Impact Assessment of Time of Use Pricing for Electricity:

Evidence from a Natural Experiment in Ontario

Hyungkwan Kim[*]

(kim1841@purdue.edu)

Paul V. Preckel

James S. Eales

Douglas Gotham

Andrew L. Liu

Abstract

The purpose of this study is to evaluate price elasticities of electricity demand by time of use (TOU) pricing in Ontario and thus to contribute to the knowledge base regarding consumer response to price-based demand side management programs. In this study, we will estimate a system of log-linear equations for on-peak, mid-peak and off-peak electricity consumption employing load data. The goal is to estimate the price elasticities of demand for electricity. Preliminary findings indicate that own-price elasticities are: -0.10 during the on-peak period, -0.25 during the mid-peak period and -0.06 during the off-peak period.

1. Introduction

For the several past decades, Canadian utilities, like their U.S. counterparts, have been slow to invest in electricity generation and transmission infrastructure. Burgeoning demand for electricity has created a challenge for this aging and less quickly growing infrastructure resulting in a system that is stretched to near capacity. Electric utilities are faced with two choices: build additional generation and transmission capacity or find ways of better utilizing existing resources. Methods for utilizing resources more efficiently either rely on consumers ceding more control of the time pattern of their electricity use to utilities or on consumer responses to price signals.

The purpose of this study is to estimate price elasticities of electricity demand by time-of-use (TOU) pricing block in Ontario and thus to contribute to the knowledge base regarding consumer response to price-based demand side management programs. We estimate a set of log-log linear equations for on-peak, mid-peak, and off-peak electricity consumption using load data between May 2006 and October 2014. Explanatory variables include the electricity prices, seasonal dummy variables, and measures of economic activity.

Unlike prior studies that have analyzed shorter-term data typically gathered from pilot studies, this study examines multiple years of aggregated hourly demand data and a broader range of explanatory variables including measures of economic activities affected by seasonal weather conditions. Understanding of how consumers respond to these electricity price signals is not well established, and yet it is a critical factor for identifying the benefits of time-varying pricing programs that are expected to be an important part of the "Smart Grid" of the future. This paper contributes to the understanding of this consumer response by analyzing data from a natural experiment wherein the Province of Ontario in Canada implemented a particular type of

pricing system designed to elicit consumer behavior that will result in more efficient use of electric power generating resources.

The main question of this study is: will the reduction in electricity consumption brought about by TOU pricing be sufficient to justify the investment in smart meters? To this end, the immediate goal is to estimate the price elasticities of demand for electricity. The widespread introduction of smart meters provides an opportunity to differentiate pricing of electricity to be more in line with its marginal cost of generation. This may in turn encourage efficient utilization of existing electric plants and forestall the need for capacity expansion. To assess the benefits of TOU pricing, it is essential to understand the responsiveness of consumer demand to the price of electricity – in particular the demand response by time of use is extremely important to measure the efficiency of a time-differentiated pricing scheme. Therefore, a long-term assessment of consumer demand response will be useful for broadening the knowledge base for a cost-benefit analysis of smart metering infrastructure and TOU pricing.

We examine the demand for electricity under TOU pricing in Ontario, Canada. For this purpose, a linear log-log equation model of on-peak, mid-peak and off-peak electricity consumption is estimated using aggregated data over a period of eight years. The empirical analysis highlights some of the characteristics of the Ontario's electricity consumption. Results indicate that TOU pricing brings about lower average on-peak electricity consumption and shifts electricity use from "on peak" periods, when the electricity price is higher, to "off peak" periods when electricity is comparatively lower. The estimated own-price elasticities are -0.10 during the on-peak period, -0.25 during the mid-peak period and -0.06 during the off-peak period. These elasticities, while small, are generally statistically significant. In addition, electricity demand appears to be related to the economic activity as would be expected, and seasonality dummy

variables indicate increased demand during the peak heating and cooling months, again, as would be expected.

This paper is structured as follows. In Section 2, we present backgrounds on the economics of electricity and TOU pricing in Ontario, Canada. In Section 3, we explain the electricity data employed in the analysis. In Section 4, we present the specification of the electricity demand model. In Section 5, we address the empirical results. Concluding remarks and policy implication appear in Section 6 of this paper.

2. Background

Electricity is a peculiar commodity because it must be produced at the instant that it is needed due to a lack of economical technology for bulk storage. Electricity consumers generally are charged a flat rate per kilowatt-hour. This results in a situation where the aggregate consumer demand at any point in time, the load, fluctuates in an only somewhat predictable pattern that is affected by time of day, day of the week, season, weather, etc. Because electricity is not storable, the maximum of the fluctuating load pattern, plus an additional margin to ensure reliability, defines the system peak, which is the generating capacity that the system must have. When the peak load grows sufficiently, additional capacity must be procured, typically at high expenses.

