Capturing Smart Meter Enabled Benefits in System-Wide Rollouts

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Abstract

Smart meters can enable many new types of customer programs that encourage conservation and load shifting, such as time varying pricing, improved feedback over energy usage, and conservation voltage reduction (CVR), to name a few. In the U.S., nearly 50% of residential customers have smart meters, while the EU aims to replace at least 80% of electricity meters with smart meters by 2020 (where it is cost-effective to do so). Smart meters are usually rolled out for an entire residential customer population and thus their benefits cannot be measured using a randomized controlled trial (RCT). We discuss measurement and verification of three system-wide smart meter enabled programs—Time of Use (TOU) pricing in the province of Ontario (Canada), enhanced feedback and other smart meter-enabled customer outreach, and a Conservation Voltage Reduction (CVR) program in a mid-sized US utility. Control groups for evaluations were created depending on circumstances and data availability. Some examples include using the phased nature of the smart meter rollout, using neighboring jurisdictions, and creating sub-system pilot groups. We discuss how these control groups can be adequately selected and even optimally chosen if built into the smart meter rollout design. Finally we present results from these impact evaluations to give a sense of the benefits from deploying smart meters. We find that in Ontario, TOU results in a province wide summer peak period energy reduction of 1.5% to 2.5% (depending on the year); while for our mid-sized US utility, energy management tools and CVR result in energy savings of 1.7% and 1.4% respectively.

Introduction

Smart meters can enable many new types of customer programs that encourage conservation and load shifting, such as time-varying pricing, improved feedback over energy usage, and conservation voltage reduction (CVR) to name a few. In the U.S., nearly 50% of residential customers have smart meters, while the EU aims to replace at least 80% of electricity meters with smart meters by 2020 (where it is cost-effective to do so). Smart meters are usually rolled out for the entire customer population and thus the attendant benefits from reducing and shifting customer load cannot be measured using a randomized controlled trial (RCT). The customer load benefits from a smart meter deployment will depend on the degree to which innovative tariffs and customer education are unlocked by the new meters. By providing interval data extremely frequently to the utility (every 15 minutes as opposed to every 30 days), smart meters allow for the use of time-varying rates; greater control over power flows; and better customer feedback over energy usage. We examine instantiations of all three types of benefit programs. In Ontario we examine the system wide deployment of Time of Use (TOU) rates; while for a mid-sized U.S. utility ("Utility M") we examine enhanced feedback combined with other smart meter-enabled customer outreach as well as a Conservation Voltage Reduction (CVR) program. In each case, the deployment of the smart meters and accompanying program was not conducted as an experiment, but rather as a system-wide rollout with benefits extended to all customers.

To measure the impact of all three programs we create quasi-experimental control groups. This allows us to account for any changes in electricity usage that would have occurred in the absence of the smart meter enabled intervention. In the case of Ontario, we use the phased nature of the smart meter and TOU rollout across the province and within local distribution companies (LDCs) as one level of control, and customers who were at the tail end of the deployment as a control group in our study (at least for the first few study years). However, because we have included pre-TOU implementation data for the entire sample, there is a second set of control data across time. Finally, retail customers, who have opted out of the province-wide regulated price plan and are not on TOU rates, act as an additional control group. For Utility M's Energy Management Tool EMT program, we again used the phased nature of the smart meter deployment to create a quasi-control group of late-activation, since not all customers had access to the EMTs at the same time. Customer education was provided at a range of times based on each customer's individual installation and activation, while at the same time mass media information was available throughout the service territory. To continue the evaluation past the period where all customers have activated smart meters, we considered two adjacent territories as control groups and ultimately selected one as being the most suitable as a "but for" comparison. For Utility M's CVR program, Utility M engineering and load research experts identified seven control substations with customer and load characteristics that match closely to those of the seven CVR substations. These treatment and control substation pairs are generally adjacent to each other and the communities that they serve are similar in nature in terms of types of homes, vintages, *etc.* Moreover, since all the treatment and control substations are in the same service territory, many factors that may affect consumption, such as rates and economic factors, are similar between treatment and control substations.

About the Programs

TOU in Ontario

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

As part of TOU implementation, each of the more than 70 LDCs in Ontario was 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 territory.

As of 30 June 2012, 99% of eligible customers had their smart meters installed; 92% 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 November.[1] Consumers may be exempted from TOU pricing by executing a flat-price contract with an electricity retailer for a term generally between three and five years. 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 evening as people come home. On weekends and holidays, demand is lower overall. TOU rates were deployed as a load shifting 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. Only the commodity (generation) prices are time varying. The prices for distribution and transmission are volumetric, but time invariant. An illustration of the relevant TOU periods and commodity prices (effective November 2014, the most recent rate change) is shown in Figure 1. Electricity Prices across a Day (effective in 2014).[2] It should be noted that these TOU prices account for roughly half of the average customer's bill; other charges that the customers face are not time-varying.

