Impact Evaluation of Ontario's Time-of-Use Rates: First Year Analysis

PREPARED FOR

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List of Acronyms

OPA	Ontario Power Authority
TOU	Time-of-Use
LDC	Local Distribution Company
OEB	Ontario Energy Board
MDM/R	Meter Data Management Repository
RPP	Regulated Price Plan
EM&V	Evaluation, Measurement, and Verification
CES	Constant Elasticity of Substitution
CPI	Consumer Price Index
FEP	Final Evaluation Plan
IESO	Independent Electricity System Operator

Executive Summary

Besides Italy, the Canadian province of Ontario is the only region in the world to roll out smart meters to all its residential customers and to deploy Time-of-Use (TOU) rates for generation charges to all customers who stay with the regulated supply option. TOU rates were deployed as a conservation measure in Ontario, to incentivize customers to curtail electricity usage during the peak period and/or to shift that usage to less expensive mid-peak and off-peak periods, and possibly to reduce overall electricity usage.

The impact evaluation of Ontario's full-scale roll-out of TOU rates is a three-year project with the following objectives: (i) Quantify the change in energy usage by pricing period for the residential and general service customers (defined below) for a few carefully chosen local distribution companies (LDCs); (ii) Estimate the peak period impacts using the OPA's summer peak demand definition; (iii) Estimate the elasticity of substitution between the pricing periods and the overall price elasticity of demand.

This report presents the findings from the first year that customers were on TOU rates. The analysis was carried out using data for four LDCs: LDC#1, LDC#2, LDC#3, and LDC#4 which collectively represent roughly half of the provincial population and 47 percent of the provincial electricity usage delivered by Ontario LDCs.¹ These LDCs were selected based on their previous experience with TOU pilots, size and geographic location.

Each LDC in Ontario managed its TOU rate deployment independently. In order to implement TOU rates, LDCs had to first install smart meters that recorded electricity usage at different times of the day (interval data). Once they had smart meters installed, they could rollout the TOU rate to their customers. Both smart meters and the TOU rate were rolled out at different dates and over different time scales across the LDCs. Participant LDCs in the first year evaluation were included because they had sufficiently long pre-TOU periods, where customers had interval data but were not yet on the TOU rate. The deployment of TOU rates in Ontario was not part of an experiment and this posed an analytical challenge for constructing a control group for the impact evaluation purposes. However, heterogeneous timing of the TOU deployment worked in our favor as we were able to include customers who were at the tail end of the deployment as a proxy control group in our study².

For each LDC, we examined two customer classes: residential and general service. Single family homes and individually metered apartment buildings constitute the residential class and general

¹ "2011 Yearbook of Electricity Distributors," published by the OEB on September 13, 2102. http://www.ontarioenergyboard.ca/OEB/ Documents/RRR/2011 electricity vearbook.pdf

² For the TOU billing to commence, the meters needed to be deployed and then registered with the MDM/r (central data repository maintained by the IESO). Customers could move onto TOU billing only after the meters were registered with the MDM/r.

service customers are non-residential customers with demands less than 50 kW. However, we were unable to include general service customers for the LDC#2 and LDC#4 analyses because of data availability issues.

In the second and third years of the TOU study, we will analyze the same LDCs to explore whether there is persistency in the price responsiveness of the TOU customers. Moreover, we will add more LDCs to the analysis in order to increase the geographical representativeness as well as the customer diversity of the LDCs analyzed and introduce census information in our models which will allow us to estimate a statistically significant, reliable, and representative province-wide impact.

Methodology

We employ a two-pronged approach to achieve the first and second objectives of the TOU study: (i) estimation of an advanced model of consumer behavior called the "Addilog Demand System" to discern load shifting effects that are triggered by the TOU rates and to estimate inter-period elasticities of substitution; (ii) estimation of a simple monthly consumption model to understand the overall conservation behavior of the customers and estimate an overall price elasticity of demand. By solving together the two estimated models, we calculate the impact that TOU rates have had on energy consumption by period and for the month as a whole.

The 3^{rd} objective of the TOU study is to estimate peak period impacts coinciding with OPA's EM&V Protocols and Requirements definition of peak ("OPA peak demand") which is, defined as the average demand between 1 pm – 7 pm on weekdays during June, July, and August³. In order to estimate the OPA peak demand impacts, we re-estimated the Addilog model and the monthly conservation model over just the peak summer months (June - August) and load-weighted the peak and afternoon mid-peak period impacts to infer an average impact for 1 pm-7 pm window

Results

The key findings are summarized below:

- Residential customers show a consistent pattern of load shifting behavior across the LDCs analyzed;
- General service customers show less consistent patterns of load shifting behavior across the LDCs analyzed and are less responsive to the TOU prices than residential customers;
- The load shifting model parameters generally have the expected signs and have magnitudes that have been observed in pilots;

³ See "OPA EM&V Protocols STG-10: Demand Savings Calculation Guidelines". http://www.cleanairpartnership.org/files/EMV%20Protocols%20and%20Requirements.pdf

• There are some unexpected, positive and significant elasticities in the conservation models, likely due to insufficient data history and little price variation.

In terms of the *residential class results*, there is significant evidence of load shifting across all LDCs:

- There is reduction in usage in the peak and mid-peak periods (generally highest in the peak periods) and increase in usage in the off-peak periods;
- Load shifting is higher in the summer rate periods than in the winter rate periods;
- OPA peak demand impacts range from -1.3% to -5.6%, depending on the LDC;
- Summer peak period impacts range from -2.6% to -5.7%, depending on the LDC⁴;
- Winter peak period impacts range from -1.6% to -3.2%, depending on the LDC;
- Peak period substitution elasticities range from -0.12 to -0.27, depending on the LDC;⁵
- Evidence on energy conservation due to the TOU rates is limited, being very small or zero. Figure ES.1 shows the residential summer peak period impacts and their 95 percent confidence intervals. All the impacts are statistically significant.

⁴ LDC#4 TOU customers show the largest peak period impact. As we will discuss later in the report, LDC#4 sample was not selected using the same approach used with the other LDCs due to data limitations, therefore may not be representative of the entire population.

⁵ The substitution elasticity indicates the percent change in the ratio of peak-to-off-peak consumption that occurs due to a one percent change in the peak-to-off-peak price ratio. For instance, a substitution elasticity of -0.10 implies that, when the peak to off-peak price ratio increases by 1%, the corresponding peak to off-peak usage ratio decreases by 0.10%. Or put another way, if the peak to off-peak price ratio was to be doubled, the corresponding usage ratio would fall by 10%.