The most common pricing system for electricity is what we call flat-rate pricing. This is the situation where consumers pay the same amount per unit of energy regardless of the time or system conditions when the electricity is consumed. This is in sharp contrast to the marginal-cost pricing of electricity production, which can differ over a year. This disconnects between marginal cost and consumer price signals effectively encourage more consumption during the

on-peak periods and less consumption during the off-peak periods, relative to what would be economically efficient.

In order to better utilize existing resources and diminish power cost, policy makers and utilities are considering demand side management programs. The recent boom of smart meters, part of the advanced metering infrastructure that enables two-way communication between the meter and the central system (smart grid), allows advanced demand management programs such as automated control and time-differentiated pricing. The automated control allows the electricity service provider to pre-program a control strategy that automatically adjusts the customer's electric appliances during high-priced periods.

Time differentiated pricing has several variants. Examples of time-varying pricing based demand management programs include real-time pricing, critical peak pricing and Time-of-Use (TOU) pricing. Real-time pricing sets the consumer price at the marginal cost of generation plus an additional amount to allow for capital cost recovery. With critical peak pricing, utilities contact consumers when periods of exceptionally high load are expected to warn them that higher prices will be instituted during those periods, with the goal of encouraging consumers to curtail electricity use during these periods. Time of use pricing classifies the hours during the day into a few categories (e.g. on-peak, mid-peak, and off-peak) and charges different prices during these different time blocks and possibly during different seasons.

TOU pricing allows utilities to charge more during peak periods. It is increasingly viewed as a viable demand management strategy because TOU pricing avoids the two-way communications between utilities and customers that is required for real-time pricing and critical peak pricing. The consumers under TOU pricing expect a certain price of the different time of

the day while the other price-based programs of demand management provide varied price following the electricity cost at real-time. Theoretically, TOU pricing should allow policy makers to encourage shifting of demand across time blocks. If these shifts result in a demand reduction during the on-peak times, it may enable a forestalling of the need for generation capacity expansion.

Infrastructure augmentation is needed to implement time-varying pricing. Traditional electricity usage meters simply track the total energy consumption over a billing period, typically a month. This is insufficient information to implement time-varying pricing of electricity, such as TOU pricing. What is needed is a "smart meter" that not only tracks how much energy is used, but when it is used. By using the technology of communications and information, smart meters are an initial step toward a smart grid to increase the electricity system function and optimize the electricity usage. Recently, the smart meter has received much support with generous federal funding in the U.S. (Fan and Hyndman, 2011). Smart meters are an expensive, upfront infrastructure cost needed to implement mandatory TOU pricing. An important question is whether the demand response from TOU pricing is likely to be sufficient to allow enough savings from delays in generating capacity expansion to offset the investment in smart grid technology.

In April 2004, the Canadian Province of Ontario announced a policy to reduce energy consumption via the smart grid and time-varying pricing. In 2006, the Ontario government implemented TOU pricing program for residential and small business electricity consumers with three periods (On-Peak, Mid-Peak, Off-Peak) and two seasons (November to April, May to October) structure with prices adjusted semi-annually. In 2010, the provincial government mandated installation of smart meters and the transition of TOU pricing for all households in the

province. The TOU rates introduced in Ontario were intended to incentivize customers to curtail electricity usage during the high priced on-peak period and to shift that demand to the lower priced mid-peak and off-peak periods, and to lead to overall electricity demand reduction. By shifting electricity use during the on-peak period, consumers certainly participate activities in the management of Ontario's electricity system. It reflected the intention of the government to utilize the current capacity of electricity generation by implementing electricity price based demand management policy in Ontario (Faruqui et al., 2013). As of 2013, aside from Italy, Ontario is the only region in the world to implement smart meters to all of its residential customers. (Faruqui et al., 2013). This makes Ontario an ideal source of data for estimating the impact of TOU pricing on consumer demand.

With the growing popularity of smart metering devices, a great deal has been written about time-varying pricing of electricity integrated with demand side management program including TOU pricing. The current literature regarding elasticities of electricity price under TOU pricing regime are Filippini (1995), Filippini (2011), Torriti (2012), Fan and Hyndman (2011), and Gans et al. (2013). General consent among economists has been that such a shift from the current flat pricing scheme available in most areas to time-varying pricing would provide benefit. According to Faruqui et al. (2010), analysis of 15 experimental studies shows that TOU rates encourage a fall in peak demand that arrays between 3 and 6%. However, most previous studies are based on voluntary participation and a short-term experimental period. The real-world impact of TOU pricing on electricity consumption under normal market conditions remains uncertain.

