Discussion Paper

CHUNG-HUA INSTITUTION FOR ECONOMIC RESEARCH
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This paper is derived from a research report "A study on Electricity Priority Service Program in Taiwan," done by the authors in July 1991 at CIER.

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George J. Y. Hsu*, Pao-long Chang** and Tser-yieth Chen***

ABSTRACT

The implementation of a curtailable rate program through an appropriately designed menu, mainly determined by the customer's outage costs, is one feasible solution to a power shortage problem. In Taiwan, this issue is particularly important because currently Taiwan is facing a shortage of power generation supply in the summer peak period. In the present study, we have conducted a survey to examine the market acceptance for the proposed curtailable rate menu and have investigated customers' imputed outage costs in relation to their attributes. The survey results show that the imputed outage costs range from $2.25/KW to $3.15/KW and a potentiality of 5.6% to 18.1% of high-tension power peak load supply of the surveyed customers could be curtailed. The economic implications of the research results are presented, and further research is also recommended.

Keywords: Outage costs, Curtailable rate program, Outage condition, Reliability

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I. Introduction

A curtailable rate program[1] promises to be a useful demand-side management instrument for electric utilities. In terms of power dispatch, the capacity contracted by power users could be deemed a "quasi-reserve margin" and many utilities use this program to cope with the power capacity shortage problem in the peak load periods. Also, the transaction costs involved in implementing a curtailable rate program are relatively low and the peak-clipping in KW per customer is high. Furthermore, a curtailable rate is also one of the concepts of priority service. Priority service, which offers customers a selection of service options at a range of prices for all, or portions of their loads, allows for utility flexibility and generating efficiency. At the same time, it can lower customers' costs. Obviously, the implementation of a curtailable rate, through an appropriately designed menu, mainly determined by the customer's outage costs, would be one feasible solution to the power shortage problem. In Taiwan, this issue is particularly important because the summer electricity peak load is facing a shortage of power generation supply.

Taiwan is a small island with a high economic growth rate, which has averaged 8.9% over the last four decades resulting in a 62 fold increase in electricity demand, from 1,420GWH in 1952 to 87,939GWH in 1990. In the past five years, Taiwan Power Company (Taipower) has experienced an annual two-digit rate of growth during the periods of system peak-load demand. However, since reaching a respectable level of per capita income ($7,332 in 1990), the people in Taiwan have become more and more

[1] The term "curtailable" is different from "interruptible" in the sense that the former means partial load curtailment while the latter means total load interruption.

concerned with the quality of the environment, which has been significantly sacrificed in Taiwan's quest for economic growth. Moreover, during the last few years, many power plant development programs have been postponed due to the opposition of the local population near the proposed plant sites. As a result, the reserve margin of Taipower's generating capacity dropped to 5.4% in 1990. In the summers of 1989, 1990 and 1991, several power outages occurred due to a shortage in generating capacity. This problem is likely to continue since there won't be enough generating units on-line to meet the projected growth in peak-load demand. Under these circumstances, a curtailable rate program could be an effective strategy to mitigate the power shortage problem in Taiwan.

According to the above background information, the purpose of this paper is to analyze customers' imputed outage costs of a proposed curtailable rate program in relation to their attributes in Taiwan. To fulfill this objective, we conducted a survey on 825 high-tension power customers with contracted demand capacities of 1,800KW or greater. The questionnaires were designed to help us determine industrial consumers' willingness to accept the proposed curtailable rate programs. Using the results of the survey, we estimated imputed outage costs, which could be deemed as the upper bounds of outage costs, of different customer groups. The structure of the paper is organized as follows. Section two presents the survey framework. Section three illustrates the research analytical procedure. Section four analyzes the estimated results of the survey. In the final section, conclusions are drawn and areas for further research are suggested.

