		Satisfaction of Dynamic Electricity Tariff
		Dissatisfaction of Dynamic Electricity Tariff
	Satisfaction	Degrees of Satisfaction
		Reason of Satisfaction
		Reason of Dissatisfaction
Generals of Electricity Tariff	Details of Electricity Tariff	Opinion of Electricity Tariff
		Opinion of Dynamic Electricity Tariff Cost
		Effect of Dynamic Electricity Tariff

Table 3. shows general information of respondents, it has 4 categories which are monthly income, residential area, number of residents and residential type. Each Questionnaire has its question such as monthly income amount, size of residential area, how many persons are lived and type of residence. For example, a number of household who earned 2M ~ 3M KRW monthly is 240 and it is a 28.9% of all responds.

Table 3. General information of respondents

Questionnaire		Number of responds	Percent(%)
Monthly Income	Under 1M KRW	20	2.4
	1M ~ 2M KRW	50	6.0
	2M ~ 3M KRW	240	28.9
	3M ~ 4M KRW	160	19.3
	4M ~ 5M KRW	150	18.1
	Over 5M KRW	210	25.3
Residential Area	Under 66 m^2	70	8.4
	66 m^2 ~ 99 m^2	310	37.3
	99 m^2 ~ 132 m^2	380	45.8
	132 m^2 ~ 165 m^2	40	4.8
	165 m^2 ~ 198 m^2	0	0
	Over than 198 m^2	30	3.6
Number of Residents	1	60	7.2
	2	110	13.3
	3	180	21.7
	4	380	45.8
	5	90	10.8
	Over than 6	10	1.2
Residential Type	Landlord	500	60.2
	Deposit basis lease	280	33.7
	Monthly Rent	50	6.0

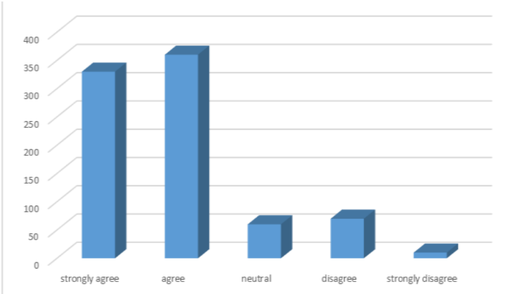

Figure 4. Interest of Electricity Tariff

Fig 4. shows interest of electricity tariff survey data. According to the survey data, most numerous respond is 360 to the interest of electricity tariff and then 330 people says very interest to electricity tariff. It reaches 83.2% of total responds.

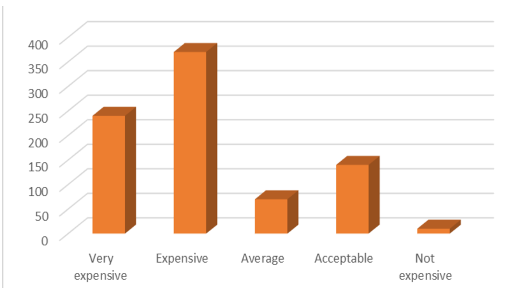

Figure 5. Opinion of Electricity Tariff Cost

Fig 5. shows opinion of electricity tariff cost. 240 people answered electricity cost is very expensive and 370 respondents said expensive. It reaches 73.5% of total responds. From Fig 4. and Fig 5, most of respondents are interested to electricity tariff and considered the price of electricity expensive.

To verify the reliability of survey data, Cronbach's α test was conducted. If the value of Cronbach's α is greater than 0.6, then the data has reliability. As the Table 4, all Cronbach's α test result are greater than 0.6. We consider all data is reliable.

Table 4. Reliability test

Division	Questionnaire	Cronbach's α
Acceptance and Preference of Dynamic Electricity Tariff	Interest of Dynamic Electricity Tariff	0.736
	Select of Dynamic Electricity Tariff	0.872
	Preference of Dynamic Electricity Tariff	0.648
	Satisfaction of Dynamic Electricity Tariff	0.928
	Dissatisfaction of Dynamic Electricity Tariff	0.630
	Degrees of Satisfaction	0.837
	Reason of Satisfaction	0.726
	Reason of Dissatisfaction	0.837
Generals of Electricity Tariff	Opinion of Dynamic Electricity Tariff	0.629
	Opinion of Dynamic Electricity Tariff Cost	0.720
	Effect of Dynamic Electricity Tariff	0.893