Ontario is the only region to roll-out smart meters to all its residential customers and to deploy mandate TOU pricing regime for multiple years rather than an optional plan, which is the

case in most previous studies. This makes the Ontario case a natural experiment for evaluating the impact of electricity pricing, providing a full-scale observational dataset. Few reports have been written for the economic analysis of TOU pricing in Ontario, and academic papers are particularly scarce. The Ontario Power Authority (Faruqui et al., 2013) and Ontario Energy Board (Navigant Consulting, 2013) released separate consulting studies indicating the moderate impact on consumers by TOU pricing that reduced the peak time demand by about 3% after one year of mandatory TOU pricing. As both studies were conducted around 2010, they used only one year of data after the compulsory TOU pricing implementation from a relatively smaller number of electricity customers. The present study uses a substantially longer data period and covers a much greater fraction of Ontario electricity demand. This study analyses eight years of data covers all of the five million electricity consumers in Ontario, while the Ontario Energy Board (Navigant Consulting, 2013) used data of approximately 14,000 customers and the Ontario Power Authority (Faruqui et al., 2013) used data of 138,275 customers.

3. Data and Variables

The electricity price and load data during on-peak, mid-peak and off-peak periods span 102 months from May 2006 to October 2014 and covers residential, small business and industrial electricity customers in Ontario. The TOU price and aggregate electricity demand data were collected from the data directory on the Independent Electricity System Operator's web site (IESO, 2015). The data for the economic variables of the Province of Ontario were taken from the Statistics Canada (Statistics Canada, n.d.). We chose Ontario Province's real Gross Domestic Product based on income to represent Ontario's economy.

Dependent variables are monthly electricity demand during on-peak, mid-peak and off-peak periods are the. This is calculated by combining the hourly aggregated electricity demand data to monthly data incorporating changes of schedule for time periods of on-peak, mid-peak and off-peak periods and holidays.

The TOU price schedule changes at six-month intervals. The winter price schedule, from November 1 to April 30, incorporates peaks both in the morning and evening, reflecting increased needs for lighting during the shorter winter days. By contrast, the summer peak, from May 1 to October 31, takes place in the afternoon when the use of air conditioning is at a peak. Off-peak rates apply on holidays such as Canada Day. As a whole, off-peak periods account for roughly 50 percent of the week. The recent TOU prices for the winter season, which runs from November 1, 2014 to April 30, 2015, is 7.7 ¢/kWh during the off-peak, 11.4 ¢/kWh during the mid-peak and 14.0 ¢/kWh during the on-peak. For the summer season from May 1, 2015 to October 31, 2015 is 8.0 ¢/kWh during the off-peak, 12.2 ¢/kWh during the mid-peak and 16.1 ¢/kWh during the on-peak.

The model includes monthly dummy variables to explain the impact of the seasonality of weather, holidays and other factors that vary across months on electricity demand. Because the Province of Ontario clearly has four seasons with hot summers and cold winters, a change in electricity demand pattern by season would be expected.

The dataset used in this work is the hourly aggregate demand of Ontario, which is publicly available through IESO's website. It fits our study because it allows us to evaluate aggregate load characteristics of the TOU scheme since its inception. These hourly demands aggregate residential, small business, and industrial loads while TOU pricing in Ontario is for

residential and small business. We assume that TOU pricing is responsible for most of the change in demand response between 2006 and 2014, because demand in other sectors (i.e. large industrial and commercial, which are not subject to TOU pricing) is typically negotiated through long-term bilateral contracts, which are unaffected by TOU pricing.

4. Method

This study evaluates the elasticities of electricity demand related to TOU pricing. The importance of this approach lies in the estimation of the impacts of TOU pricing on changes in electricity demand at the aggregate level, integrating the effect of economic activity and monthly seasonality. The evaluation is based on the comparison of elasticities of electricity demand during on-peak, mid-peak and off-peak periods from a data of electricity consumer in Ontario as a consequence of TOU pricing.

In line with economic theory, holding all other things constant, electricity demand should decrease when the price increases. The customer demand to electricity changed by electricity price is represented by price elasticity of electricity demand. Consumers possibly decide to modify their consumption pattern to reduce electricity costs fronting expected volatile electricity prices. The own-price elasticity of demand, measuring the adjustment of electricity consumption of customers to an increase in the price of electricity, is typically negative. This demonstrates the inverse relationship between demand and price (Fan and Hyndman, 2011).