Figure ES.1: First Year Residential Load Shifting Results

In terms of the *general service class results*, there is some evidence of load shifting across all LDCs but it is <u>not</u> as statistically significant and pronounced as in the residential sector:

- There is a small reduction in usage in the peak and mid-peak periods, generally higher in the peak periods. There is a small increase in usage in the off-peak periods;
- There are a few odd results, most likely because of the heterogeneity in the types of businesses that are included in the general service class;
- Impacts are far smaller for general service than residential class;
- There is no clear pattern of winter versus summer load shifting impacts;
- OPA peak demand impacts range from -0.7% to 0.0%, depending on the LDC;
- Summer peak period impacts range from -0.6% to 0%, depending on the LDC;
- Winter peak period impacts range from -0.2% to -1%, depending on the LDC;
- Peak period substitution elasticity is -0.03 for LDC#1, and zero for LDC#3;
- Evidence on energy conservation due to the TOU rates is negligible and generally insignificant.

Limitations of the Study

As stated earlier, the TOU roll-out in Ontario was not a randomized control experiment⁶. This posed some unique challenges in study design. We were able to exploit the phased nature of the deployment to approximate a "difference-in-differences" analysis. The amount and quality of the pre-TOU data differed widely across LDCs. By determining an eligible customer list with at least 6 months of pre-TOU data, we have mitigated this issue to a large extent⁷. Due to the large degree of variation in the TOU deployment timing within and across the LDCs, we reported the results for the first year of TOU participation for all LDCs. It is anticipated that in the second and third years of the TOU study, all customers will have been on the TOU rates which will then allow the computation of calendar year impacts.

It is also important to note that short history with little price variation led to difficulties with conservation equations leading us to zero out implausible conservation elasticities for impact calculations. Finally, as the First Year Study involves four LDCs and the models do not incorporate the census characteristics, it is not possible to develop a province-wide impact at this time. However, we plan to add more LDCs in the study design in the second and third years of the TOU study, and develop a statistically significant and reliable province-wide impact.

⁶ In randomized controlled experiments, eligible customers are randomly allocated into the treatment and control groups. The treatment customers receive the "treatment" (TOU rates in this context), whereas the control customers do not receive the treatment.

At least six months data availability was required for determining the list of eligible customers. Once we verified that there were a large number of customers with at least six months of pre-TOU data availability, we have selected our sample and requested at least twelve months of pre-TOU data to be provided to us for the impact evaluation.

Introduction

Pursuant to the *Electricity Restructuring Act, 2004*, the Ontario Energy Board ("OEB") is mandated to develop a regulated price plan (the "RPP"), which includes a TOU pricing structure whose purpose is to provide stable and predictable electricity pricing for consumers that more accurately reflects the actual costs of generation.

As part of TOU implementation, each of the 73⁸ LDCs in Ontario is accountable for:

- undertaking the installation of smart meters for all residential customers and general service customers under 50 kW;
- enrolling smart meters in the centralized provincial Meter Data Management Repository ("MDM/R"); and
- activating TOU pricing across its service territory⁹.

LDC progress on TOU implementation is monitored by OEB-mandated monthly reporting obligations¹⁰. As of June 30, 2012, 99 percent of the RPP eligible customers had their smart meters installed; 92 percent were enrolled with MDM/R, and 89% were on TOU billing.

TOU prices are set by the OEB and reviewed bi-annually in May and November¹¹. The OEB price review is based on an analysis of electricity supply cost forecasts for the year ahead and a true-up between the price paid by consumers and the actual cost of generation in the previous billing period. Consumers may be exempted from TOU pricing by executing a fixed-price contract with an electricity retailer for a term generally between three to five years.

Besides Italy, Ontario is the only region in the world to roll out smart meters to all its residential customers and to deploy Time-of-Use (TOU) rates for generation charges to all customers who stay with regulated supply.

The rationale for TOU pricing is clear. Electricity cannot be stored economically in large quantities and the demand for electricity varies throughout the day. On weekdays, demand starts to rise in the morning as people get up and continues to its peak in the late afternoon or

⁸ In Ontario, there are a total of 76 LDCs, however only 73 are "registered"

⁹ Full implementation of TOU pricing across all LDC service territories was initially scheduled for June 2011. However LDCs had the opportunity to apply for full or partial OEB exemption from this compliance deadline due to limitations with existing telecommunications infrastructure and other circumstances

¹⁰<u>http://www.ontarioenergyboard.ca/OEB/Industry/Regulatory+Proceedings/Policy+Initiatives+and+Cons</u> ultations/Smart+Metering+Initiative+(SMI)/Smart+Meter+Deployment+Reporting

¹¹ www.ontarioenergyboard.ca/OEB/Consumers/Electricity/Smart+Meters/FAQ+-+Time+of+Use+Prices

evening as people come home. On weekends and holidays, demand is lower overall. This is illustrated in Figure 1.1.



Figure 1.1: Ontario Load Profile

Source: Independent Electricity System Operator at <u>www.ieso.com</u>.

Weather exercises a very important influence on how much and when Ontarians consume electricity. Over the last few decades, peak demands have become much more pronounced over the summer months as more people install air conditioning in homes and businesses. Peaks in the summer usually take place in the mid- to late-afternoon. Lighting also affects peak. In the winter, peaks typically occur in the morning, when people wake-up in darkness to begin their day and in the evening as night falls early. TOU rates were deployed as a conservation measure in Ontario, to incentivize customers to curtail electricity usage during the peak period and/or to shift that usage to less expensive mid-peak and off-peak periods, and possibly to reduce overall electricity usage. By conserving or shifting electricity use during peak periods, consumers can take an active role in the management of Ontario's electricity system.

Ontario's TOU consists of three pricing periods. Commodity (generation) prices are determined by the Ontario Energy Board (OEB). The rates are seasonal and may be adjusted every six months to reflect changes in system conditions and market prices. An illustration of the current TOU (effective November 2012) is shown in Figure 1.2. It should be noted that these TOU prices account for roughly only half of the average customer's bill; other charges that the customers face (e.g., distribution charges, regulatory charges, etc.) are not time-varying.

Figure 1.2: Ontario's TOU Rate



Source: Ontario Energy Board Website.

Historically, these prices have risen over time. They have also converged slightly, and when combined with non-time-varying charges on the customer's bill, have resulted in a progressively smaller differential between the peak and off-peak prices. As of November 2012, the peak to off-peak price ratio is 1.9 for the generation component only. When other bill components are included (excluding customer charges) to result in an "all-in" rate, the peak to off-peak price ratio is roughly 1.5.

Now that TOU rates have been deployed for a year or two in most LDCs, the data exists to measure the changes in customer usage patterns that have occurred in response to the TOU rates. The measurements will be carried out over a three year period, 2012 through 2014. This report contains the First Year Impact Evaluation of the TOU rates in Ontario by carrying out an econometric analysis at the LDC level. It is important to note that due to the large degree of variation in the TOU deployment timing within and across the LDCs, we reported the results for the first year of TOU participation for all LDCs rather than calendar year impacts in this study. It is anticipated that in the second and third years of the TOU study, all customers will have been on the TOU rates which will then allow the computation of calendar year impacts.

