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The effect of demand response on electricity consumption under the existence of the reference price effect: Evidence from a dynamic pricing experiment in Japan

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ABSTRACT

This paper investigates the effect of demand response on households' electricity consumption under the existence of the reference price effect. The reference price effect is observed in peak and shoulder hours. Consistent with reference price theory predictions, our results show that the reduction of electricity consumption is greater in the case where the current price is higher than the previous price than in the case where the current price is lower than the previous price.

1. Introduction

Reducing electricity consumption in peak hours has become an increasingly important issue in resource conservation, and economists such as Stern (1986) and Berry (1993) have advocated the application of peak-load pricing theory, most commonly through demand response (DR). Expected to encourage consumers to change their electricity consumption pattern in response to a certain incentive, DR can be implemented in many ways, such as time of use (TOU), critical peak pricing (CPP), variable peak pricing (VPP), or providing moral incentives. TOU sets a fixed price for electricity according to season and time, CPP sets a high price only during peak time, and VPP is a variation on CPP in that the price during peak time is adjusted according to demand recorded on the previous day. These DR schemes have been developed to reduce electricity consumption during a certain period of time, and many researchers, such as Faruqui and George (2005) and Herter et al. (2007), have studied their effects. DR can also create moral incentives through requests to households to reduce consumption during a certain time, or through other frameworks such as nudges. The effect of moral incentives has been analyzed in many previous studies, such as Ida et al. (2013), Costa and Kahn (2013), and Ito et al. (2015).

Although numerous studies have been done on DR, an important topic remains to be addressed: the effect of reference price. Reference prices are standards against which the purchase price of a product is judged (Monroe, 1973). According to the reference price theory, the consumer might feel the present price cheaper (more expensive) than the actual price when the present price he/she faces is lower (higher) than the reference price, and would as a result increase (decrease) his/her consumption.

In recent decades, the effect of reference price on consumer demand has received much attention in the marketing research area, and previous studies have revealed that reference prices have a consistent and significant impact on consumer demand (Mazumdar et al., 2005; Kalyanaram and Winer, 1995; Winer, 1986; Kalwani et al., 1990; Mazumdar and Papalta, 2000). However, as far as we know, no literature exists that applies this theory to electricity consumption.

The purpose of this paper is to investigate the effect of DR on households' electricity consumption while considering the effect of reference prices. Our paper makes the following contributions.

First, our paper is probably the first to analyze the effect of reference price under the DR program. Reference price is used in the field of marketing, and to examine how it affects electricity consumption would be useful.

Our second contribution is that the results of our analysis provide important policy implications for DR programs. That is, the effect of DR on electricity consumption varies with the price schedule if the reference price effect exists. For example, consumers might feel the present DR price cheaper (more expensive) when the price is lower (higher) than the reference price (the previous DR price they faced), and would increase (decrease) their consumption. This means that, to formulate an efficient DR program, policymakers should carefully consider a schedule of dynamic pricing.

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Third, our study adds to the reference price literature, although this is not related to regulatory economics. As far as we know, although most previous studies on the reference price effect have used data on products having many substitutional goods, such as food and beverage, there have been no studies focusing on a product with few or no substitutional goods, such as electricity, which we examine here.

Furthermore, the present work deepens the study of the reference price effect. Although previous studies used point-of-sales (POS) data or individual panel data, there may still remain the endogeneity problem for price variables, because they are not randomized experimental data. By using randomized field experiment data, this paper estimates the more consistent effect of DR under the existence of the reference price effect on households' electricity consumption.

This paper consists of five sections after the introduction. Section 2 reviews previous studies on the DR scheme, its impact on consumption, and the reference price effect. Section 3 explains data. Section 4 introduces the estimation model, and Section 5 shows the estimation results. Finally, Section 6 summarizes the conclusions.

2. Previous studies

2.1. Demand response as an application of peak-load pricing

In this section, we will summarize major previous studies on the DR scheme and electricity consumption, focusing especially on empirical analysis. Since many countries have introduced a DR scheme in the forms of TOU, CPP, VPP, and so on, there exist empirical studies based on actual data obtained from DR implementation or experimentation.

Previous studies on the DR scheme and electricity consumption have certain common characteristics. First, most studies conclude that the DR scheme has a significant effect on electricity consumption but that its impact is different depending on the situation. For example, Herter and Wayland (2010) argue that the DR scheme surely reduces electricity consumption during the implementation time of DR, while it increases consumption on the previous and subsequent days. Jessoe and Rapson (2014) indicate that the effect of a DR scheme can change according to whether the households are provided information about the amount of their electricity consumption. Households provided more information consume less electricity, and households able to check their information on home displays more often can reduce their consumption through the learning effect. Similarly, Faruqui et al. (2014) show that ecological facilities can enhance the reduction effect of DR on electricity consumption.