II. The Survey Framework

A market acceptance survey was conducted in March 1991 and focused on all high-tension power customers in manufacturing with contracted capacities of 1,800KW or greater. The reason behind this is that we looked at the problem from the viewpoint of Taiwan's electricity sales structure. Taipower's industrial power users (including agriculture, mining, manufacturing, and the service industry) account for 69.7% of total electricity sales, while these users represent only 3.2% of the total number of users. General users, whose consumption of electricity is primarily for the purpose of lighting (residential and commercial), account for 30.3% of total electricity sales, and these users make up 96.8% of the total users. This is quite different from the situation in the United States and other OECD countries, where about one-third of electricity sales goes to the industrial, commercial and residential sectors respectively. In addition, manufacturing industries in Taiwan account for 78.5%, (40,697GWH out of 51,841GWH) of total industrial power sales. Because electricity users in the manufacturing sector are, as a whole, the major consumers of electricity, they should be the focus of attention of a proposed curtailable rate program.

Of the 825 surveys, the reply rate was 52.9% (437 respondents). Among those who responded, 353 were useable and constituted the effective sample size in this study. For grouping of the firms, industrial sectors, and firms' scale of operation, were used as categories. The former was categorized into eight different groups according to the electricity-intensity, i.e., basic metals, non-metal products, paper products, chemicals, metallic products, food products, fabric products, and machinery/electronics. The scale of operation category was also classified according to four different levels of contracted capacity, i.e., below 3,000KW, 3,001-5,000KW, 5,001-12,000KW and above 12,000KW respectively.

For the proposed curtailable rate program, there are I, II, III and IV rates as defined in Table 1. The questionnaires focused on partial outage and their outage conditions. This included the combinations of the outage depth (ratio), pertaining to the customer's contracted capacity in KW, i.e., 10%, 15%, 20%, 25%, 30%, or greater; the outage duration, i.e., four-hours or eight-hours; the outage frequency per month, i.e. two , four or eight times; and prior notification of the outage, i.e., one-hour, four-hours or sixteen-hours. These conditions were determined by several pre-tests considering the possible scope of the outages that were acceptable by the customers. Also, note that these four rate schedules compete with each other, and none of them are notably dominant to the others.

Table 1 Proposed Curtailable Rate Program

Rates / conditions	I	II	III	IV
Outage prior notification	1 hr	4 hrs	16 hrs	16 hrs
Outage duration	4 hrs	4 hrs	4 hrs	8 hrs
Outage frequency per month	2 days	4 days	8 days	4 days

Notes: 1. Outage period must be in working days from July 1 to September 30.
2. Outage depth must not be less than 10% of customer's contracted capacity.
3. Rate incentive ranges from a 40% to 70% discount of the demand change per KW per month. The current demand charge is $0.62/KW/month.

III. The Analytic Procedure

Figure 1 illustrates the analytic procedure of the study. We first examined the market acceptance of the proposed rate menus, and then utilized this information to calculate the upper bounds of the imputed outage costs of potential customers. The magnitude of the upper bounds of outage costs involves the production characteristics of the industrial customer, e.g., production technology, product feature, and scale of production. From the viewpoint of the end-customer, there are both external and internal attributes in relation to the power outage. The former attribute can be characterized by the type of industry and contracted capacity, while the latter can be categorized by the outage condition of prior notification, frequency per month, duration and outage depth. Therefore, the relationship between the customer's outage costs and their attributes could be examined though statistical analysis including: (1) using analysis of variance (ANOVA) to verify if there are any significant differences among those attributes; (2) using cluster analysis among all external attributes, in order to discriminate the market; and (3) using analysis of covariance (ANCOVA) process to identify the quantitative relationship between the upper bounds of outage costs and both external and internal attributes.

Note that a customer will join the curtailable rate program if he can enjoy marginal benefits greater than his expected marginal costs due to the inconvenience of the power outages, i.e., marginal outage costs. In general, we can assert the rule by using the following criterion:

$$C_I < R_I$$

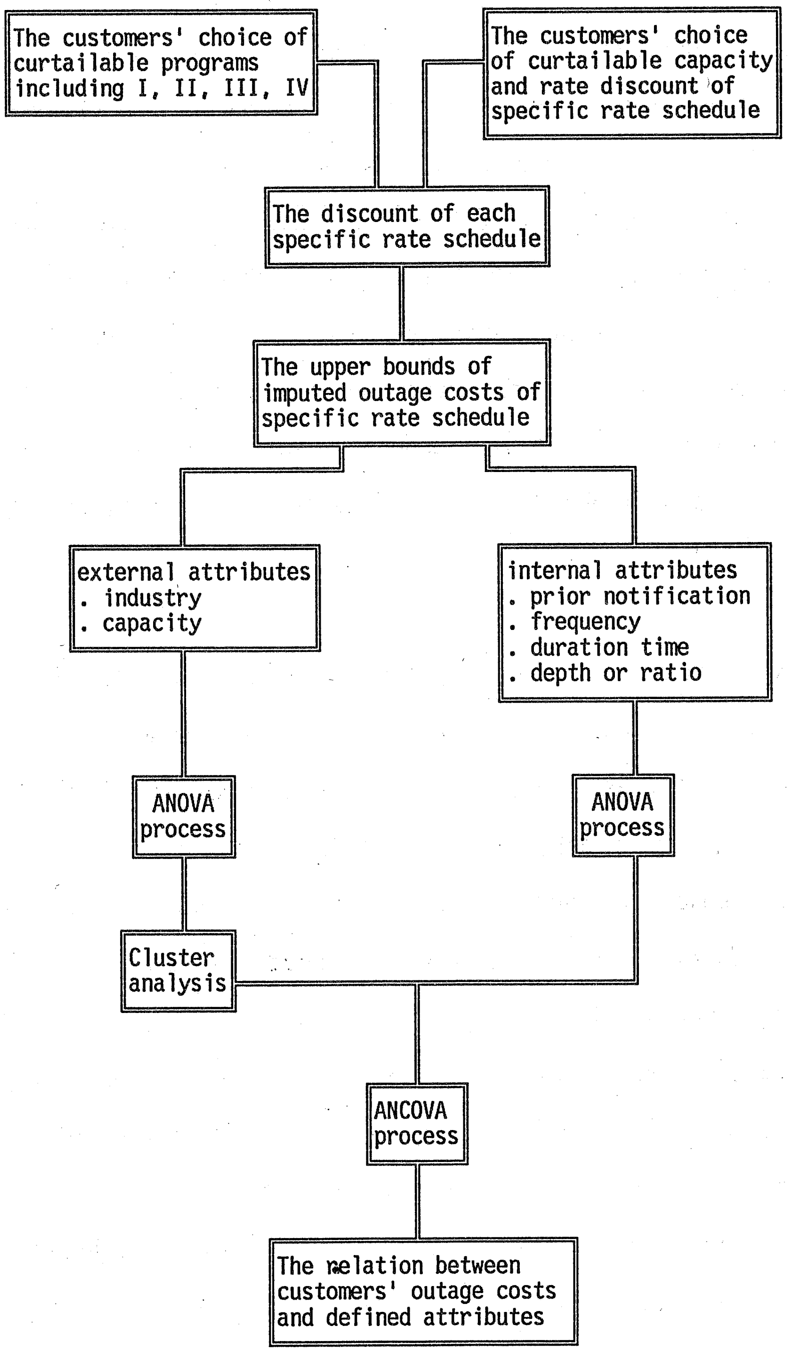

Figure 1: The Analytic Procedure

where R_i is the marginal rate incentive of the ith load slice given by the utility under a specific curtailable rate program and C_i is the marginal outage costs of the ith load slice of the customer under specific curtailed conditions. Also note that the right-hand side could be considered as the upper bounds of the outage costs of customers who are willing to participate in the curtailable rate program. Based on the above criterion and utilizing the survey data, we can illustrate the relationship between customers' outage costs and their chosen curtailable rate program. This approach is essentially a contingent valuation method in the context of economics and is extensively used for pricing of non-market goods. From the curtailable rate schedule that the surveyed customers chose, we were able to derive the level of their "willingness to accept" a more reliable power supply (rather than their willingness to pay as by Hsu and Lee (1990)).

Also note that we adopted the KW basis for analysis, instead of the KWH basis. This is because the main purpose of this study was to estimate a single number for the imputed outage costs for the total sample. In order to achieve this objective, we had to lump together all customers' outage costs for statistical inference. We found that the KW is a better measurement unit than the KWH in line with the above purpose. The reasons are as follows. If we use KWH as the measurement unit, outage duration and outage frequency per month will be internalized into the calculated KWH and leaves only "outage prior notification" as a power outage condition. Under this circumstance, rate schedules III and IV will apparently dominate rate schedule II, and rate schedule II will apparently dominate rate schedule I. Thus, we would not be able to lump different customers' outage costs together under different rate schedules. This is apparent because for different conditions of outage prior notification, there is no equal basis to merge together the data.