Study Objectives

The First Year TOU study has three primary objectives:

- 1. Estimate the peak period impacts using the OPA's peak demand period definition;
- 2. Quantify the change in energy usage by pricing period for the residential and general service customers for each of the five LDCs; and
- 3. Estimate the substitution elasticity between the pricing periods and the overall price elasticity of demand/.

In the First Year Study, we originally planned to analyze hourly customer data from five LDCs: LDC#1, LDC#2, LDC#3, LDC#4, and LDC#5. However, due to data issues and time constraints to address those data issues, it was not possible to analyze the LDC#5 by the time this report was being written. The remaining four LDCs represent roughly 50 percent of the Ontario population. These LDCs were selected based on their previous experience with TOU pilots, general size and geographic location. All four LDCs have a sufficiently long period of pre-TOU data to allow impact evaluation to be carried out. Even though the TOU roll-out was not a randomized control experiment, in the First Year Study, we were able to exploit the phased nature of the deployment to approximate a "difference-in-differences" analysis¹². Moreover, we relied on the data for customers who are at the tail end of the deployment to constitute the control group.

For each LDC, we examined residential class customers. For LDC#1 and LDC#3, we also examined the general services (<50kW)¹³.

Methodology

We employ a two-pronged approach to achieve the first and second objectives of the TOU study: (1) estimate an advanced model of consumer behavior called the Addilog Demand System to discern load shifting effects that are triggered by the TOU rates and to estimate inter-period elasticities of substitution; the Addilog System is estimated over six pricing periods that are described later; (2) estimate a simple monthly consumption model to understand the overall conservation behavior of the customers and estimate an overall price elasticity of demand¹⁴. By using the parameter estimates from these two models and solving them together, we calculate the

¹² Difference-in-Differences is a conceptual technique for ensuring that TOU impact measurements do not include any changes that would have occurred in the absence of TOU. It does this by netting off any changes that occur between the post-TOU and pre-TOU period for customers who never received TOU from those who did.

¹³ Single family homes and individually metered apartment buildings constitute the residential class. When the metering takes place at the building level, they are classified as general service.

¹⁴ In this study, we estimate two types of elasticities. The first one is the "substitution elasticity" which indicates the percent change in the ratio of peak-to-off-peak consumption due to 1% change in the peak-to-off-peak price ratio. For instance, a substitution elasticity of -0.10 implies that, when the peak-to-off-peak price ratio increases by 1%, the usage ratio decreases by 0.10%. In the economics literature, the negative sign is removed from the substitution elasticity. However, consistent with our prior papers on the subject, we have kept it in, since it is mathematically correct and easier to interpret. The second one is the "overall conservation elasticity" which indicates the percent change in the average monthly consumption due to a 1% change in the average monthly price. For instance, an overall conservation elasticity of -0.05 implies that, when the average monthly price increases by 1%, the average monthly usage decreases by 0.05%

impact that TOU rates have had on energy consumption by period and for the month as a whole¹⁵.



Figure 3.1: Two-pronged Approach to Estimating the TOU impacts

The 3^{rd} objective of the TOU study is to estimate peak period impacts as defined by the OPA's EM&V Protocol definition. The OPA peak demand is defined as the average demand between 1 pm – 7 pm on weekdays during June, July, and August. To achieve this objective, we re-estimate the Addilog model and the monthly conservation model over just the peak summer months (June - August) and reweighting the peak and evening mid-peak impacts to infer an average impact for 1 pm- 7 pm window¹⁶.

Below, is a description of each of the estimated models in further detail.

A. ADDILOG SYSTEM ESTIMATION

As indicated above, an advanced model of consumer behavior called the Addilog Demand System was estimated to discern load shifting effects that are triggered by the TOU rates and to estimate inter-period elasticities of substitution.

The Addilog System, first formulated by Houthakker (1960, Econometrica) and more recently extended by Conniffe (2006, Canadian Journal of Economics) and Jensen, et al. (2011, Journal of

¹⁵ Originally, we had planned to survey the customers included in the sample and use the survey data to be able to report the impacts for different customer characteristics. However, due to limitations in customer privacy, we were not able to survey the customers analyzed in this study.

¹⁶ The period 4 covers the 11 am – 4 pm window and the period 5 covers the 5 pm – 7 pm window. The period definitions are introduced later in the report.

Economics), is a well-behaved demand system which is capable of estimating small elasticities of substitution.¹⁷ Unlike more flexible demand systems, the Addilog System, like the Constant Elasticity of Substitution ("CES") demand system, is known to satisfy regularity conditions (e.g., concavity) globally. As noted in Mountain and Hsiao (1989, Journal of the American Statistical Association), even though the intent of flexible functional forms is to permit testing of hypotheses about elasticities of substitution over a wide range of possible data points, the available Monte Carlo studies (e.g., Gallant (1981, Journal of Econometrics) and Guilkey, Lovell, and Sickles (1983, International Economic Review)) and the results of Caves and Christensen (1980, American Economic Review) suggest that the available flexible functional forms cannot totally serve the purposes for which they were originally produced. Consequently, the CES was also used in earlier work by Caves and Christensen (The Energy Journal, 1980) who analyzed data from the Wisconsin TOU experiment and later in a meta-analysis of data from five TOU experiments (Journal of Econometrics, 1983). Moreover, as a reflection of the advantages of these more parsimonious demand systems for estimating the impact of dynamic pricing, the predominance of recently published papers in applied energy journals has used the CES demand system. For example, see the published papers of Faruqui and Sergici (2011, Journal of Regulatory Economics), Faruqui and George (2005, The Electricity Journal), Faruqui, Sergici and Akaba (The Energy Journal, forthcoming) and Faruqui, Sergici and Akaba (Energy Efficiency, 2013), in their analyses of the pricing experiments in Baltimore, California, Connecticut, and Michigan, respectively.

The addilog system was separately estimated for summer and winter seasons over six pricing periods.¹⁸

¹⁷ Unlike more flexible functional forms, which can violate the second-order conditions for utility maximization, the Addilog Demand System is globally concave and always satisfies those conditions. This property is not only valuable for estimating theoretically consistent elasticities but also essential for estimating out-of-sample province-wide impacts. (This is a reason Addilog Sytems are often used in CGE models for long-term simulations.)

¹⁸ The authors of this study have initially considered estimating an ANOVA analysis mostly due to its simplicity and flexibility. However, as the ANOVA approach is not derived from the theory of consumer demand, it is not possible to use this approach to separate out and identify the responsiveness due to changes in relative prices. By using a structured approach such as demand systems, we remain consistent with modern microeconomic theory. This allows us to test wellknown consumer theories, (e.g., whether or not price elasticities are negative or not, and statistically distinctly different from zero), ensures that changes in consumption by pricing period add up to changes in monthly consumption, and allows us to place our estimated impacts in perspective by comparing them to the elasticities and impacts found in the literature.