We used linear equations for a log-log model of consumer demand to estimate own-price elasticities of electricity demand during on-peak, mid-peak and off-peak periods. This model of average hourly electricity demand during different periods estimates an overall price elasticity of

demand. Own-price elasticities indicate the percent change in the average monthly consumption due to a 1 percent change in the average monthly price. For instance, an elasticity of -0.10 implies that, when the price increases by 1 percent, the electricity usage decreases by 0.10 percent. By using the parameter estimates from this model in a counterfactual mode, we can calculate the impact that TOU pricing had on electricity consumption by different periods of Time-of-Use.

The equations to be estimated are:

$$\ln Don_{y,m} = I + a_1 \ln Pon_{y,m} + a_2 \ln GPP_{y,m} + D_m + uon_{y,m}$$

$$\ln Dmid_{y,m} = I + a_1 \ln Pmid_{y,m} + a_2 \ln GPP_{y,m} + D_m + umid_{y,m}$$

$$\ln Doff_{y,m} = I + a_1 \ln Poff_{y,m} + a_2 \ln GPP_{y,m} + D_m + uoff_{y,m}$$

where

y	= year index
m	= month index
I	= constant
$Don_{y,m}$	= electricity demand per month during the on-peak period in MWh/h
$Dmid_{y,m}$	= electricity demand per month during the mid-peak period in MWh/h
$Doff_{y,m}$	= electricity demand per month during the off-peak period in MWh/h
$Pon_{y,m}$	= Time-of-Use electricity price during the on-peak period in ¢ per kWh
$Pmid_{y,m}$	= Time-of-Use electricity price during the mid-peak period in ¢ per kWh
$Poff_{y,m}$	= Time-of-Use electricity price during the off-peak period in ¢ per kWh
$GPP_{y,m}$	= gross product in Ontario using the income approach in millions of dollars
D_m	= monthly binary dummy for seasonality of the weather
$uon_{y,m}$	= error term for the on-peak equation

$umid_{y,m}$ = error term for the mid-peak equation

$uoff_{y,m}$ = error term for the off-peak equation

The demand elasticities are directly derived from the coefficients when regressors and electricity demand are in logarithm form. The individual error components are assumed to be uncorrelated to each other. To adjust serial correlation in error terms, we used Cochrane-Orcutt estimation with regards to choice of econometric technique. Severe multicollinearity between price variables of on-peak, mid-peak and off-peak limited the estimation of cross-price elasticity. Table 1 provides details on the employed variables in this study.

Table 1. Description of variables.

Variables	Descriptions	Mean	S.D.	Min	Max
Don	Electricity demand per month during on-peak period (MWh/h)	18122.50	1474.46	15457.52	21615.77
Dmid	Electricity demand per month during mid-peak period (MWh/h)	17611.54	1209.92	15389.23	20310.18
Doff	Electricity demand per month during off-peak period (MWh/h)	15610.77	1189.77	13383.86	18811.35
Pon	TOU electricity price during on-peak period (¢ per kWh)	11.24	1.17	9.72	13.50
Pmid	TOU electricity price during mid-peak period (¢ per kWh)	9.16	1.11	7.82	11.20
Poff	TOU electricity price during off-peak period (¢ per kWh)	5.33	1.43	2.90	7.50
GPP	Income-Based Gross Product in Ontario ($ millions)	604871.20	20317.47	565339.90	640692.50

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5. Results and Discussion

This study examines the impact of a change in electricity pricing in electricity consumption behavior. In order to motivate reducing peak electricity demand, TOU periods and prices should

be designed to offer an incentive to reduce electricity demand during the on-peak periods, when price and demand are high, perhaps shifting some or all of it to the off-peak times, when price and demand are low. This paper focuses on the demand response in the electricity consumer, estimating the elasticity of electricity demand of TOU pricing incorporating economic factor and seasonality of the weather.

5.1 Estimation Results

In general, the results are satisfactory as presented in Table 2. The primary concern in this study, the own-price elasticities are mostly significant with expected signs in the model. The most essential explanatory variables are electricity prices by TOU pricing that enables to enumerate price elasticities directly from our linear equations for log-log form model. The estimated own-price elasticities are -0.10 during the on-peak period, -0.25 during the mid-peak period and -0.06 during the off-peak period. These elasticities indicate that electricity consumption behaviors respond to the change in TOU prices. The estimated elasticities are of similar magnitude to those cited in the literature survey of Lijesen (2007). The median value of the surveyed five papers long-term (more than a year) own-price elasticities by time block are, -0.05 for on-peak and -0.038 for off-peak.