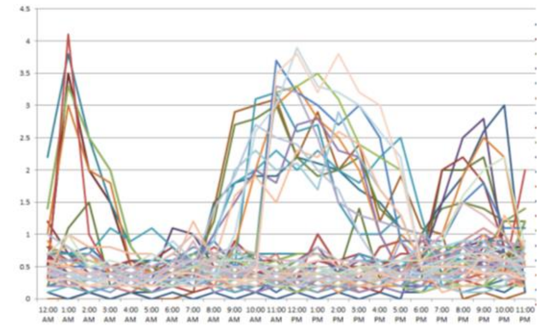
Figure 6. Electricity consumption pattern

Fig 6. Shows the 24 hours' electricity consumption data from re spondents, those data are collected from 96 households at Jul 2, 2015

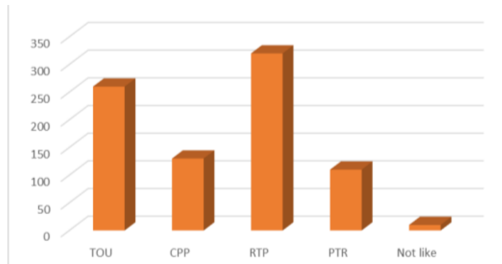

Figure 7. Preference of Dynamic Electricity Tariff

Fig 7. shows preference of dynamic electricity tariff survey data. According to the survey data, most numerous respond is 320 to the RTP and then 260 people says TOU. It reaches 39% and 31.7% respectively.

5. ANALYSIS RESULTS

For the acceptance of dynamic electricity tariff, ordered probit model was conducted and the analysis result is shown at Table 5. Effected variables about dynamic electricity tariff are monthly income, numbers of residents, Interest of Electricity Tariff and Select of Dynamic Electricity Tariff. As a monthly income, who has less monthly income accept Dynamic Electricity Tariff (Y=3,4). The greater the number of residence would accommodate the dynamic electricity tariff(Y=3,4). The greater the impact on electricity tariff for consumers accept dynamic electricity tariff(Y=3,4).

Table 5. Acceptance analysis from ordered probit model

Division	Model		Effect				
	β	t	Y=0	Y=1	Y=2	Y=3	Y=4
Monthly Income	-0.290	-6.192	-0.002	-0.001	-0.003	0.007	0.028
Residential Area	-	-	-	-	-	-	
Number of Residents	0.293	6.001	-0.005	-0.004	-0.005	0.009	0.032
Interest of Electricity Tariff	0.101	2.001	-0.006	-0.005	-0.006	0.005	0.034
Select of Dynamic Electricity Tariff	0.102	2.008	-0.002	-0.002	-0.003	0.009	0.012

For the preference of dynamic electricity tariff, binary logit model was conducted and the demographic characteristic of respondents are shown from table 6 to table 9. According to table 6, depending on demographic characteristics of the respondent's monthly income, TOU is most common answers from the respondents with a monthly income of 2M-3M KRW.

From table 7, depending on demographic characteristics of the respondent's residential area, CPP is 50% from the respondents with a Residential area of 132 m^2 ~ 165 m^2.

In table 8, depending on demographic characteristics of the respondent's monthly income, TOU is most common answers from the respondents with Number of residents, 3.

Table 9 shows Preferred Dynamic Electricity Tariff from Residential type, depending on demographic characteristics of Residential type, 99 people chose CPP from the respondents with Deposit basis lease.

Table 6. Preferred Dynamic Electricity Tariff from monthly income

Div	Monthly Income						Frequency (%)	Chi Square
	Under 1M KRW	1M ~ 2M KRW	2M ~ 3M KRW	3M ~ 4M KRW	4M ~ 5M KRW	Over 5M KRW		
TOU	10	20	150	60	10	10	260(31.7)	65.345
CPP	5	10	75	23	12	5	130(15.9)	
PTR	3	17	5	5	10	70	110(13.4)	
RTP	5	10	5	55	200	45	320(39.0)	