[1] OEB Time of Use Pricing Website:
www.ontarioenergyboard.ca/OEB/Consumers/Electricity/Smart+Meters/FAQ+-+Time+of+Use+Prices

[2] Source: Ontario Energy Board website.
http://www.ontarioenergyboard.ca/OEB/Consumers/Electricity/Electricity+Prices

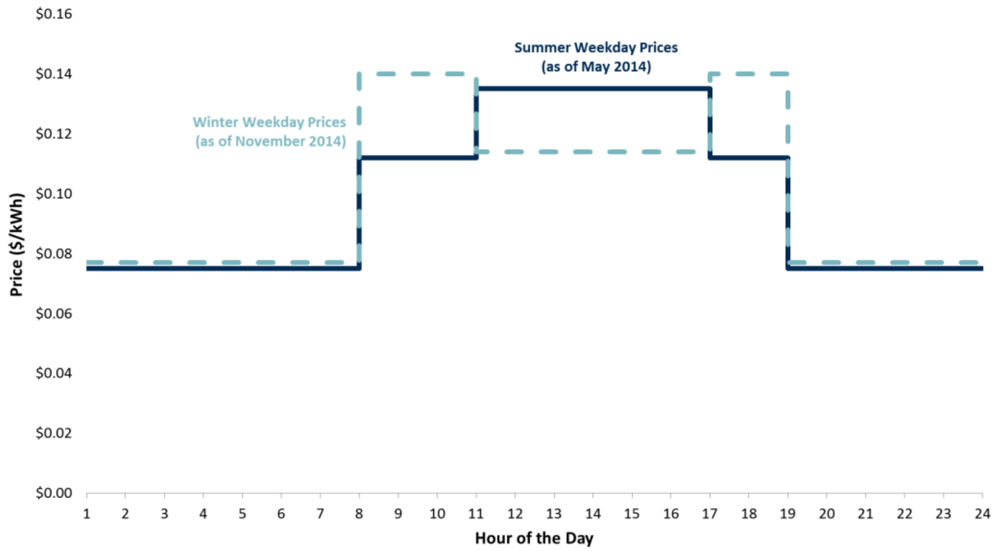


Figure 1. Electricity Prices across a Day (effective in 2014)[3]

Differentials between the peak and off-peak prices have remained relatively stable since 2010. As of November 2014, the peak to off-peak price ratio is 1.8 for the generation component only. When other non-volumetric 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.

Energy Management Tools (EMTs) at Utility M

Utility M does not have TOU rates, but uses its smart meter infrastructure to target both peak period usage and overall energy usage. The former is done with a Peak Time Rebate (PTR). This offers customers a rebate for conserving energy in peak periods, relative to their baseline consumption. These peak periods are chosen dynamically and announced a day in advance. Peak periods occur only a few times per year and are relatively short in duration (4 hours). This makes them relatively easy to measure, even without a control group, since customer usage on all other days can act as a control for their usage on a peak day. If the peak day is very different from other days, even after accounting for observable factors like weather, then alternative measures can be used to evaluate the PTR impact, such as Quantile Regression.

Utility M has several service territories and had completed its smart meter deployment for most of them as of the end of 2014. In the service territory of interest smart meter activation began in mid-2012 and extended through mid-2013. Using the data from its smart meters, Utility M has developed a portfolio of Energy Management Tools (EMTs) that provides residential customers with information about their electricity usage and helps them to make better informed choices about their electricity consumption. The EMTs cover a wide range of information outlets including:

1. Web portal: customers can log on to their web portal and see their hourly usage of electricity; view user-friendly charts comparing consumption to selected periods, *i.e.*, same

[3] Data is shown as "hour ending", so 1 is the hour starting at midnight and ending at 1 am.

month last year; projected bills; tips on energy conservation; and several other useful analytics on their electricity consumption patterns.

2. Detailed bill presentment: after the activation of smart meters, monthly electricity bills include more details about each customer's usage including monthly electricity usage charts and daily consumption charts. These details allow customers to relate their activities on certain days and months to the resulting level of electricity consumption.

3. Educational campaigns in multiple forms including:

   - Letters and fact sheets regarding the installation of smart meters;
   - Postcards announcing the availability of new tools;
   - Newsletters discussing the new tools, energy savings tips, and the benefits of smart meters;
   - Mass media advertising related to saving energy and availability of new tools to help consumers save energy;
   - Customer education related to the announcement of the Peak Time Rebate, including energy savings tips and ideas for reducing energy during the summer;
   - Community meetings and events that involved presentations, individual discussions, demonstrations of the web portal, and providing customer education handouts.