Considering the differences between the estimated figures of price elasticity of on-peak and off-peak, electricity consumers are seemed reducing their on-peak consumption and shifting the necessary consumption during the off-peak in response to TOU prices. Thus, TOU pricing appears to provide electricity consumers with an incentive to shift from the on-peak period consumption, serving to reduce the need for additional capacity.

Differences in price elasticities address the dissimilar sensitivity of electricity demand for each TOU period. The high price elasticity for the mid-peak period suggests that consumers have more flexibility in the electricity consumption activities to adjust. The relatively modest level of responsiveness of electricity demand during the on-peak and the off-peak seems to be related to the inflexible nature of some electricity consuming activities and services. This may be because many of the activities during the on-peak time, such as cooling and heating, are needed to be done during the on-peak period and are not easily shifted to the other time periods.

The demand for electricity during the on-peak, mid-peak and off-peak times shows different directions of responsiveness to the level of Ontario Province's GDP (GPP), gross product in Ontario using the income approach. The sign of the estimated coefficient of the on-peak price is negative. Thus, an increase in income seems to bring about a reduction in electricity demand during the on-peak period. As the economy is growing and generating more income, people may replace existing appliances (or acquire new ones) that are operated during the on-peak periods with more energy efficient models. At the same time, they may have more choices for the same activity; for instance, they can use a gas heater for winter or use heat pump based electricity cooling systems for summer. Since the estimated coefficients of GPP are statistically insignificant in our model, however, the interpretation is somewhat speculative.

The monthly dummy variable (D_m) has been included in our model in order to control the seasonal factors on electricity demand. Seasonality of the weather, especially during summer and winter season ought to give positive influence in electricity demand since electricity generally plays a role in both heating and cooling. In the model, seasonality is reflected through monthly dummy variables. The coefficients for the dummies have consistent signs across time blocks for all months except July and August. Unlike to the other months, for D_{July} and D_{August}, the signs of

coefficients for on-peak are positive while the sign for off-peak is negative. This pattern may be due to use of electricity for cooling during the on-peak and mid-peak periods when the temperature is high and less use of cooling during the off-peak period when the temperature is relatively low. This reflects the fact that weather and other seasonal factors are strong drivers of electricity demand across all time blocks. It makes sense considering the TOU pricing schedule for summer season, from May 1 to October 31, imposing the on-peak period on the afternoon when use of cooling is at its highest. Fairly high estimated coefficients of monthly dummy variable for the winter season, $D_{January}$ and $D_{February}$, address the stylized fact that people use heating appliances during most of the day to cope with relatively low temperatures during the winter season.

The results of the estimated values show that the magnitudes of the coefficient of price variables are larger than weather dummies and more significant than the economic activity variable. Thus, the fundamental effect is that electricity demand has a stronger relationship with its own price than with economic activity and seasonality.

The R^2 values of the demand models are calculated to present the variation of the explanatory power of demand data in each equation and to assess the fitting performances. These values are moderately high, between 0.755 and 0.785, indicating a reasonable explanatory power of the selected independent variables. The differences in R^2 between equations are not substantial.

Table 2. Estimated TOU electricity pricing demand equations.

Variables	On-Peak	Mid-Peak	Off-Peak
Pon	-0.104		
	(0.1200)		
Pmid		-0.253***	
		(0.0884)	
Poff			-0.0586*
			(0.0302)
GPP	-0.223	0.147	0.287
	(0.3040)	(0.2660)	(0.2290)
$D_{January}$	0.0476***	0.0440***	0.0488***
	(0.0130)	(0.0113)	(0.0115)
$D_{February}$	0.0296*	0.0217	0.0498***
	(0.0169)	(0.0145)	(0.0145)
D_{March}	-0.0416**	-0.0484***	-0.0316*
	(0.0191)	(0.0162)	(0.0160)
D_{April}	-0.122***	-0.116***	-0.121***
	(0.0203)	(0.0171)	(0.0168)
D_{May}	-0.116***	-0.118***	-0.149***
	(0.0209)	(0.0176)	(0.0172)
D_{June}	-0.00606	-0.0369**	-0.0784***
	(0.0208)	(0.0173)	(0.0170)
D_{July}	0.0674***	0.0222	-0.023
	(0.0205)	(0.0171)	(0.0168)
D_{August}	0.0444**	-0.00048	-0.0359**
	(0.0200)	(0.0167)	(0.0164)
$D_{September}$	-0.0629***	-0.0793***	-0.112***
	(0.0187)	(0.0158)	(0.0157)
$D_{October}$	-0.115***	-0.0933***	-0.130***
	(0.0168)	(0.0143)	(0.0143)
$D_{November}$	-0.0551***	-0.0545***	-0.0670***
	(0.0130)	(0.0113)	(0.0114)
Constant	13.03***	8.354**	5.958*
	(3.9040)	(3.4230)	(3.0300)
Rho	0.6873	0.6409	0.6036
Sample Size	101	101	101
R-square	0.782	0.755	0.785