Table 7. Preferred Dynamic Electricity Tariff from Residential area

Div	Residential Area						Frequency (%)	Chi Square
	Under 66 m^2	66 ~ 99 m^2	99 ~ 132 m^2	132 ~ 165 m^2	165 ~ 198 m^2	Over 198 m^2		
TOU	3	27	154	56	13	7	260(31.7)	31.102
CPP	2	8	15	65	28	12	130(15.9)	
PTR	5	10	5	16	50	24	110(13.4)	
RTP	10	15	15	10	50	220	320(39.0)	

Table 8. Preferred Dynamic Electricity Tariff from Number of residents

Div	Number of Residents						Frequency (%)	Chi Square
	1	2	3	4	5	Over 6		
TOU	13	27	121	49	25	15	260(31.7)	20.487
CPP	5	10	60	34	16	5	130(15.9)	
PTR	5	15	49	21	12	8	110(13.4)	
RTP	2	22	20	26	191	59	320(39.0)	

Table 9. Preferred Dynamic Electricity Tariff from Residential type

Div	Residential Type			Frequency (%)	Chi Square
	Landlord	Deposit basis lease	Monthly Rent		
TOU	45	200	15	260 (31.7)	19.298
CPP	21	99	10	130(15.9)	
PTR	60	44	6	110(13.4)	
RTP	280	35	5	320(39.0)	

6. CONCLUSION

This study develops an approach to dynamic pricing in support of Electricity Tariff Design in South Korea. Dynamic pricing for electricity is intended to reveal how consumers respond to electricity prices. Traditional electricity pricing structures do not reflect the cost difference of supplying electricity in peak versus off-peak hours. Therefore, the customer has no market incentive to adjust their pattern of electricity consumption. Dynamic pricing options such as time of use (TOU), critical peak pricing (CPP), real time pricing (RTP), and Peak Time Rebate (PTR), that reflect time-varying cost of electricity supply, have been in use worldwide to encourage peak load management and demand reduction. Most residential electricity customers in South Korea are on a graduating pricing system, meaning when they use electricity, it costs different based on their consumption amount. Currently, it is composed of 6 levels and the cost level 6 is 11.7 times more than level 1. Consumer perception about the level of electricity price, the amount of household electricity consumption and consumer perception on dynamic electricity pricing system are investigated. For data collection, a survey was conducted between July 24 and August 17,2015. To analyze for the preference, Binary Logistic Model is applied and for the acceptance, Ordered Probit Model is used. The major findings are as follows: Household size and income were significantly associated with electricity consumption. The acceptance rate for dynamic electricity pricing system shows the less they have monthly income the more satisfied dynamic pricing. The Real time pricing is most preferred dynamic pricing system and it reaches about 40%. Successful introduction of smart meters and time-based dynamic electricity pricing requires a well-planned social marketing campaign to help raise awareness and give customers the information and support they need to become more energy efficiently. Survey for dynamic pricing system and analysis will help to choose the dynamic pricing options.

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REFERENCES

[1] Shantanu Dixit, Ashwini Chitnis, Davida Wood, Bharath Jairaj and Sarah Martin, "10 Questions to ask about electricity tariffs"., World Resource Institute., Working paper, Apr. 2014

[2] Ahmad Faruqui, Sanem Sergici, "Household response to dynamic pricing of electricity- A survey of the experiment evidence"., Jan. 2009

[3] Janaka Ekanayake, Kithsiri Liyanage, Jianzhong Wu, Akihiko Yokoyama, Nick Jenkins, "SMART GRID-TECHNOLOGY AND APPLICATIONS", Wiley, 2012

[4] David A. Freedman, **Statistical Models: Theory and Practice**. Cambridge University Press., 2009

[5] Cox, DR, "The regression analysis of binary sequences (with discussion)"., **J Roy Stat Soc** B 20, 1958, pp.215-242

[6] Chao-Ying Joanne Peng, Kuk Lida Lee, and Gary M. Ingersoll, "An Introduction to Logistic Regression Analysis and Reporting", **The Journal of Educational Research**, Vol. 96, No.14, 2002, pp. 3-14.

[7] Anne R.Daykin, Peter G. Moffatt, "Analysing ordered responses: A Review of the ordered probit model", **Understanding Statistics**, Vol 1, Issue 3., 2002, pp. 157-166.

[8] Report. "An analysis of receptivity and preference for electricity dynamic rates of residential customer through selective model"., 2015