4. News coverage including press releases, articles and TV coverage of smart meter activation, and other energy management tools enabled by smart meters.

CVR at Utility M

The key engineering principle of CVR is that the American National Standards Institute (ANSI) standard voltage band between 114 and 126 volts can be reduced to the lower end of the standard (114–120 volts). The upper end of the spectrum is just a buffer, allowing for voltage attenuation down a feeder line, where historically it was expensive to measure. This voltage reduction has the potential to produce considerable energy savings at low cost and without harm to customer end-uses, with no impact to end-use operation.[4] CVR's effect is entirely passive for customers. That is, a customer does not notice a change in their electricity service quality and does not need to make any behavioral changes due to CVR implementation. However, certain types of load, such as motor load, may not experience a decrease in usage due to CVR because the motor may run less efficiently. Utility M initiated Phase I of its CVR program in August 2013, reducing voltage by 1.5% at seven substations.

Creating Control Groups

[4] CVR as a mechanism to decrease consumption has been known for many years. In the 1970s, CVR was tested in California and, while the California Public Utilities Commission claimed that CVR was effective and efficient, many others dismissed CVR as being too expensive and not able to achieve the conservation impact that advocates claimed.[4] The PJM Interconnection, L.L.C. has relied on temporary voltage reductions to lessen demand during periods of constrained supply.

The Value of a Control Group

One way to evaluate the treatment impact of a program would be simply to compare energy usage for the treatment group before and after treatment. This impact measure would not yield the true treatment impact because many factors that influence energy usage may have changed over time, independently of the treatment, invalidating the evaluation. The longer the treatment period, the more likely this is to occur. In order to account for what would have happened in the absence of treatment we need a properly selected control group to act as a "but-for" world for the treatment group. In full system rollouts, we do not have the luxury of a creating an entirely separate control group. However by using natural features of the smart meter deployment such as the speed of the rollout, reasonable "quasi-experimental" control groups can be created. Moreover, if Measurement and Verification (M&V) is incorporated into the design of the smart meter deployment, these natural features can be enhanced to yield the best possible non-experimental control group.

TOU Control Groups

In order to implement TOU rates, LDCs had to first install smart meters to record electricity usage at different times of the day (interval data). Once they had smart meters installed, they could roll-out the TOU rate to their customers. Each LDC in Ontario managed its TOU rate deployment independently. Both smart meters and the TOU rate were rolled out at different dates and over different time scales across the LDCs. Participant LDCs were included in the evaluation because they had sufficiently long pre-TOU periods, during which customers had interval (smart meter) data, but were not yet on the TOU rate. Even though the TOU roll-out was not a randomized control experiment, we were able to exploit the phased nature of the deployment to approximate a "difference-in-differences" analysis. Moreover, we relied on the data for customers who are at the tail end of the deployment as well as retail customers who are not on TOU rates to constitute the control group.

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 their TOU roll-out. This leads to substantial variation in the amount of pre- and post-TOU data available for our study.

Figure 2 shows the residential smart meter (also known as Advanced Metering Infrastructure or AMI) and TOU deployment in the central region (our study split Ontario into 4 regions). The dotted lines indicate the total number of smart meter customers in the sample before TOU; the solid line indicates the total number of smart meter customers in the sample on TOU. Here one can see that although smart meter data for Toronto Hydro begin in January of 2008, we do not reach the maximum sample size until the middle of 2011. By contrast, smart meter data for Newmarket-Tay Power begin in July of 2008 and is available almost immediately for the full sample. Decreases in the most recent years are due to attrition in the sample (for example a premise is no longer included in the sample once the customer residing there changes). For simplicity of exposition we exclude retail customers from the figure.