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

5.2 Counterfactual Analysis of the Impact of TOU Pricing

We conduct a counterfactual analysis by comparing the expected electricity demand under a TOU pricing regime and flat pricing regime. We assumed a flat pricing regime that sets the price of each six months so that the semi-annual revenue, electricity demand times electricity price, is the same for the flat pricing scenario and the observed TOU pricing scenario. This allows us to investigate the changes in electricity demands while holding consumer expenditures constant across the scenarios.

To determine pricing under the flat pricing regime, we proceed as follows. First, predicted demand based on the TOU demand model is evaluated for the historical prices and regression result. Second, total TOU revenues for each six-month period of constant prices are calculated. Third, a price under the flat pricing regime for each six-month period is chosen that applies to all three time blocks. Predicted demands, evaluated at these prices based on the TOU demand model, yields revenue for the six-month period that equals the revenues under TOU pricing.

The results in figure 1 suggest that a flat pricing regime would lead to an increase in on-peak electricity demand and a decrease in off-peak electricity demand relative to TOU pricing. It shows the estimated demands in both TOU pricing and flat pricing regime. Estimated demands during the on-peak and the mid-peak time blocks under a flat pricing regime (FDon and FDmid) are generally bigger than estimated demand during the on-peak and the mid-peak under TOU pricing regime (Don and Dmid) over the entire period where the difference is more persistent and larger in magnitude during the on-peak period. The graph for the off-peak period presents the opposite dynamics of relationship. The estimated demand during the off-peak under flat

pricing regime (FDoff) is lower than estimated demand during the off-peak under TOU pricing regime. This simulation implies a shift in demand from the on-peak and the mid-peak periods to the off-peak period. Thus, it appears that TOU pricing may be an effective mechanism for reducing peak demand with the possibility of delaying the need for costly electricity generating capacity additions.

These results are further illustrated in figure 2, which shows the differences over time between the two simulated demands for each of the three time blocks. For the on-peak period, the difference between FDon, the estimated demand during the on-peak under flat pricing regime and Don, estimated demand during the on-peak under TOU pricing regime is positive. This suggests that there would be an increase of electricity demand without TOU pricing for the entire period. The estimated average differences in electricity demand are 497.2 MWh/h, 2.7% increase of the mean values of hourly electricity demand under TOU pricing regime. The differences show downward trend that appears to have plateaued at around 400 MWh/h. The differences in the mid-peak period are again positive, but they are much less consistent over time. The average difference is 238 MWh/h, or 1.4% of the average hourly demand during the mid-peak under TOU pricing regime. As expected, the off-peak period has the reverse relationship to on-peak period. The differences of demand during the off-peak under flat pricing and TOU pricing regime is negative, showing decrease in electricity demand under flat pricing relative to TOU pricing. The average difference is 460.9 MWh/h which is 3% of the average hourly demand during the off-peak under TOU pricing regime. These overall results suggest that without the implementation of TOU pricing, Ontario would have been experiencing greater electricity demand during the on-peak with lesser electricity demand during the off-peak.