In contrast, if we use KW as the measurement unit, all these conditions including outage prior notification, outage duration, and outage frequency per month exist in each rate schedule. In other words, the outage costs per KW are measured in terms of each incident (rate schedule) of different outage conditions. Since these conditions are competing with each other, i.e., none of them are dominant to the others, we can assume they are seemingly indifferent and thus we can lump them together on an equal basis. Therefore, the outage costs per KW derived from this study are a weighted average number and is reflecting various, but seemingly indifferent, outage conditions as described in the four rate schedules (see Table 1).

As to the ANOVA process, it includes the following hypothetical tests: (1) an overall test of the goodness-of-fit of the relationship between outage costs and all attributes; (2) an individual attribute test which examines the significant differences between outage costs and each attribute; (3) a pair-wise test which verifies if there are any significant differences between the outage costs of any pair of each attribute; and (4) a contrast test which investigates if there are any significant differences in the outage costs between two different groups of attributes.

IV. The Empirical Results

Based on the simulated results, an average of 5.6% to 18.1% of the contracted capacity per customer of the total 835 sample members could be transferred from peak-period to off-peak period or be reduced with the curtailable rate program[2]. The total amount of estimated curtailable load range was from 149 MW to 463 MW. Also, it can be noted that the rate II and rate IV were more popular than the other two rates.

According to the responses in the questionnaires, for the customers in the eight industries who chose to participate in the proposed curtailable rate program, the imputed outage costs range from $2.25/KW to $3.15/KW as shown in Figure 2.

In order to evaluate the relationship between customer outage costs and the defined attributes, we begin with the external attributes first, and internal attributes next. With regards to the external attributes, since the overall F-value (3.09) of the ANOVA model is significant, it means that the formulated model is valid. Also the individual attributes test (i.e., industry and capacity), shows that the F-values are 4.24 (industry attribute) and 3.71 (capacity attribute), which are significantly different from zero. As to the results of the pair-wise test, Table 2 shows that each of the following groups have no significant differences in their outage costs: (1) basic metals, non-metal products and paper products; (2) chemicals and metallic products; (3) food products, fabric products and machinery/electronics. The possible reasons are the similar industrial characteristics within these sub-groups. However, there are notable different characteristics between these sub-groups. For example, for the food products industry, a total but short-lived outage may have a much smaller associated loss than a partial but long-lived one. In contrast, for the non-metal industry, a partial but long-lived outage may have a smaller associated loss than a total but short-lived outage. More details are documented in Hsu, et. al. (1989). Finally, the contrast test reveals that the

[2] If we take 353 effective samples as the basis, the curtailed capacity per customer will be 11.4% to 42.3%.