Figure 3.2: First Year TOU Study Time Periods

(May- October)						
Period	Hours	TOU Window				
1	-	Weekends & Holidays				
2	9 pm - 7 am	Off-peak				
3	7 am - 11 am	Mid-peak				
4 11 am - 5 pm		Peak				
5	5 pm - 7 pm	Mid-peak				
6 (*)	7 pm - 9 pm	Off-peak				

Summer Time Periods

Winter Time Periods					
(Januar	y- April, November and December)				

Period	Hours	TOU Window	
1	-	Weekends & Holidays	
2	9 pm - 7 am	o Off-peak	
3	7 am - 11 am	Peak	
4	11 am - 5 pm	Mid-peak	
5	5 pm - 7 pm	Peak	
6 (*)	7 pm - 9 pm	Off-peak	

(*) Period 6 was a mid-peak period before May 2011 due to OEB's pricing structure.

Following is a generalized Addilog System for the six TOU periods, with period 1 acting as base:

$$\ln\left(\frac{q_{2ht}}{q_{1ht}}\right) - \ln\left(\frac{q_{2ht-12}}{q_{1ht-12}}\right) = \beta_2 \left(\ln\left(\frac{P_{2ht}}{Y_{ht}}\right) - \ln\left(\frac{P_{2ht-12}}{Y_{ht-12}}\right) \right) - \beta_1 \left(\ln\left(\frac{P_{1ht}}{Y_{ht}}\right) - \ln\left(\frac{P_{1ht-12}}{Y_{ht-12}}\right) \right) + \sum_{k=1}^{K} \gamma_{k2} \left(X_{k2ht} - X_{k2ht-12} \right) + v_{2ht} \right) \\ \ln\left(\frac{q_{3ht}}{q_{1ht}}\right) - \ln\left(\frac{q_{3ht-12}}{q_{1ht-12}}\right) = \beta_3 \left(\ln\left(\frac{P_{3ht}}{Y_{ht}}\right) - \ln\left(\frac{P_{3ht-12}}{Y_{ht-12}}\right) \right) - \beta_1 \left(\ln\left(\frac{P_{1ht}}{Y_{ht}}\right) - \ln\left(\frac{P_{1ht-12}}{Y_{ht-12}}\right) \right) + \sum_{k=1}^{K} \gamma_{k3} \left(X_{k3ht} - X_{k3ht-12} \right) + v_{3ht} \right) \\ \ln\left(\frac{q_{4ht}}{q_{1ht}}\right) - \ln\left(\frac{q_{4ht-12}}{q_{1ht-12}}\right) = \beta_4 \left(\ln\left(\frac{P_{4ht}}{Y_{ht}}\right) - \ln\left(\frac{P_{4ht-12}}{Y_{ht-12}}\right) \right) - \beta_1 \left(\ln\left(\frac{P_{1ht}}{Y_{ht}}\right) - \ln\left(\frac{P_{1ht-12}}{Y_{ht-12}}\right) \right) + \sum_{k=1}^{K} \gamma_{k4} \left(X_{k4ht} - X_{k4ht-12} \right) + v_{4ht} \\ \ln\left(\frac{q_{5ht}}{q_{1ht}}\right) - \ln\left(\frac{q_{5ht-12}}{q_{1ht-12}}\right) = \beta_5 \left(\ln\left(\frac{P_{5ht}}{Y_{ht}}\right) - \ln\left(\frac{P_{5ht-12}}{Y_{ht-12}}\right) \right) - \beta_1 \left(\ln\left(\frac{P_{1ht}}{Y_{ht}}\right) - \ln\left(\frac{P_{1ht-12}}{Y_{ht-12}}\right) \right) + \sum_{k=1}^{K} \gamma_{k5} \left(X_{k5ht} - X_{k5ht-12} \right) + v_{5ht} \\ \ln\left(\frac{q_{6ht}}{q_{1ht}}\right) - \ln\left(\frac{q_{6ht-12}}{q_{1ht-12}}\right) = \beta_6 \left(\ln\left(\frac{P_{6ht}}{Y_{ht}}\right) - \ln\left(\frac{P_{6ht-12}}{Y_{ht-12}}\right) \right) - \beta_1 \left(\ln\left(\frac{P_{1ht}}{Y_{ht}}\right) - \ln\left(\frac{P_{1ht-12}}{Y_{ht-12}}\right) \right) + \sum_{k=1}^{K} \gamma_{k6} \left(X_{k6ht} - X_{k6ht-12} \right) + v_{6ht}$$

Where:

X refers to non-TOU variables such as weather characteristics; h refers to customer; t refers to month; q and P refer to the consumption and prices in the specific time period, respectively; Y refers to overall electricity expenditure and v is a random disturbance.

The above system of equations was estimated using the "Seemingly Unrelated Regression (SUR)" estimation routine. Even though the set of equations seem unrelated from each other, they are actually related through the correlation in their error. This routine also allows us to enforce

cross-equation restrictions, i.e., the coefficient of the period 1 price will take the same coefficient in all five equations, etc. SUR employs random effects estimator in the context of unbalanced panels (time-invariant fixed effects are accounted for using first differences). This systems estimation is consistent with the procedure used by Ham, Mountain, and Chan (1997, *Rand Journal of Economics*) where household specific effects (for which we have very little information) are differenced out avoiding possible selection biases regarding those who opted for not choosing a retail rate. Separate systems were estimated for the summer and winter. Here are the overall steps followed in estimating the Addilog System¹⁹:

- 1. Construct monthly average consumption levels for six time periods corresponding to the TOU periods on weekdays and weekends;
- 2. Normalize each period's price by the monthly expenditure for the corresponding month;
- 3. Take the natural logarithm of the price and quantity variables (but not the logarithm of the weather variables, as all the observations with 0 values would be lost with the logarithms);
- 4. Assign period 1 as the baseline period relative to which we represent quantities, prices, and weather variables of all other five periods;
- 5. Take the first differences of each of the regression variables by subtracting the previous year's values from the current year's values. First differencing will account for self-selection bias concerns related to specific fixed customer attributes that may prompt them to select into retail rates;
- 6. Parameter estimates from the Addilog system readily yield elasticity of substitution for all five periods relative to the first period²⁰. Other elasticities (such as own price and cross price elasticities), can also be derived from the estimated Addilog system.

¹⁹ While we correct for serial correlation of the error term in the monthly consumption model, we were unable to do so for the Addilog System which estimates the load shifting impacts because of time constraints. Under a certain set of assumptions, we have correctly estimated the standard errors. We plan to incorporate a correction for serial correlation in the Addilog System in the next two years of this study. However, to get a rough idea of the imprecision in the standard error estimates, we have run a few simulations based on the standard errors in the Addilog estimation being understated by a factor of two. Using this rule of thumb, we still find that the estimated impacts would are statistically significant at the 95 percent confidence level.