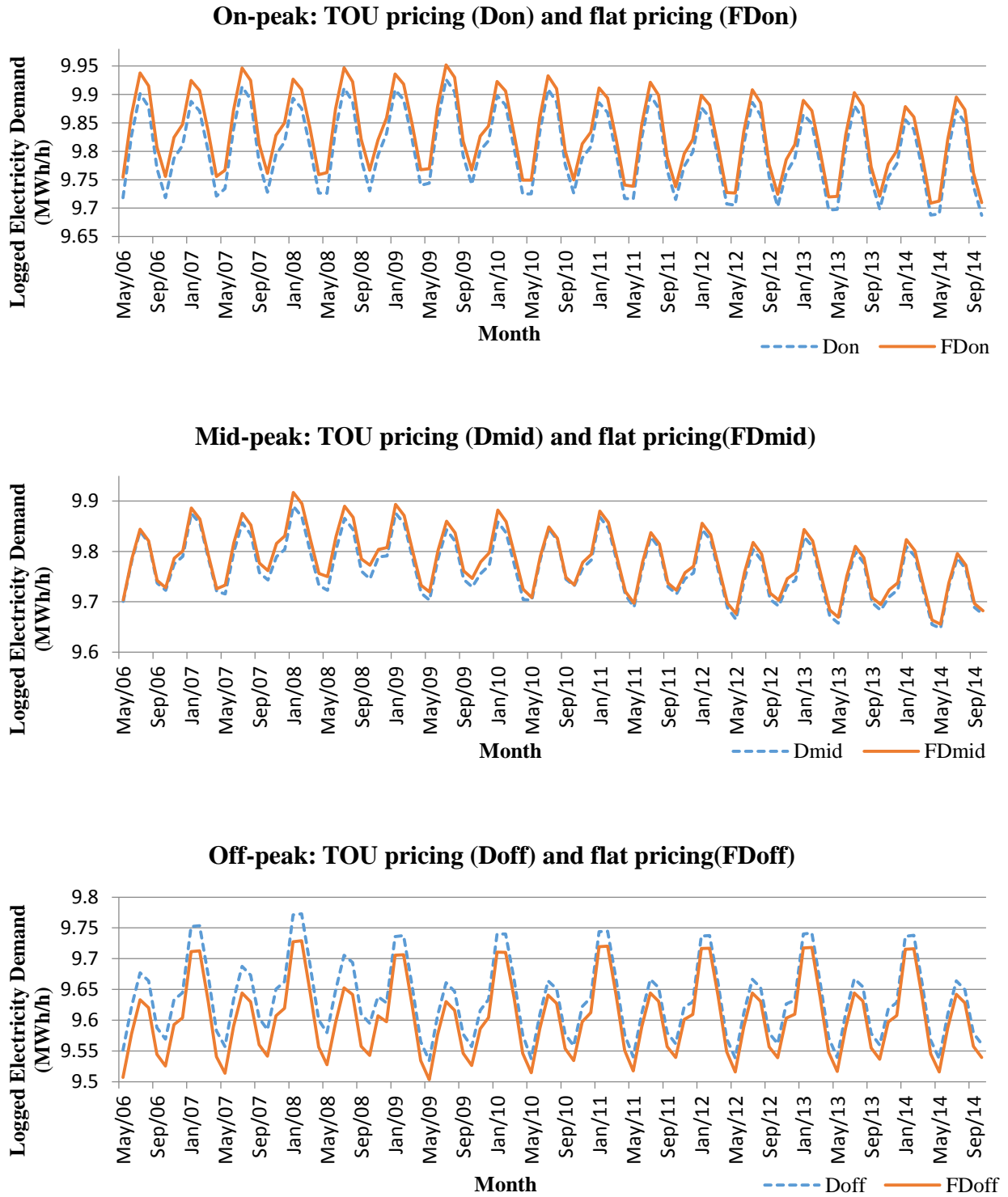**Figure 1.** Expected electricity demand of TOU pricing and flat pricing cases


On-peak: TOU pricing (Don) and flat pricing (FDon)

Mid-peak: TOU pricing (Dmid) and flat pricing(FDmid)

Off-peak: TOU pricing (Doff) and flat pricing(FDoff)

Figure 2. Expected differences of electricity demand between TOU pricing and flat pricing cases.