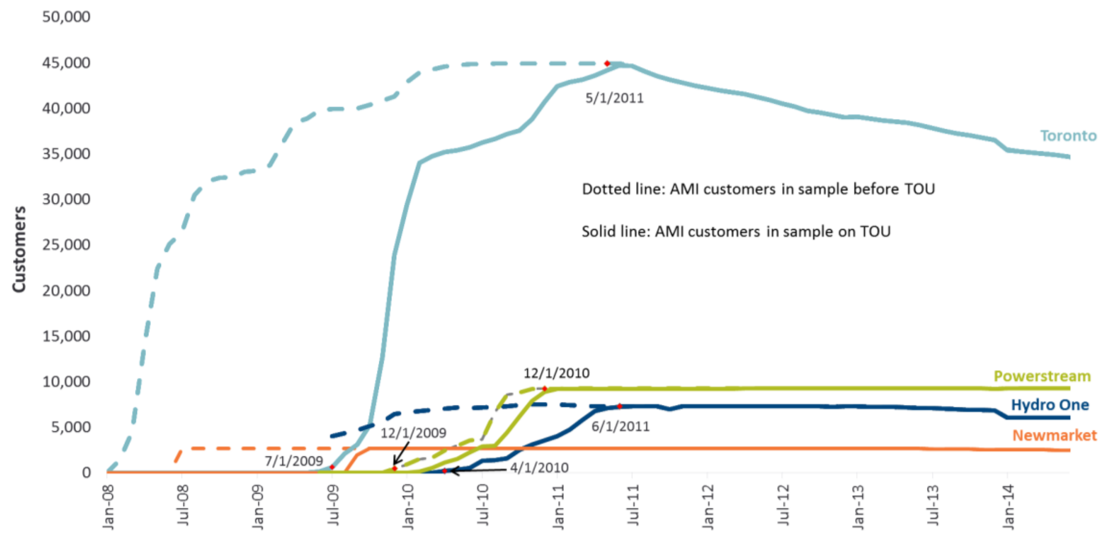


Figure 2. Central Region Residential TOU Roll-Out by Month

Customers can be on one of three rate types at any point in time: the regulated non-TOU rate (before TOU was rolled out), the regulated TOU rate, or a non-TOU retail rate. By 2012 all smart meter customers were on TOU rates, and we could no longer estimate a difference-in-difference model if we used just the TOU customers. Rather, we could only do a pre-post comparison. Fortunately, we were able to use an additional control group comprised of retail customers. These were customers who opted out of the regulated price plan and chose to go with a private retailer. In all LDCs in the study, less than 10% of the residential population is on retail rates.[5]

EMT Control Groups

For Utility M, each customer had its own unique smart meter activation date that marked the beginning of the smart meter enabled information flow from Utility M to its customers. Due to the full-scale nature of the smart meter rollout, including mass media coverage, it was not possible to set aside a control group that would be excluded from receiving the treatment. To overcome this limitation, the analysis considered data from two other Utility M jurisdictions, B and C, as potential control groups for the treatment service area, Jurisdiction A.

Although Jurisdiction A and B were both ultimately receiving the same smart meters and treatment, Jurisdiction B had started its deployments much later than Jurisdiction A and had not completed its smart meter rollout by September 2014, the end of the reporting period. In Jurisdiction C there were no plans for smart meter deployment as of the writing of this report. Since there were two candidate control groups for the study, the first step involved determining which one of these two jurisdictions looked more similar to Jurisdiction A in terms of load characteristics, average electricity rates, and local economic conditions. We compared non-farm employment, geographic proximity, monthly electricity usage, and rates and found

[5] Some of these customers opted out before TOU was instituted, some after. There may be concerns with whether customers who "self-select" into retail rates are different from other customers and whether customers opted in to retail rates as a direct consequence of TOU rates. We analyzed self-selection among retail customers and found that it was not a significant concern. In addition, we account for self-selection by first differencing observations, thereby removing any fixed differences between customers (We are assuming that self-selection is occurring due to unchanging customer factors. Time variable factors that influence self-selection will not be accounted for here).

Jurisdiction B to be very similar to Jurisdiction A.

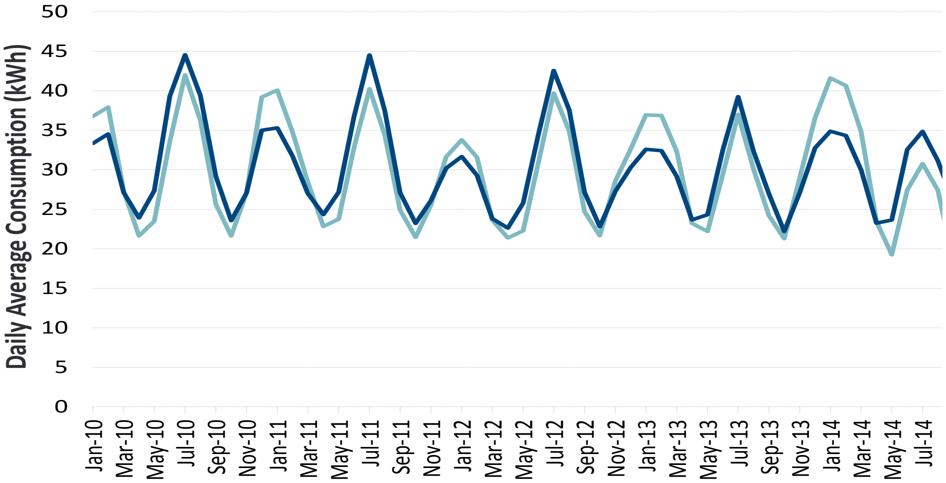


Figure 3. Daily Average Usage (kWh) Comparison across shows the average daily residential usage profile Jurisdictions A and B. Though the series do not align perfectly, the overall trends and seasonality are very similar.