²⁰ The above Addilog Demand System encompasses the CES formulation $(\beta_1 = \beta_2 = ... = \beta_6)$ and is known to be very robust in detecting small elasticities, customarily encountered in TOU implementation. Furthermore, the Addilog Demand System is globally concave. Another nice feature of the Addilog System is that it does not constrain the commodity expenditure elasticities to be 1 Continued on next page

It is important to note that the demand systems approach is needed not only to predict the impact of the TOU rates that have actually been deployed but also the impact of alternative TOU rates in the future.

B. MONTHLY CONSERVATION MODEL

The Addilog system and the load shifting behavior is only one piece of the puzzle. The other piece is the monthly conservation model. We estimate a monthly conservation model to estimate the overall price elasticity of demand and the conservation impact. Our model takes the following generalized form:

$$\ln Q_{ht} - \ln Q_{ht-12} = \theta \left(\ln \left(\frac{PE_{ht}}{CPI_{t}} \right) - \ln \left(\frac{PE_{ht-12}}{CPI_{t-12}} \right) \right) + \sum_{k=1}^{K} \tau_{k} \left(X_{hkt} - X_{hkt-12} \right) + e_{ht}$$

Where:

X refers to non-TOU variables such as weather; h refers to customer; t refers to month; *PE* is the overall monthly price of electricity; CPI is the consumer price index; Q is the monthly consumption of electricity; and e is a random disturbance.

Here are the steps followed in estimating the monthly conservation model:

- 1. Construct monthly consumption variable by multiplying the average usage and the number of hours in each period and aggregating over all six periods;
- 2. Construct average monthly price by dividing the monthly expenditure by monthly usage and convert to real prices using the LDC-specific CPI series;
- 3. Construct monthly Cooling Degree Humidex ("CDH") and Heating Degree Wind-Chill ("HDW") variables by summing up the period totals and calculating a monthly average;
- 4. Take the natural logarithm for monthly consumption and price (do not take logarithm for the weather variables);
- 5. Take the first differences.

We estimate the monthly conservation model using fixed effects estimation corrected for the first order autocorrelation. Parameter estimates from this equation yield the overall price elasticity of demand.

Continued from previous page

⁽homotheticity). This implies that the overall conservation coming from TOU would not necessarily correspond to equiproportional decreases in all time periods.

After estimating the Addilog system and monthly consumption models for summer and winter seasons by class, we then solve these equations together and calculate the impacts by period. These impacts are summarized in the Results section.

C. OPA PEAK DEMAND MODEL

The OPA defines their peak as the average demand between 1 pm through 7 pm on weekdays during June, July, and August. The OPA peak demand window, 1 pm-7 pm, is not a standalone time period in our modeling framework, but it is a combination of peak and mid-peak periods. As the peak period covers the time window from 1 pm to 7 pm; our estimate of impact for that period has to be consistent with the impacts in the peak and mid-peak periods that overlap extensively with the peak period. To be able to achieve that consistency, we have adapted the methodology described above to account for the OPA peak demand definition²¹. Here are the steps followed in estimating the OPA peak demand model:

- 1. Estimate the Addilog and monthly conservation models for the OPA peak demand months of June, July, and August;
- 2. Calculate the impacts for each of the six periods ;
- Calculate a weighted average impact for the peak period by aggregating the results of Period 4 (11 am - 5 pm) and Period 5 (5 pm - 7 pm) impacts. We use the non-TOU period loads for Periods 4 and 5 as the weights.

These impacts are summarized in the "Results" section.

Data

D. A. DATA COMPILATION

Data compilation process for the First Year TOU study involved iterative communication and coordination among the LDCs, OPA, IESO and The Brattle Group. It was the largest EM&V data collection process carried out by the OPA and the partner LDCs; as well as first time extracting large volumes of data from MDM/R for evaluation purposes.

²¹ In the Final Evaluation Plan (FEP) submitted to the OPA at the beginning of the project, we had proposed a different methodology to estimate the OPA peak demand impact. However, we believe that the approach described above and employed in the study yields impacts that are more consistent with the summer peak demand impacts.

The process started with the development of privacy and data collection protocols by the OPA and The Brattle Group. The OPA oversaw the entire data collection process; ensuring OPA's privacy and data collection protocols were respected by all parties involved. Throughout the data compilation process, The Brattle Group provided technical guidance and supported the LDCs and the IESO. The LDCs provided data required for the sample size calculations and the hourly interval data for the pre-TOU period. The IESO extracted the hourly interval data from the MDM/R for the post-TOU period and sent the data set to the LDCs for review and removal of any customer identifying information. eMeter provided the data extraction templates and the virtual platform for data transfer between the LDCs and The Brattle Group. Figure 4.1 provides an overview of the data compilation process.

Figure 4.1: Overview of Data Compilation Process



E. B. DETERMINING SAMPLE SIZES

In studies with repeated measurements taken at points preceding and following a treatment, it is possible to achieve a substantial increase in efficiency (variance reduction) due to the correlation between measurements at different time points as compared to studies with single measurements. The increased efficiency in measurements implies that it is possible to meet a given statistical reliability criteria with a smaller sample size. This study will utilize repeated measurements for study participants (*i.e.*, a panel data structure) therefore it will be possible to measure a given impact with desired precision by using a smaller sample size.

"Statistical power calculations" were conducted in order to determine the minimum sample sizes required to achieve a pre-determined statistical precision level. As the peak-to-off peak price ratio is low (roughly 1.5), based on our work on 34 pilots from around the globe summarized in the Arcturus database (discussed in more detail in the Results section of the report), we expected the peak and conservation impacts flowing from the TOU rates to be small. This implied that we would need larger sample sizes to be able to detect a statistically significant impact than other studies which had used higher price ratios. For our sample size calculations, we assumed a minimum detectable difference of 1.5 percent, 5 percent statistical significance, and 90 percent power of the test. The sample size results for the 5 LDCs are show in Figure 4.2 below:



Figure 4.2: Targeted Sample Sizes for Each of the Five LDCs

For a customer to be eligible for the study, they needed at least six months of pre-TOU and one year of post-TOU hourly billing data. Each utility varied in when they started and ended installing both smart meters and when they started and ended their TOU rollout. This leads to substantial variation in the amount of pre-and-post TOU data available for our study.

Figure 4.3 shows the actual sample sizes that we landed up with for each LDC. These numbers reflect the maximum sample size observed in our data, and may have in fact been smaller at the start of the study period as smart meters were rolled out to more customers. The actual residential sample size is larger than the targeted sample size for some LDCs. Since these LDCs had more eligible customers than we had initially targeted as a minimum sample size, we were able to use all of these customers.

