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The effects of critical peak pricing for electricity demand management on home-based trip generation

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ABSTRACT

This paper examines electricity critical peak pricing (CPP) as a measure for controlling electricity demand at critical peak times. This pricing scheme is designed to facilitate energy conservation not only inside but also outside the home. For this study, we surveyed consumer propensity to leave the home under CPP schemes and analyzed the impact of CPP on consumer cost. The results indicated that higher prices induce a higher rate of going out, while residential conditions such as population density and access to public transportation have a relatively small impact on leaving the home and average energy conservation. However, this is not always the case for aged households with limited mobility; residential conditions have a substantial effect on this segment of the population. Combined with a reduced ability to go out, electricity pricing has a greater negative impact on aged people. These results imply that improving accessibility through transportation development and urban compaction is an effective means of saving electricity alleviating the negative impact of CPP on the aged society of the future.

1. Introduction

Recent shutdowns of nuclear power plants have raised concerns about electric power supply shortages in Japan. Under the tight demand–supply balance, critical peak pricing (CPP) is a means of controlling electricity demand and alleviating the tight balance. CPP increases electricity prices to punitive levels at peak hours on critical days announced beforehand. In response to CPP strategies, people may change their patterns of electricity usage by turning off their air conditioners at home and/or leaving the home to minimize electricity consumption. This assumption suggests a correlation between electricity demand and trip generation, which past studies on electricity pricing and transportation research have yet to investigate fully.

The purpose of this study is to assess the effect of CPP on trip generation to provide a perspective for the integrated analysis of electricity demand and travel behavior. In this paper, we analyze the impact of CPP on home-based trip generation using stated preference (SP) data, clarify the cost of CPP for the households, and discuss the possibilities of improving accessibility to help conserve energy.

The paper is structured as follows. Section 2 gives a literature review for demand response analyses of electricity and its relationships with transportation. Section 3 describes the inquiry survey and data used in this study. Section 4 explains the models of behavior for electricity consumption and trip generation. Section 5 provides the results of an assessment of CPP's impact on both energy conservation and cost for aged households. Section 6 is the conclusion.

2. Literature review

Many empirical and experimental studies have estimated the impact of peak load pricing on electricity demand since the 1970s [1–5]. Recent studies have revealed the actual demand response to CPP via experiments [6,7], compared the impact of several experiments of peak pricing [8,9], and discussed possible pricing schemes using smart meters [10], including real-time electricity pricing [11]. Many studies have estimated the price elasticity of demand based on experimental data on actual response to electricity price changes; these investigations have found that the pricing scheme has a substantial effect on demand control. However, no study has clarified how people reduce their electricity consumption: apparently, they have been assumed to turn off their air conditioners at home or leave the home. It is important to deconstruct electricity-saving behavior because it might raise other concerns in energy demand for transportation.

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Nakai and Morimoto [12] estimated the impact of urban compaction on the consumption of electricity and transportation by household. However, the authors considered these two types of energy demand separately without examining their interaction. Yu et al. [13] developed a household location choice and energy consumption model for Beijing, China. The study explained household preference for end-use hardware, including air conditioners and cars, according to the attributes of house location and household socio-economic characteristics. The authors calculated the energy consumption for each piece of hardware to maximize the utility of household under total expenditure constraints. The utility function, a log-linear model of expenditure, expresses the substitutability between electricity consumption in the house and energy use by car. As the utility is constituted by the expenditure in this model, however, it cannot analyze the impact of electricity price changes on travel behavior.

In summary, many studies have analyzed electricity and transportation energy demand, but very few studies have dealt with their substitutability. In addition, no study has assessed the impact of electricity prices on home-based trip generation explicitly. This study analyzes the impact of CPP on both energy conservation in the home and trip generation and assesses its effects on electricity demand and disbenefit to the household.

3. Data

We obtained inquiry survey data on household use of and attitudes toward electricity in the Kinki region (Osaka, Kyoto, Nara, Hyogo, Shiga, and Wakayama). The questionnaire contains 411 items, including household characteristics, ownership of home appliances like air conditioners and power generators, consciousness of electricity conservation, and reactions to proposed pricing plans. The survey was conducted over the Internet from February to March 2012, and 64,000 valid responses were collected. This study analyzes energy-saving behavior against the CPP; therefore, households in which more than one person stays at home during the day were extracted. The number of samples meeting this condition was 44,804.

Fig. 1 shows the number of sample households by prefecture. This figure shows that the study obtained a larger number of samples from more urbanized prefectures like Osaka, Hyogo, and Kyoto. Fig. 2 shows the number of people in the sample households by age. This figure indicates that the dataset represents the demography of the region well compared with the demographic census data in 2010 and that there are enough sample households with infants and/or aged people.