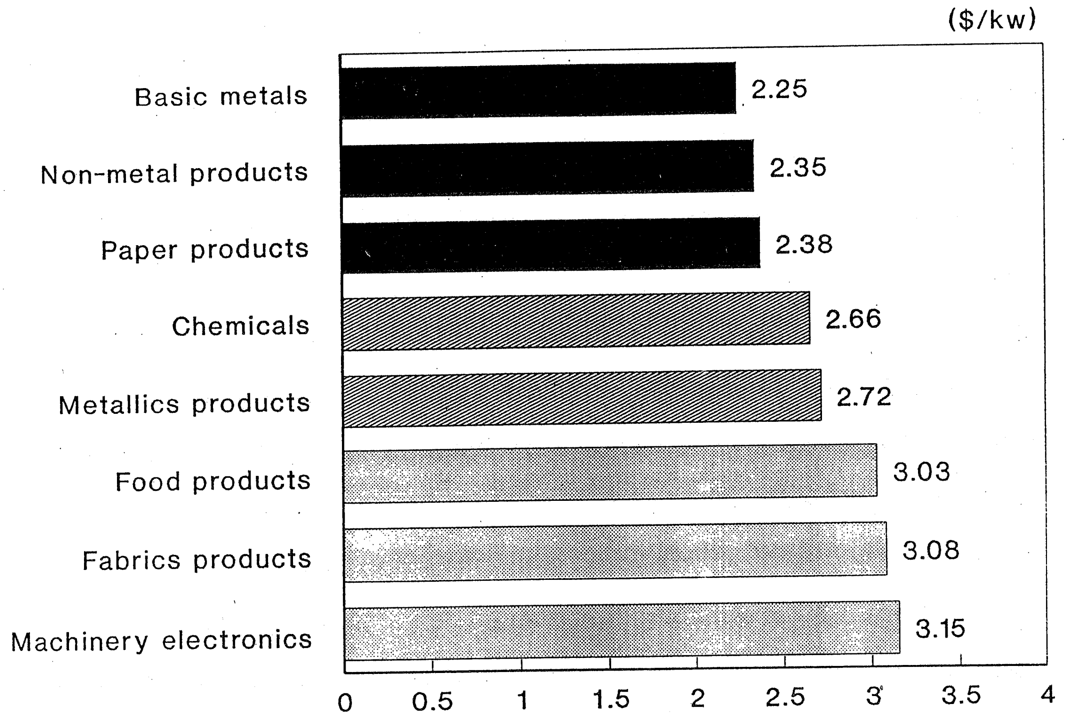

Figure 2: The upper bound of the outage costs by industry

Table 2 The Results of the Pair-wise Test Among the Industries

Industry / Industry	Food products	Fabric products	Paper products	Chemical	Non-metal products	Basic metal	Metallic products	Machinery / electronics
Food products	.	0.7040	0.0001*	0.0066*	0.0001*	0.0001*	0.0442*	0.6656
Fabric products	-	.	0.0001*	0.0007*	0.0001*	0.0001*	0.0147*	0.3801
Paper products	-	-	.	0.0457*	0.9755	0.3893	0.0424*	0.0001*
Chemicals	-	-	-	.	0.0469*	0.0010*	0.6591	0.0090*
Non-metal products	-	-	-	-	.	0.3441	0.0387*	0.0001*
Basic metals	-	-	-	-	-	.	0.0016*	0.0001*
Metallic products	-	-	-	-	-	-	.	0.0318*
Machinery/ electronics	-	-	-	-	-	-	-	.

Note: "*" means significant at 5%, "-" means same as the corresponding diagonal, i.e., the matrix is symmetric.

high-electricity-intensive industries (including basic metals, non-metal products and paper industries) vs. low-electricity-intensive industries (including food products and machinery/electronics industries) are significantly different in their outage costs, and the F-value is 17.68.

As to the internal attributes, the model test of all attributes is also valid (F-value is 6.52). The model test of individual attributes as well had the following F-values which are significantly different from zero: outage duration (21.66); outage depth (31.41); their interactive effects (2.99); and outage frequency (4.89). The attribute of prior notification is not significant according to its F-value(2.82). For the pair-wise test, Table 3(a)-(d) presents the results. In Table 3(a), it shows that outage depth is insignificantly different between 20% and 30%, and between 30% and 40% or above. While other cases are all significantly different from each other. In Table 3(b), it

Table 3 The Results of Pair-wise Tests Among Outage Conditions:

(a) Outage Depth

depth	10%	20%	30%	40% or above
10%	.	0.0001*	0.0001*	0.0001*
20%	-	.	0.4550	0.0453*
30%	-	-	.	0.2976
40% or above	-	-	-	.

Note: Same as Table 2.

(b) Duration

outage duration	4hrs	8hrs
4 hrs	.	0.0001*
8 hrs	-	.

Note: Same as Table 2.

(c) Frequency

frequency	2-times	4-times	8-times
2-times	.	0.0046*	0.0249*
4-times	-	.	0.7795
8-times	-	-	.

Note: Same as Table 2.

(d) Prior Notifications

prior notification	1hr	4hrs	16hrs
1 hr	.	0.7930	0.0001*
4 hrs	-	.	0.0001*
16 hrs	-	-	.

Note: Same as Table 2.

shows that outage duration is significantly different between 4-hrs and 8-hrs. Table 3(c) shows that outage frequency is significantly different between 2-times and 4-times, and 2-times and 8-times, while it's not significantly different between 4-times and 8-times. Table 3(d) shows that outage prior notification is significantly different between 1-hr and 16-hrs, and 4-hrs and 16-hrs, while it is insignificantly different between 1-hr and 4-hrs.