Figure 4.3: Actual sample sizes across all five of the LDCs							
LDC	Region	Residential		General Service			
		Sample Size	Eligible Population	Sample Size	Eligible Population		

Avail Commission Change Annual all Elvis a

Total	_	105,873	1,364,331	32,402	149,946

Notes:

LDC#2 did not have a sufficient number of general service customers that meet the eligibility criteria for pre-TOU data availability. Therefore, general service class was excluded from the analysis.

LDC#4 only had a small sample of residential customers meeting the eligibility criteria.

As mentioned above, the maximum sample size was not reached instantaneously because not all smart meters were rolled out at the same time and neither was the TOU rate. Figure 4.4 below shows how our sample size changes over the study period for each LDC and the composition of the sample by the rates that they face. Customers are split by three types of rates, retail rates; TOU rates; and the pre-existing non-retail, non-TOU rate²². There is substantial variation in when we received data from each LDC and how long until we reached the maximum sample size. For example data for LDC#2 begins in January of 2008, but we do not reach the maximum sample size until the end of 2009. By contrast data for LDC#1 begins in July of 2009 and is available immediately for the full sample. Figure 4.4 also shows variation in the number of retail customers we have for each LDC and how these change over time. There may be concern with whether customers opted in to retail rates as a direct consequence of TOU rates. We address these concerns later in the report.

²² Some customers in Ontario (fewer than one in ten) get their electricity from an electricity retailer. These customers have signed a contract and pay a fixed volumetric price for the generated commodity, which is determined by the terms of their contract. See <u>http://www.ontarioenergyboard.ca/OEB/Consumers/OEB+and+You/Ontario+Energy+Sector</u> for more details.



Figure 4.4: Sample Size over Time and Number of Customers on Each Rate

Figure 4.5 below compares the all-in TOU peak price comparison across the LDCs.



Figure 4.5: All-in TOU Peak Price Comparison

Moving from Theory to Application

Impacts were first calculated for each year that a customer is on TOU rates, rather than for a particular calendar year. This was because the variation in when the TOU rollout began and how long it persisted for across LDCs made it difficult to map the rollout to calendar years. For example when examining 2012, most LDC#3 customers are in their first year of TOU rates, while most LDC#2 customers are already in their third year of TOU. This report only presents results for customers on their first year of TOU. This allows for a more "apples-to-apples" comparison and allows us to report comparable impacts across all LDCs. This has the added advantage of ensuring that the pre-TOU period for each customer is the year immediately prior to the TOU year being evaluated, which gives us the cleanest measure of "before" and "after". In future years of the study we will be comparing TOU usage with a pre-TOU period that is several years in the past. Having this more narrow comparison in year one will allow for a good anchoring point for future evaluations.

Figure 5.1 shows how the mapping of the TOU rollout and of the subsequent impact estimation to calendar years. Panel 1 shows the TOU rollout for LDC#2. It starts in July of 2009 and ends in April of 2011. Panel 2 shows three distinct periods in the rollout. In period A, no one has TOU. In period B the rollout has begun and some customers have TOU and some do not. In period C, the rollout has ended and all customers are now on TOU rates. In Panel 3, the blue block shows the Pre-TOU period, in which at least some customers are not yet on TOU. In panel 4, the green

block shows the entire period during which at least some customers are in their first year of TOU rates. This period extends from July 2009 until April 2012. Finally in Panel 5, the overlap between the blue and green rectangles shows the period when some customers are in their first year of TOU while others are not yet on TOU. This final panel is reproduced for all four LDCs included in the first year study in Figure 5.2.



Figure 5.1: Explanation of the TOU Rollout Window



Figure 5.2: TOU Rollout and First Year of TOU Window

Results

F. A. OVERVIEW

For each of the LDCs we estimated load shifting impacts; energy conservation impacts, and conservation and substitution elasticities. This was separately done for the summer, winter and OPA peak demand months (June, July & August). Overall, the load shifting model parameters have the expected signs and have magnitudes that have been observed in previous pilots. We find that residential customers show more consistent patterns of load shifting behavior than general service customers and that general service customers are less responsive to the TOU prices than residential customers. These results are consistent with findings from other studies²³. There are however some unexpected, positive and significant elasticities in several of the conservation models for both residential and general service customers. This is most likely due to insufficient data history and little variation in the overall monthly prices that customers face.

²³ See for a review of similar studies, Ahmad Faruqui and Sanem Sergici. "Household Response to Dynamic Pricing of Electricity: A Survey of 15 Experiments," Journal of Regulatory Economics (2010), 38:193-225.

G. B. RESIDENTIAL RESULTS

Overall, we find that there is significant evidence of load shifting across all LDCs for residential customers, with reductions in usage in the peak and mid-peak periods and increases in the off-peak periods. Generally the peak reductions are greater than those in the mid-peak periods (in percentage terms).

Figure 6.1 summarizes the impacts and substitution elasticities for the OPA peak demand period, as well as the summer and winter rates period. For each LDC, load shifting is higher in the summer rates period than the winter. The OPA peak demand occurs in the months of June, July and August between 1 and 7pm. The summer rates period extends from May 1st until October 31st, with the peak being from 11am until 5pm. The winter rates period extends from November 1st through April 30th with peaks at 9-11am and 5-7pm.

		95% C.I. for Impact		Substitution
	Impact	Lower Bound	Upper Bound	Elasticity
OPA Peak Demand Period				
(June, July, August 1-7pm)				
LDC#2	-2.3%	-2.4%	-2.1%	-0.11
LDC#1	-3.3%	-3.6%	-3.0%	-0.22
LDC#3	-1.3%	-1.5%	-1.1%	-0.08
LDC#4	-5.6%	-6.1%	-5.1%	-0.39
Summer Peak Period				
(11am-5pm)				
LDC#2	-2.8%	-2.9%	-2.7%	-0.13
LDC#1	-4.3%	-4.5%	-4.0%	-0.20
LDC#3	-2.6%	-2.8%	-2.4%	-0.12
LDC#4	-5.7%	-6.1%	-5.3%	-0.27
Winter Peak Periods				
(9-11am & 5-7pm)				
LDC#2	-2.3%	-2.3%	-2.1%	-0.07
LDC#1	-2.9%	-3.1%	-2.7%	-0.14
LDC#3	-1.6%	-1.8%	-1.4%	-0.08
LDC#4	-3.2%	-3.7%	-2.7%	-0.15

Figure 6.1: Summary of Residential Impacts and Substitution Elasticities during the Peak Period(s)²⁴

²⁴ The impacts for LDC#1 are initially estimated by region (Central, East, North, and West) and then aggregated up to a single number for the entire territory using the population weights from each class and region.