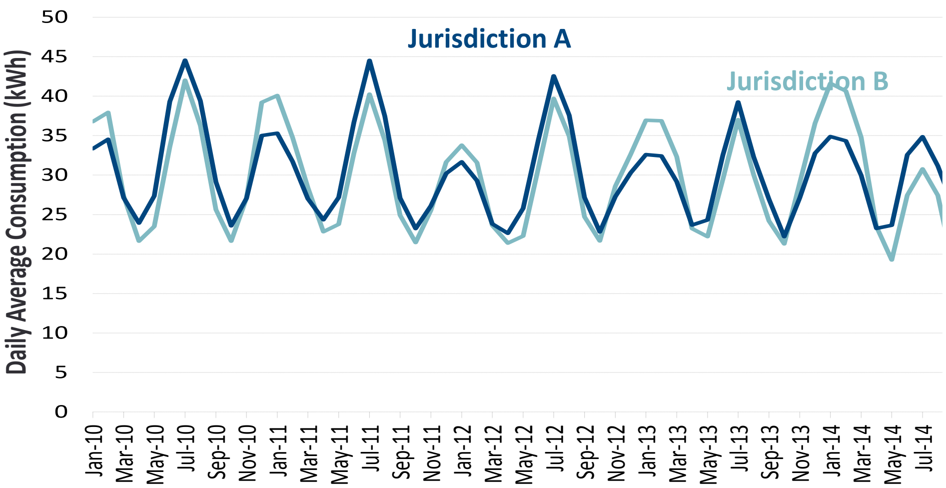


Figure 3. Daily Average Usage (kWh) Comparison across Jurisdictions A and B

It is important to note that even though the Jurisdiction B residential customers ultimately received the EMT treatment starting in December 2013, the rollout of EMTs was not completed by September 2014. Therefore, our analysis started dropping Jurisdiction B customers from the dataset as they received EMTs starting in January 2014. By September 2014, 32% of Jurisdiction B customers had still not received EMT treatment, which resulted in an ample number of customers that our analysis could rely on for control group purposes. During the study period, the number of control group customers ranged between 135,000 and 32,000.

CVR Control Groups

To measure the impact of CVR, Utility M engineering and load research experts identified seven control substations with the customer and load characteristics that match closely to those of the seven CVR substations. These treatment and control substation pairs are generally adjacent to each other and the communities that they serve are similar in nature in terms of types of homes, vintages, *etc*. Moreover, since all the treatment and control substations are in the same service territory, many factors that may affect consumption, such as rates and economic factors, are similar between treatment and control substations.

In order to assess the comparability of the treatment and control group substations, *ex-post* comparisons were conducted of the treatment and control customer load profiles in the pre-treatment period (for the peak demand analysis). As presented in **Error! Reference source not found.**, these comparisons were performed separately by time period (peak and off-peak) and it was determined that the residential treatment and control group load profiles are very similar to each other in terms of their shape and levels.