Differences of electricity demand: on-peak

Differences of electricity demand: mid-peak

Differences of electricity demand: off-peak
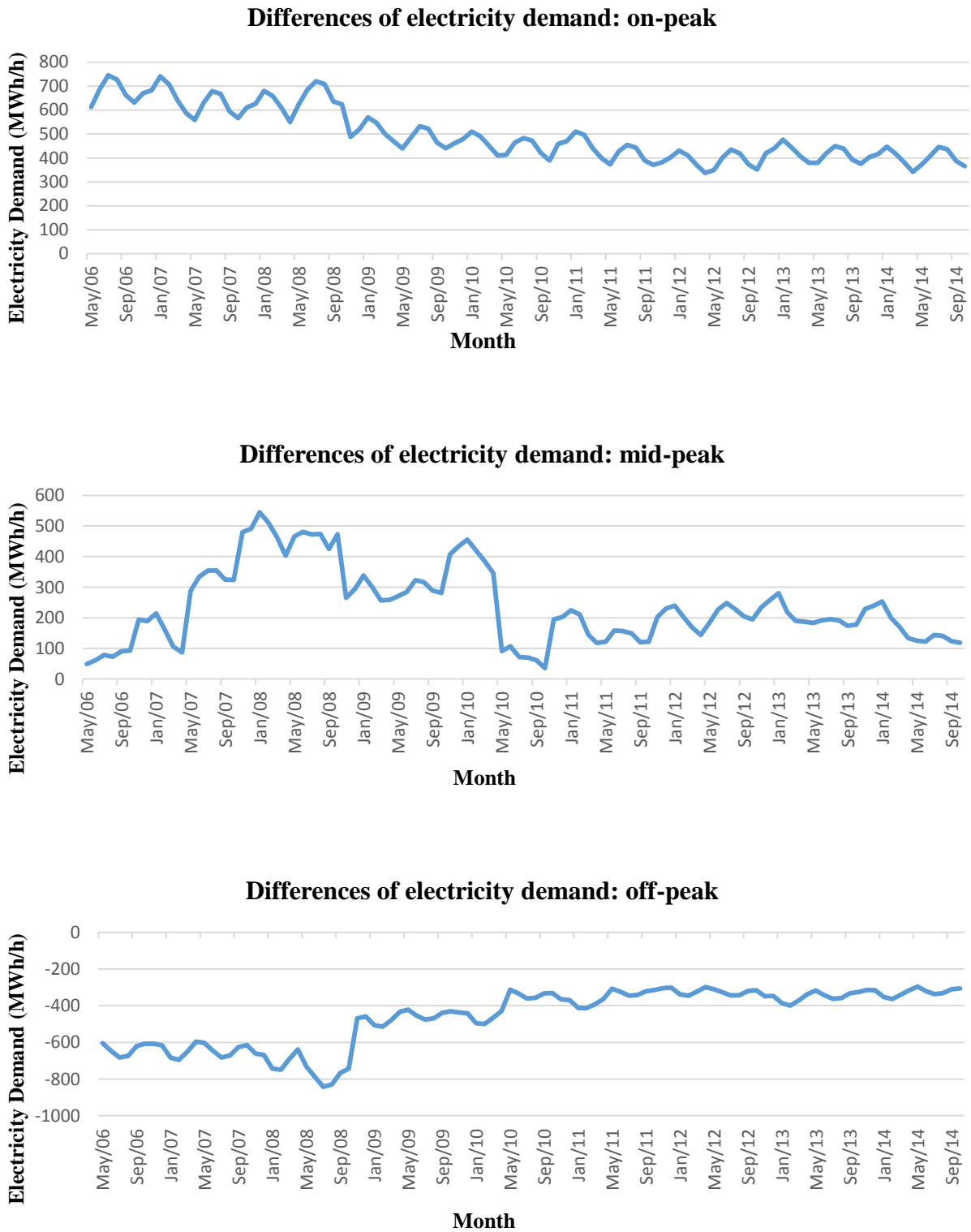
6. Conclusions and Policy Implications

In this study, we have studied the impact of Time-of-Use pricing on the demand for electricity in the Province of Ontario in Canada. Purposefully, a model of log-log linear equations for on-peak, mid-peak and off-peak electricity consumption was assessed using aggregated data covering eight years.

The empirical analysis has illuminated some of the features of the Ontario's electricity demand with TOU pricing. The estimated own-price elasticities of electricity demand are -0.10 during the on-peak period, -0.25 during the mid-peak period and -0.06 during the off-peak period. These elasticities propose moderate sensitivity of electricity consumption to price changes. Furthermore, the differences between own price elasticities of the on-peak and the off-peak period encourage a shift of electricity demand from the on-peak to the off-peak times.

The impact of TOU pricing scheme is further investigated through a counterfactual prediction of what demand would have been in the absence of TOU pricing. TOU pricing seems to have a substantial impact on average electricity consumption and on the on-peak consumption. Overall economic activity appears to reduce electricity demand during the on-peak period, while increasing demand in the other periods. Seasonality also influences demands, especially in the months when cooling and heating demands are the greatest. On the whole, however, the own price effect is stronger than the effects of overall economic activity and seasonality.

From the standpoint of load shaping of electricity demand by end-use, it should be of great interest to identify how much of electricity demand have been changed under the TOU pricing regime. The fact that the all negative signs of own-price elasticities suggests that TOU pricing may be an effective policy instrument for reshaping load. The estimated increase in

electricity demand during the on-peak period and a decrease in the off-peak period of flat pricing in counterfactual analysis strengthen the evidence of load shaping under TOU pricing. This indicates that time-of-use pricing can be considered in policy design to utilize existing production capacity more efficiently that forestalls the augmentation of generation capacity. In this instance, it appears that an estimated increase of peak electricity demand of about 400 MW that would have occurred under flat pricing regime was avoided with TOU pricing.

Further investigation along these lines may be worthwhile. For instance, estimating the responses from disaggregated the load data among residential, small business and industrial sectors to electricity rate may yield a more refined understanding of the nature of the impact on aggregate demand.

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