During the OPA peak demand period, the reductions ranged from 1.3 to 5.6 percent. During the summer peak period, we estimated that TOU rates induced reductions of 2.6 to 5.7 percent, depending on the LDC. Winter peak reductions ranged from 1.6 to 3.2 percent. Evidence on energy conservation due to the TOU rates was limited, with all estimates showing very small or zero conservation impacts (with the exception of LDC#2 in the winter rates period).

Figure 6.2 shows the impacts for the OPA peak demand, which is calculated over June, July and August from 1 to 7 pm. The blue bars show our estimated impacts, while the red brackets show a 95 percent confidence interval²⁵. The confidence intervals are narrow relative to the magnitude of the impacts and lie far away from zero, leading us to be fairly confident that we can reject the null hypothesis of zero load shifting.



Figure 6.2: Residential OPA Peak Demand Impact (June, July, August, 1-7pm)

A 95 percent confidence interval for the estimated impact means that if random samples are drawn repeatedly, with lower and upper bounds computed each time, the unknown population value for the estimated impact would lie in the lower and upper bound interval for 95 percent of the samples

Figure 6.3 below shows the impacts during the summer peak period across the LDCs for residential customers.





We are able to compare the Ontario residential summer peak results to results collected from around the world using Brattle's Arcturus database. Figure 6.4 shows the results from 42 different TOU studies. On the y-axis is the percentage peak reduction, while the x-axis shows the peak to off-peak price ratio. The blue curve is Brattle's Arc of price responsiveness, which is an econometric estimation of the curve that best fits the data. The arc can be used to make predictions of peak reductions for various peak to-off peak price ratios. In Ontario the peak-to-off peak price ratio for all of the LDCs was approximately 1.5. This would correspond to a 3 percent reduction in peak usage, which is similar to the LDC#3 (2.6 percent) and LDC#2 (2.7 percent) impacts. The LDC#1 (4.3 percent) and LDC#4 (5.7 percent) impacts are somewhat higher than the arc of responsiveness. As indicated earlier, the LDC#4 analysis used a different sample generating process due to data limitations, therefore the study sample may not be representative of the overall population.





Only LDC#2 and LDC#1 had non-zero energy conservation impacts. Conservation impacts are estimated on a seasonal basis and aggregated to an annual impact. Overall conservation is pretty low with annual conservation of 0.45 percent at LDC#2 and 0.05 percent at LDC#1. Both results were statistically significantly different from zero. The larger LDC#2 impact is driven by conservation in the winter rate period. Further analysis on conservation impacts will be investigated in second and third years of the evaluation.

Finally we estimated substitution and overall conservation elasticities. A substitution elasticity indicates the percent change in the ratio of peak-to-off-peak consumption due to 1 percent change in the peak-to-off-peak price ratio. For instance, a substitution elasticity of -0.10 implies that, when the peak-to-off-peak price ratio increases by 1 percent, the usage ratio decreases by 0.10 percent. Likewise, overall conservation elasticities indicate the percent change in the average monthly consumption due to a 1 percent change in the average monthly price. For instance, an overall conservation elasticity of -0.05 implies that, when the average monthly price increases by 1 percent, the average monthly usage decreases by 0.05 percent.

Figure 6.5 shows substitution elasticities from several other studies alongside the Ontario residential summer peak elasticities. The Ontario elasticities, which range from -0.12 to -0.27, are

shown in the red box on the right. Notably, LDC#2 and LDC#3 elasticities are similar in magnitude to elasticities observed elsewhere.





C. GENERAL SERVICE RESULTS

Overall we find that there is some evidence of load shifting across all LDCs for general service customers, with small reductions in usage in the peak and mid-peak periods and small increases in the off-peak periods. It should be noted that impacts are far smaller than those estimated for the residential customer class and results are not as distinct, with some odd substitution patterns. This is most likely an artifact of large variability in customers that comprise the general service class.

Figure 6.6 summarizes the impacts and substitution elasticities for the OPA peak demand period, summer and winter peak periods for the general service class. Unlike for the residential class, there is no clear pattern of winter versus summer load shifting impacts.

²⁶ Detailed information and impact estimates for each LDC are available based on request. LDC#1 results are estimated by region (North, East, Central, West) as well as an aggregate.

	Impact	95% C.I. for Impact		Substitution
	Impact	Lower Bound	Upper Bound	Elasticity
OPA Peak Demand Period				
(June, July, August 1-7pm)				
LDC#1	-0.53%	-0.83%	0.22%	-0.04
LDC#3	-0.10%	-1.21%	0.52%	0.00
Summer Peak Period				
(11am-5pm)				
LDC#1	-0.43%	-1.03%	0.05%	-0.03
LDC#3	0.16%	-0.56%	0.78%	0.00
Winter Peak Periods				
(9-11am & 5-7pm)				
LDC#1	-0.32%	-0.55%	-0.03%	-0.02
LDC#3	-0.99%	-1.50%	-0.48%	-0.06

Figure 6.6: Summary of General Service Impacts and Elasticities during the Peak Period(s)

During the OPA peak demand period, the reductions ranged from -0.5 to -0.1 percent. During the summer peak period, the TOU rates induced reductions of -0.4 percent for LDC#1 and zero percent for LDC#3 (since the impact was not statistically significant). The positive sign on the peak impact in LDC#3 arises not because there is a positive elasticity in that period, but rather because there is a significant decrease in usage in period 2 coupled with zero conservation. This means that usage in other periods must rise to compensate. Winter peak reductions were -0.3 percent for LDC#1 and -1 percent for LDC#3. Evidence on conservation was negligible and generally insignificant. The peak period substitution elasticity was -0.03 for LDC#1, and zero for LDC#3.

Figure 6.7 and Figure 6.8 respectively show the OPA peak demand and summer peak period impacts across the LDCs.



Figure 6.7: General Service OPA Peak Demand Impacts (June, July, August, 1-7pm)²⁷

²⁷ LDC#1 results are estimated by region (North, East, Central, West) as well as an aggregate.





Challenges and Limitations

In this section, we describe the challenges and limitations of this study and our approach to overcoming them, where feasible.

- 1. Full-scale deployment of TOU rates poses two challenges for the impact evaluation:
 - a. The TOU rollout was not designed as a randomized controlled experiment and there is no control group, yet in the First Year Study, we were able to exploit the phased nature of the deployment within the LDCs to construct a proxy control group. We allocated the eligible customer lists into two groups using the median TOU start date. Customers who got the TOU rates after the median date were classified in the "potential control group" bucket, whereas the customers who got the rates before this date were placed in the "potential treatment group" bucket.