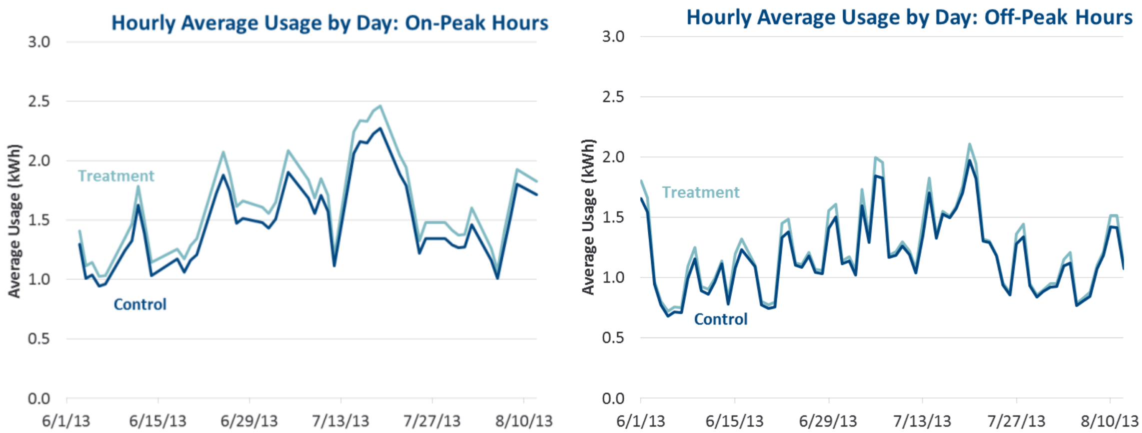


Figure 4. Pre-Treatment Period (June-August 2013) Profiles of Consumptions

Estimation

All of the evaluations use some form of difference-in-difference analysis, with additional controls for weather, calendar impacts, and other programs. The TOU analysis is more complicated since we are estimating consistent load shifting parameters between periods, as well as conservation. To do this we: (1) estimate an advanced model of consumer behavior called the Addilog Demand System model to discern load shifting effects that are triggered by the TOU rates and to estimate inter-period elasticities of substitution[6]; and (2) estimate a simple Monthly Consumption model to understand the overall conservation behavior of the customers and to estimate an overall price elasticity of demand. By using the parameter estimates from these two

[6] The Addilog Demand System model, first formulated by Houthakker (1960, Econometrica) and more recently extended by Conniffe (2006, Canadian Journal of Economics) and Jensen, et al. (2011, Journal of Economics), is a well-behaved demand system, which is capable of estimating small elasticities of substitution. Unlike more flexible demand systems, the Addilog Demand 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 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).

models and solving them together, we calculate the impact that TOU rates have had on energy consumption by period and for the month as a whole. We estimated the Addilog Demand System model separately for summer and winter seasons over six pricing periods.

To obtain representative impacts from a non-representative population, we allowed for heterogeneous treatment responses to TOU by interacting the price and weather impacts with census variables. This allows for customers in different census areas with different characteristics to respond differently to both prices and weather. We could then re-weight impacts, which are a function of customer characteristics, by the correct proportion of characteristics for the population of that region. For example, say that the impact was a function of household size such that the impact was 0.1*household size. If the average household size in the sample was 2, but the average household size in the region was 3, we can move from the sample impact to a representative regional impact by inserting 3, the region's average household size, into the equation. This allowed us to ultimately obtain representative provincial impacts.

Results

TOU Impacts

The TOU analysis was conducted at the regional level, with the province split into four regions, and aggregated to the provincial level. Load shifting impacts were split into four separate calendar periods: pre-2012, 2012, 2013, and 2014. The pre-2012 period reflects all of the years that LDCs within a region were on TOU rates prior to 2012. Some LDCs started TOU as early as 2009, while others began in 2012, resulting in compositional changes potentially affecting the comparison between pre-2012 and later years. By 2012, all LDCs in the study were on TOU rates. Residential customers show clear patterns of load shifting behavior across regions and study years, but little evidence of conservation. The magnitude of load shifting appears to diminish over time. The residential load shifting model parameters are generally consistent across regions and years and have magnitudes that have been observed in other pilots. There are some unexpected positive elasticities in the conservation models, likely due to little price variation during the study period. None of these elasticities are statistically significant.

Error! Reference source not found. shows residential load shifting across all periods in the summer for the whole province. Period 1 is weekends and holidays, which are off-peak. Period 2 is from 9pm to 7am and is also off-peak. Period 3 is from 7am to 11am and is mid-peak. Period 4 is the peak period from 11am to 5pm. Period 5 is the second mid-peak from 5pm to 7pm. Period 6 from 7pm to 9pm is currently off-peak, but was mid-peak before May of 2011.[7] Load is shifted from the peak and evening mid-peak period to the off-peak periods. In 2014, there is evidence of increasing load shifting into the mid-peak periods (additional shifting into the morning mid-peak period relative to prior years, and shifting into the evening mid-peak period, for which negative impacts were previously observed).

[7] Note that the assignment of the peak and mid-peak periods change in the winter months.