Second, most studies use data only about individual households. For example, Jessoe and Rapson (2014) use data on households in Connecticut, and Faruqui and George (2005), Herter et al. (2007), and Herter and Wayland (2010) use household data from California. Faruqui and Sergici (2011) use data about individual households in Baltimore, and Ida et al. (2013) use household data from Kyoto and Kitakyushu in Japan. While these studies examine the DR from the perspective of demand for electricity among households, rarely have studies examined the issue of companies' electricity consumption. For example, Faruqui et al. (2014) include data on commercial and industrial electricity consumers in addition to households. They indicate that households are more sensitive than commercial and industrial users.

Third, previous empirical studies have included certain variables, such as ecological technology, temperature, and the use of certain appliances, and evaluated the effect of these variables requiring large amounts of electricity as determinants of electricity consumption. For example, Herter et al. (2007), Faruqui and Sergici (2011), and Faruqui et al. (2014) include variable of ecological facilities at home, and Herter and Wayland (2010), Faruqui and Sergici (2011), and Faruqui et al. (2014) include variables on temperature variability in their estimation.

Types of DR examined in previous studies cover a wide range: time of use (TOU), critical peak pricing (CPP), real-time price (RTP), peak-time rebate, and variable peak pricing (VPP). Faruqui and George (2005) compare the effects of CPP, VPP, and TOU, and conclude that VPP is the most effective, CPP is the second best, and TOU is the third best. Faruqui et al. (2014) investigate TOU, CPP, and PTR, while Ida et al. (2013) examine TOU and CP Faruqui and Sergici (2011) focus on PTR, while Herter et al. (2007), Faruqui and Sergici (2011), and Herter and Wayland (2010) focus on CPP.

2.2. Reference price research

For the last several decades, the effect of reference price on consumer demand has received much attention in the marketing research area, and previous studies have revealed that reference prices have a consistent and significant impact on consumer demand (Mazumdar et al., 2005; Kalyanaram and Winer, 1995; Winer, 1986; Kalwani et al., 1990; Mazumdar and Papalta, 2000).

According to Monroe (1973), reference prices are standard prices used in decision-making about whether or not the purchase price of a product is high or low. Reference prices are also considered as an application of behavioral economics, with regard to, for example, reference point dependence and the framing effect.[1] According to the reference price theory, consumers might feel the presented price cheaper (more expensive) when the presented price is lower (higher) than their reference price, and would increase (decrease) their consumption.

In general, reference prices are categorized into two types: external reference price (hereafter, ERP), which is constructed by simply referring to external environments, and internal reference price (hereafter, IRP), which is gradually formed in the consumer's mind. An example of ERP can be seen in a price advertisement that uses phrases like "Today only, get a discount off the regular price!" On the other hand, IRP is formed inside a consumer's mind and updated by external stimulation. Both types of reference price have been commonly analyzed in previous marketing research studies.[2]

We should note that most previous studies focus on the effect of reference price in the discrete choice analysis, such as consumers' brand choice (Bell and Latin, 2000; Mazumdar and Papalta, 2000; Erdem et al., 2001 etc.), while few studies analyze the effect of reference price on consumers' quantitative choice (Krishnamurthi et al., 1992). Furthermore, most previous studies use data on product categories that have many substitutional goods, such as food and beverage. To investigate the effect of reference price on consumer quantity choice in a product category which has few substitutional goods, we focus in this study on household electricity consumption.

3. Data

We use data from a social experiment on the effect of DR on households' electricity consumption, called *Keihanna Ecological City Next Generation's Energy and Social System Experimental Project (Keihanna Ekoshithi Jisedai d Enerugi Syakai Shisutemu Jissho Purojekuto)*. This project was carried out in Kyoto Prefecture in Japan between July 23 and Sept. 28, 2012. The experiment was planned by the Ministry of Economy, Trade and Industry and implemented by *Keihanna Eco-City Promotion Council*, an organization consisting of local government, energy-related private companies, universities, and various research institutions, with the purpose of demonstrating an energy system for a

[1] Reference prices are also considered as an application of behavioral economics, which examines reference point dependence and the framing effect. The former indicates that people measure the value of a good as a deviation from the reference point rather than from the absolute level, while the latter assumes that people tend to perceive content in different ways, depending on the situation.

[2] Biswas and Blair (1991) and Mayhew and Winer (1992) analyzed the process of the formation of ERP and the effect of ERP on consumer demand. On the other hand, Breish et al. (1997) and Kalwani et al. (1990) analyzed the effect of IRP.