After determining the sample sizes, we conducted stratified (by pre-TOU kwh size and FSA, forward sorting area) random sampling to select the treatment and control groups from these two buckets. In the future, all customers will eventually be on the TOU rates leaving no customers in the control group. However, this is not a problem for the First Year Study as: (i) we have sufficient data history with the control group customers based on the roll-out schedules; (ii) our methodology can accommodate unbalanced panels; that is, it does not require a complete history on every individual customer

- b. For some LDCs, the TOU rates were deployed very shortly after the smart meter deployment. This implies that there is a very short window with pre-TOU data available. We addresses this issue in the sample design process by defining eligible customers to be included in the study as those who have at least 6 months of pre-TOU and at least 12 months of post-TOU data.
- 2. We use a small group of retail customers as an additional control group as some LDCs completed the TOU deployment over a short period. There may be a concern that those customers who "self-select" into the retail rates may be different from other customers, particularly if they do so as a reaction to TOU rates. In order to account for this potential self-selection bias, we ran our regressions using first differences (year t - year t - 1) to remove any customer specific characteristics that do not change over time. If there is a specific customer attribute that prompts them to select into the retail rate, this attribute will be removed by taking the first differences. For example if customers have higher than average usage in the peak periods, this usage pattern will be removed by taking the difference between the current and previous year. Moreover, if customers opted out of TOU because they anticipated their usage becoming "peakier", we would find larger negative elasticities than we should and in such a case we would be overstating the TOU impacts. We found that excluding retail customers does not change impacts for LDC#1, LDC#3, and LDC#4 analyses. Excluding retail customer results in slightly larger impacts for LDC#2 customers which goes in the opposite direction of the anticipated bias and means that our reported impacts are not overstated.
- 3. Short history with little price variation led to difficulties with conservation equations and resulted in occasional implausible conservation elasticities. We zeroed out implausible conservation elasticities for impact calculations.

- 4. Due to the large degree of variation in the TOU deployment timing within and across the LDCs, we reported the results for the first year of TOU participation for all LDCs. In the second and third years of the TOU study, all (non-retail) customers will have been on the TOU rates which will then allow the computation of calendar year impacts.
- 5. As the First Year Study involves four LDCs and the models do not incorporate the census characteristics, it is not possible to develop a province-wide impact at this time. In the second and third years of the study, more LDCs will be added to the study in order to increase the geographical representativeness as well as the customer diversity of the LDCs analyzed, and introduce census information in our models which will allow us to estimate a statistically significant, reliable, and representative province-wide impact.
- 6. Due to data availability issues, we did not report the general service class results for LDC#2 and LDC#4.
- 7. The LDC#4 sample was not drawn using the procedure for the other LDCs due to data availability problems, therefore may not be representative of the relevant population. This issue will be investigated further in the Second Year TOU study.

Conclusion and Next Steps

The First Year Analysis of Ontario's Full-scale TOU Program revealed that the residential customers responded to the TOU rates by shifting their usage from peak to off-peak and mid-peak periods and have magnitudes that have been observed in pilots.. The load shifting impacts for general service customers were far smaller than those estimated for the residential customer class and results are not as distinct, with some odd substitution patterns. This is most likely an artifact of large variability in customers that comprise the general service class. Evidence on energy conservation was negligible and generally insignificant in both the residential and general service class.

The First Year Analysis involved some challenges mostly in the process of data compilation as this was the largest scale data extraction process for the participating LDCs and the IESO. However, as a result of impressive cooperation from all the involved parties, the First Year Study has streamlined the data compilation process which should make this exercise more straightforward for the Year Two and Three Analyses. The analysis also involved some methodological challenges due to the heterogeneity in the timing of the TOU deployments and the resulting difficulties associated with defining comparable impacts across all LDCs. We have overcome these challenges by carefully crafting our methodology.

In the Second and Third Year Analyses, we will build up on the foundation established in this study; add more LDCs to the study in order to increase the geographical representativeness as well as the customer diversity of the LDCs analyzed, and introduce census information in our models which will allow us to better estimate a statistically significant, reliable, and representative province-wide impact.

GLOSSARY

Addilog Demand System: it is a well-behaved demand system which is capable of estimating small elasticities of substitution. Unlike more flexible demand systems, the Addilog System satisfies regularity conditions (e.g., concavity) globally.

Constant Elasticity of Substitution System: is a well-behaved demand system which allows the elasticity of substitution to take any value. The CES model has been found to be well-suited to TOU pricing studies involving electricity since there is strong prior evidence suggesting that these elasticities are going to be small.

Cooling Degree Humidex Index: is a warm weather indicator defined as follows,

 $CDHM_{t} = \max \left[HM_{t} - 22,0\right]$ where $HM_{t} = \max \left[H_{t} \cdot d_{t}, T_{t}\right]$ with $d_{t} = \begin{cases} 1 \text{ if } H_{t} \text{ is reported} \\ 0 \text{ otherwise} \end{cases}$

 T_t is hourly outdoor air temperature at hour t.

Difference-in-Differences Estimation: is a technique to measure the effect of a treatment by first calculating the difference between pre and post treatment periods for the treatment group and then netting it off by the difference between these two periods for the control group.

General Service Customer: are non-residential customers with demands less than 50 kW

Heating Degree Wind-Chill Index: is a cold weather indicator defined as follows,

$$HDW_t = max[18 - W_t, 0]$$

with $W_t = min[T_{wct} \cdot v_t, T_t]$ with $v_t = \begin{cases} 1 & if T_{wct} & is reported \\ otherwise \end{cases}$

 T_t is hourly outdoor air temperature at hour t, and

 T_{wct} is the wind chill statistic reported by Environment Canada.

Price Elasticity of Demand: represents the percentage change in quantity demanded in response to a one percent change in price holding constant all the other determinants of demand.

Randomized Control Experiment: in randomized controlled experiments, eligible customers are randomly allocated into the treatment and control groups. The treatment customers receive the "treatment" (TOU rates in this context), whereas the control customers do not receive the treatment.

Residential Service Customer: refers to single family homes and individually metered apartment buildings. When the metering takes place at the building level, they are classified as general service customers.

Seemingly Unrelated Regression: is a generalization of a linear regression model that consists of several regression equations, each having its own dependent variable and potentially different sets of exogenous explanatory variables. Each equation is a valid linear regression on its own and can be estimated separately, which is why the system is called *seemingly unrelated*, although some authors suggest that the term *seemingly related* would be more appropriate, since the errors are assumed to be correlated across the equations.

Substitution Elasticity: indicates the percent change in the ratio of peak-to-off-peak consumption that occurs due to a one percent change in the peak-to-off-peak price ratio. For instance, a substitution elasticity of -0.10 implies that, when the peak to off-peak price ratio increases by 1%, the corresponding peak to off-peak usage ratio decreases by 0.10%. Or put another way, if the peak to off-peak price ratio was to be doubled, the corresponding usage ratio would fall by 10%.

Minimum Detectable Difference: refers to the minimum difference between the mean usages of treatment and control groups that we can reliably quantify, given a statistical precision criteria and size of the analysis sample. In a given M&V effort, as the MDD becomes smaller, the sample size that is required to detect the program impact with the same statistical precision criteria becomes larger.

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THE Brattle GROUP