Fig. 3 shows the locations of sample households, a set of data derived by matching the corresponding postal codes with GIS information. The figure illustrates that many sample households were located in urban areas, and substantial number of samples were located in the countryside as well. This distribution ensured that the sample included households that are subject to a variety of different transportation conditions.

The questionnaire investigates the stated preference of households regarding their energy-saving behavior under assumed CPP levels and weather conditions. In this survey, the respondent were reminded the tight supply–demand balance as the aftermath of the 2011 Great East Japan Earthquake, and CPP was assumed to be introduced mandatory to all households by government. This context is quite different from a situation of energy efficiency improvement to achieve environmental goals at ordinary period. The choice set for the air conditioner (AC) is "turn off," "raise (lower) the preset temperature in summer (winter)," and "use as usual." For the television (TV), households can choose between "turn off" and "use as usual." They can also choose "stay at home" or "go out" to save electricity usage. All of these items are presented in the choice set at once, and respondents check all that apply. They may choose plural items considering different situations such as having visitors or illness of family members. However, it is natural to assume that respondent households that choose "go out" have no choices for AC and TV usage (people are assumed to turn them off when they go out). In other words, "go out" and the other items are exclusive in actual situation. The plural responses can be interpreted as potential choices of behavior under various situations with CPP. The CPP levels are set to twice, four times, six times, and 10 times of the current price, and the weather conditions are set to "heat wave day" (a day on which the maximum temperature exceeds 35 °C), "hot day" (a day on which the maximum temperature exceeds 30 °C), and "freezing day" (day on which the minimum temperature drops below 0 °C). Peak hours are

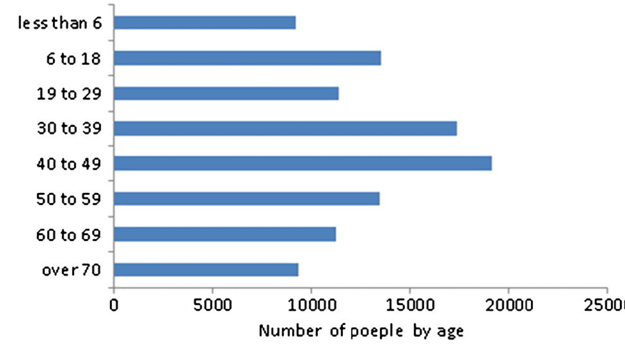

Fig. 2. Number of people by age.

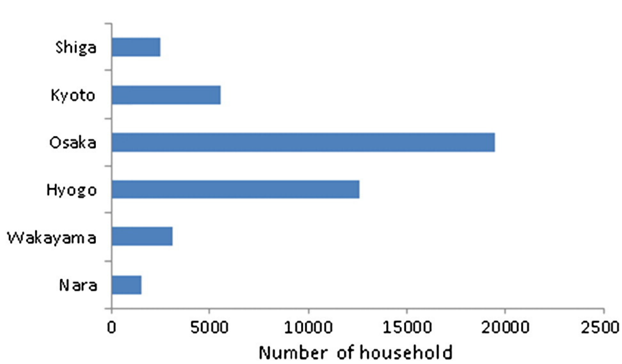

Fig. 1. Number of samples by prefecture.

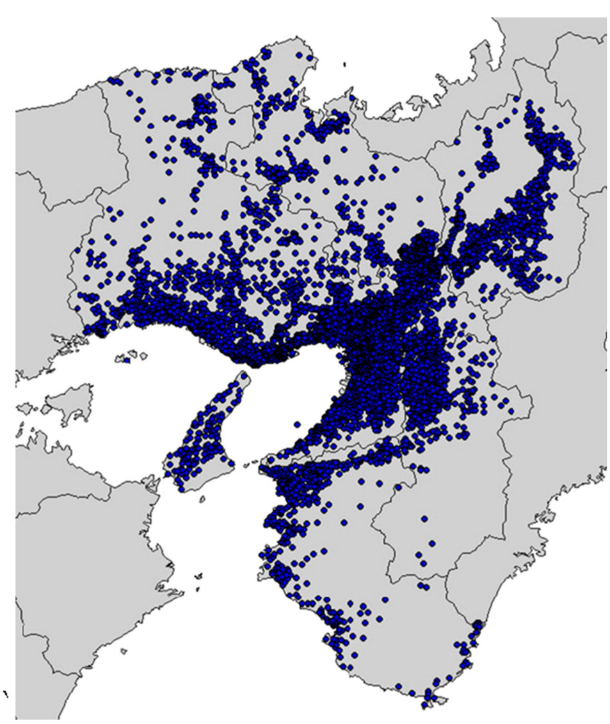

Fig. 3. Locations of sample households.