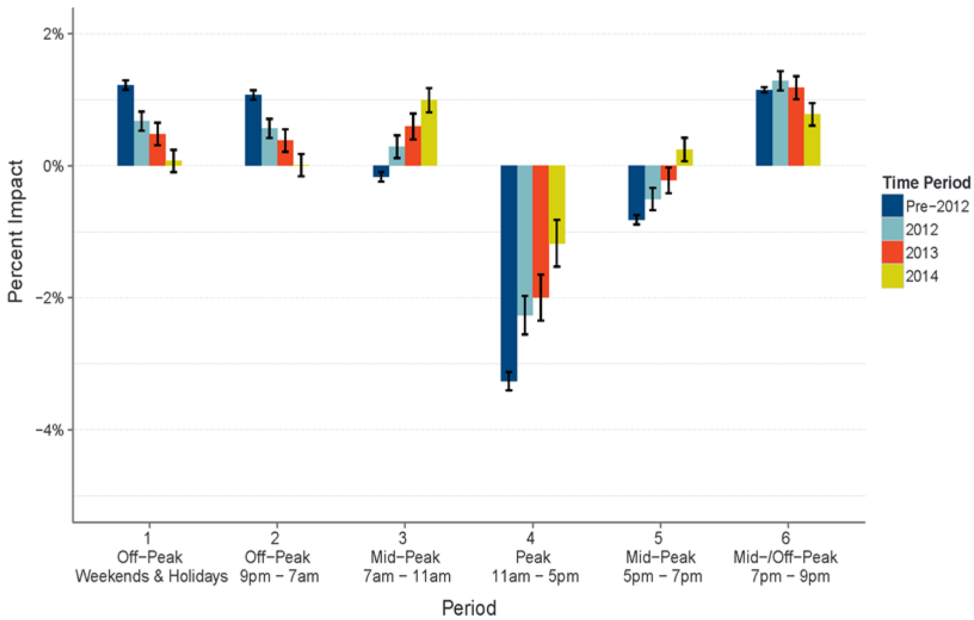
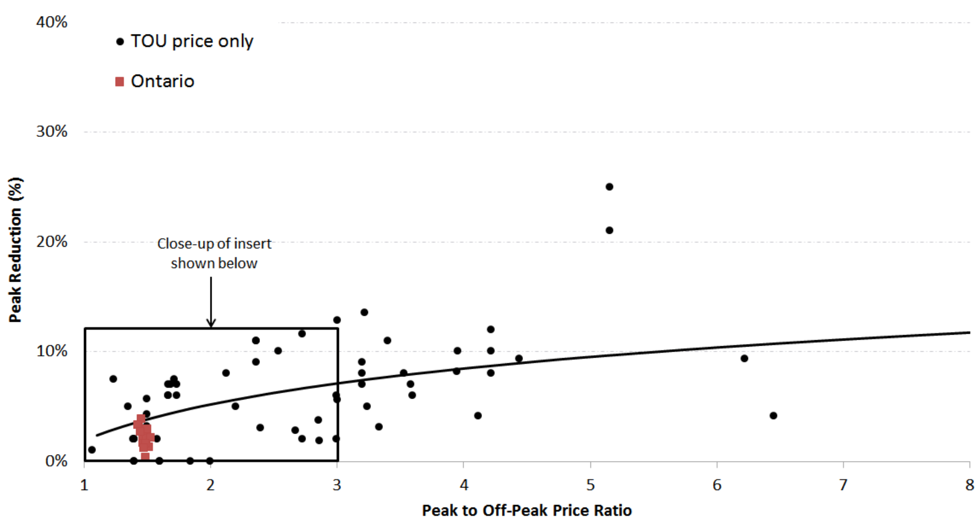


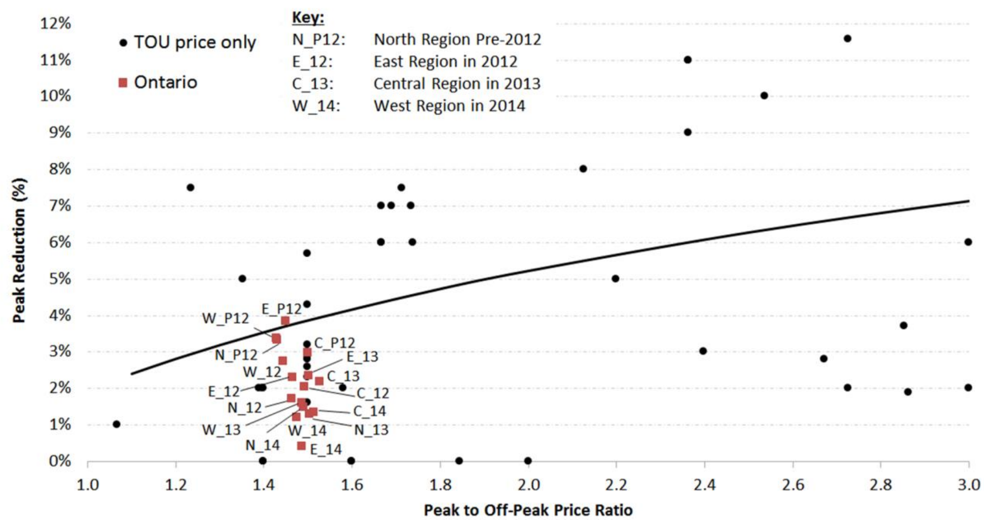
Figure 5. Province-Level Summer Load Shifting

Error! Reference source not found. and **Error! Reference source not found.** compare the Ontario residential summer TOU peak period results to results collected from 77 pilots around the world using Brattle's Arcturus database. The Ontario impacts are the only impacts reported in both figures obtained from a full scale roll-out rather than a pilot. 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% reduction in peak usage, which is slightly lower than the provincial estimate for pre-2012, but higher than the provincial estimates in 2012, 2013, and 2014. The lower bounds of the 95% confidence bound on the summer TOU peak period impacts for these years were 2.55, 2.34, and 1.53%, respectively.