We also used cluster analysis to investigate how to group different customers with different capacities from different industries. It shows that the large scale, high-electricity-intensive customers belong to the same cluster (cluster I), medium scale, medium-electricity-intensive customers belong to another cluster (cluster II) and small scale, low-electricity-intensive customers belong to the third cluster (cluster III). This information is useful for separating different customer groups so that we can focus on each individual customer group (cluster) and investigate the relationship between each group's outage costs and their internal attributes through an ANCOVA process. The reason for focusing on the internal attributes is that these attributes are more meaningful in terms of formulating a curtailable rate program, while the external attributes such as industry type or capacity size are the ones beyond the utility firm's control.

Given the classification of each cluster, we utilized covariance analysis (ANCOVA) to identify the quantitative relationship among the imputed outage costs, the frequency of power outages, the duration of the power outages, the prior notification time of power outages, the ratio of outages, and the relationship between each cluster. Table 4 shows the definitions of each variable in the ANCOVA model and Table 5 presents the estimated results. From Table 5, we obtain the coefficients of the explanatory

Table 4 Definitions Used in the ANCOVA Model

Variables	Definitions
OC	The upper bounds of outage costs ($/KW)
D4	Outage duration is 4-hrs, if the observations belong to D4, then D4=1; otherwise D4=0.
D8	Outage duration is 8-hrs, if the observations belong to D8, then D8=1; otherwise D8=0.
F2	Outage frequency per month is 2-times, if the observations belong to F2, then F2=1; otherwise F2=0.
F4	Outage frequency per month is 4-times, if the observations belong to F4, then F4=1; otherwise F4=0.
F8	Outage frequency per month is 8-times, if the observations belong to F8, then F8=1; otherwise F8=0.
N1	Outage prior notification time is 1-hr, if the observations belong to N1, then N1=1; otherwise N1=0.
N4	Outage prior notification time is 4-hrs, if the observations belong to N4, then N4=1; otherwise N4=0.
N16	Outage prior notification time is 16-hrs, if the observations belong to N16, then N16=1; otherwise N16=0.
R1	Outage ratio (depth) is 10%,if the observations belong to R1, then R1=1; otherwise R1=0.
R2	Outage ratio (depth) is 20%,if the observations belong to R2, then R2=1; otherwise R2=0.
R3	Outage ratio (depth) is 30%,if the observations belong to R3, then R3=1; otherwise R3=0.
R4	Outage ratio (depth) is more than 30%, if the observations belong to R4, then R4=1; otherwise R4=0.
CL1	Cluster I, if the observations belong to CL1, then CL1=1; otherwise CL1=0.
CL2	Cluster II, if the observations belong to CL2, then CL2=1; otherwise CL2=0.
CL3	Cluster III, if the observations belong to CL3, then CL3=1; otherwise CL3=0.

Table 5 The Estimated Results in the ANCOVA Model

Variables	Parameters	t-statistic	P-value
Intercept	80.3507	30.50	0.0001*
D4	9.0514	6.96	0.0001*
F2	9.1089	4.58	0.0001*
F4	3.8908	5.70	0.0001*
N1	8.4123	0.85	0.6540
N4	6.0211	0.12	0.9811
R1	-14.9955	-8.18	0.0001*
R2	-5.5586	-3.08	0.0021*
R3	-3.4889	-1.65	0.0884
CL1	-3.3669	-2.26	0.0282*
CL2	-0.9153	-1.80	0.0685

Notes: 1. D8, F8, N16, R4 and CL3 are those of the reference case, i.e., their coefficients are zero, and do not show.
2. $R^2=0.2281$; $F=17.46$
3. "*" means significant at 5%.