Source: Faruqui, Ahmad. "Arcturus." The Brattle Group.

Figure 6. Ontario Residential TOU Summer Impacts Compared to TOU Pilots from around the World



Source: Faruqui, Ahmad. "Arcturus." The Brattle Group.

Figure 7. Close-up of Ontario Residential TOU Summer Impacts Compared to TOU Pilots from around the World

EMT Impacts

We found that Utility M customers reduced their average daily consumption by 1.73% after the activation of the smart meters and the roll-out of the EMTs. This impact is statistically significant at the 1% level.

In the light of this finding, we conjecture that the customers reduced their electricity usage in response to multiple rounds of communication from Utility M starting with the deployment of smart meters and being provided access to detailed information on their electricity use through the web portal and on monthly electricity bills. Concurrent implementation of dynamic pricing may have increased customers' awareness and the value of the available energy usage information. Customers received a variety of messages related to saving energy and tips for doing so during the time period. It is important to note that the estimated 1.73% reduction in overall electricity consumption holds after properly controlling for confounding factors such as weather conditions, economic activity, and demand side management (DSM) program participation. All of the estimated coefficients of the model have the expected signs and magnitudes.

CVR Impacts

The results of the conservation analysis show that a 1.5% reduction in voltage levels leads to a 1.4% usage reduction for residential customers. This number is statistically significant at the one percent level. The results of the peak analysis show that during the peak period of 2 pm to 7 pm on the hottest days of the summer, the residential customers have seen a reduction in their usage by 1.1%. This impact is statistically significant at the one percent level.

Ex-Ante Quasi-Experimental Design

We have used two natural features of system-wide smart meter rollouts: the phased nature of the rollout and eligibility criteria to create quasi-experimental control groups. In the examples above, this was done *ex-post* by the evaluator, however it can be improved upon if done *ex-ante* by the program designer, while planning the smart meter rollout.

Since a smart meter rollout with accompanying programs takes time both to physically install units and ramp up capacity to deal with a full scale program, differences in program start times will arise between customers. System planners, aware that M&V will be required at a later date, can exploit this timing differential with smart design. The actual implementation of this will depend on the spatial economies of scope contingent in installing smart meters and the amount of heterogeneity between residential neighborhoods. One approach would be to subdivide a service territory into a set number of blocks and randomly select treatment and control blocks. However, if there are relatively few blocks, or a particular sub-group of customers is of interest, then it would be better to match treatment and control blocks on observables.

In terms of eligibility criteria, these factors are often irrelevant to customers; for example in the CVR study, customers do not know or care on which feeder they are. Similarly customers do not choose their utility—it is just a function of where they live. Customers who live in the adjacent town may be very similar, but will be excluded from the benefits of a smart meter rollout because they use a different utility. There is limited scope to use exclusion criteria *ex-ante* more efficiently than *ex-post*. One suggestion would be to use eligibility criteria to create a phased rollout over several years, with the highest value customers from the utility's point of view receiving treatment first. This works as long as the selection criteria have to do with the utility's infrastructure rather than customer attributes. Another suggestion would be to plan strategically with adjacent service territories. For example: Utility A puts smart meters in in year 1 and then evaluates impacts in year 2, relative to Utility B. Utility B can then do the reverse in year 3 creating two sets of difference-in-differences. Additionally, having a long lead time on M&V can help facilitate time consuming processes such as exchanging data between utilities and creating geographic matched control groups.

Conclusions

We evaluate the customer load benefits of three system-wide smart meter rollouts and accompanying smart meter enabled programs, using natural features of the rollouts to create quasi-experimental control groups. In each case, the deployment of the smart meters and accompanying program was not done as an experiment, with benefits extended to all customers. This posed an analytical challenge for constructing a control group for impact evaluation purposes. We overcome these difficulties by exploiting two natural features of system-wide smart meter rollouts: the phased nature of the rollout and eligibility criteria to create quasi-experimental control groups. Finally we recommend that these quasi-experimental control groups can be improved upon if designed *ex-ante* as part of the smart meter deployment strategy, rather than *ex-post*. We find that in Ontario, TOU results in a province wide summer peak period energy reduction of 1.5% to 2.5% (depending on the year); while for our mid-sized US utility, energy management tools and CVR result in energy savings of 1.7% and 1.4% respectively.

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