variables of outage costs including: the frequency of the power outages (F); the duration of power outages (D); the prior notification of power outages (N); the ratio of power outages (R); and variables between each cluster (CL). Table 5 also shows that all coefficients of parameters are significantly different from zero except for the ones of N1, N4, CL2 and R3. Note that the coefficients of the dummy variables R1, R2 and CL1 are all negative. This implies that, other things being equal, the smaller the coefficients of these variables, the smaller the imputed outage costs. Also note that the coefficients of R3 and CL2 are negative, which conforms to expectations. However, their t statistics are insignificant. Furthermore, because there are no dummy variables for R4 and CL3, their coefficients could be deemed equal to zero which are greater than the coefficients of the other dummy variables (negative as mentioned-above). This implication can be verified by looking at the coefficients of R1, R2, and those of CL1 and CL2; i.e., the coefficients of R1 and CL1 are smaller than those of R2 and CL2. This is because customers curtail their load so as to minimize their outage costs, starting from switching off the least costly end-use first, followed by the next least costly, etc.. This shows an apparent upward trend with the average imputed outage costs increasing as the outage depth increases[3]. As well, the imputed outage costs in cluster I (large scale and high-electricity-intensive customers) are significantly lower than that of cluster III (small scale and low-electricity-intensive customers). Furthermore, the coefficients of D4, F2 and F4 are all positive and significantly different from zero. This means that where there is a shorter outage duration, and a lower outage frequency, there is a higher upper bound of outage costs. However, the prior notification is not significantly different from zero. The underlying reasons behind this phenomenon may be the experience in responding to power outages. Another reason may be that, for most customers, any prior notification of curtailment less than 16 hours is beyond the customer's tolerance limitations and, therefore, the incremental cost thereafter is not a seemingly linear relationship.

V. Concluding Remarks

In the present study, we have conducted a survey to examine the market acceptance of a proposed curtailable rate program and have investigated customers' imputed outage costs for such a program. The survey is based on 825 high-tension power customers, among those, 353 are effective samples, with contracted capacities of 1,800KW or greater. The survey results show that between 5.6% and 18.1% of the

[3] Note that there normally is a discrete parametric form rather than a derivative form, to outage costs relative to the outage depth because most equipment is turned-off with the same switch, that is, they generally run on the same electrical circuit system.

average peak load could be curtailed. The imputed outage cost is the basic element used to delineate a customer's attributes for choosing the curtailable rate program. These attributes include external ones e.g., industry type and capacity size, and internal ones e.g., outage conditions of prior notification, frequency per month, duration time and outage depth. Based on the survey results, the attributes including industry type, capacity size, frequency per month, duration time and outage depth are significant in relation to customers' imputed outage costs. Prior notification of outages is insignificant.

Moreover, we found that high-electricity-intensive industries, e.g., basic metals, non-metallic products and the paper products industry have the lowest upper bounds of outage costs. These range from \$2.25/KW to \$2.38/KW, while low-electricity-intensive industries, e.g., food products, fabric products, and machinery/electronics possess the highest imputed outage costs ranging from \$3.03/KW to \$3.15/KW. Through cluster analysis and ANCOVA, we obtained three important results: (1) the imputed outage costs for large scale, high-electricity-intensive firms (cluster I) are significantly lower than that of small scale, low-electricity-intensive firms (cluster III); (2) there is an apparent upward trend whereby the average imputed outage costs increase as the outage depth increases; (3) where there is a shorter outage duration and a decreased outage frequency, there are higher imputed outage costs.

Note that service quality demands a high degree of reliability and it is a prime consideration for utilities to maintain a high level of reliability for its customers. The degree of power supply reliability is determined by the attributes as discussed in this paper, i.e., duration, frequency, prior notification and depth, of power outages. If we have a fixed power generating capacity situation, then in a short-term scenario the utility firm could establish rates for different levels of curtailable loads to obtain the needed loads from low priority customers so that reliable service is provided to the high-priority customers. As well, enough benefits/profits from the load sales to high-priority customers must be procured so that the utility firm can recover its capacity costs and maintain economic viability. Taking a long-term perspective, the utility can adjust the capacity configuration so as to allow the curtailable rate program to reflect the associated capacity and operating costs. This scenario is probably one of the most realistic and effective solutions for Taiwan's power shortage concerns in the future[4].

Finally, this study was conducted from a short-run viewpoint, a long-term viewpoint may lead to different results. Also, the study has not considered whether the implementing cost of a curtailable program should be investigated before such a program could be realized.

Moreover, this study may be expanded to examine the service industries and residential customers. Other load management programs such as real-time-pricing, an interruptible rate program without notification, and the combined effect with the time-of-use could be interesting topics to study in the future as well.

[4] Taipower is the sole power company in Taiwan, and it is owned by the government. Therefore, the curtailable rate program would be easy to implement and enforce if the regulatory body of government made the decision to do so.

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