A. Faruqui  
Direct Testimony  
MD P.S.C. -- April, 2016  

Introduced as:  
PEFCO ________ (AF)
My name is Ahmad Faruqui. I am a Principal with The Brattle Group. My business address is 201 Mission Street, Suite 2800, San Francisco, California 94105. I am filing testimony on behalf of the Potomac Electric Power Company (Pepco or the Company).

I have 35 years of consulting and research experience in the utility industry. During my career, I have advised some 125 electric and gas utilities, regulatory commissions, government agencies, transmission system operators, private energy companies, equipment manufacturers and IT companies. Besides the United States, my clients have been located in Australia, Canada, Chile, Egypt, Hong Kong, Jamaica, Philippines, Saudi Arabia, South Africa and Vietnam. I have advised them on a wide range of issues including rate design, load forecasting, demand response, energy efficiency, distributed energy resources, cost-benefit analysis of emerging technologies such as advanced metering infrastructure (AMI), integration of retail and wholesale markets, and integrated resource planning. I have testified or appeared before a dozen state and provincial regulatory commissions and legislative bodies. I
have authored or co-authored more than one hundred papers on energy economics and co-edited three books on electricity pricing and customer choice.

More details regarding my professional background and experience are set forth in my Statement of Qualifications, included as Schedule (AF)-1.

Q3. What are your responsibilities as a principal with the Brattle Group?

A3. I lead the firm's practice in understanding and managing the changing needs of energy consumers.

Q4. Please summarize your testimony.

A4. The first part of my testimony presents an analysis of the impact of the Energy Management Tools (EMTs) on Pepco's residential customer energy consumption. I tested the hypothesis that the customers reduced their electricity usage in response to the additional energy use information presented to them through the EMTs. Specifically, this included multiple rounds of communications from Pepco starting with the deployment of AMI meters and the availability of detailed information on their usage pattern through Pepco's My Account portal and monthly detailed electric bills. Concurrent implementation of dynamic pricing by Pepco has also contributed to an increased focus on energy usage through increased messaging related to saving energy and the awareness of tools within My Account and monthly electric bills. My analysis relied on a comprehensive data compilation effort and used robust analytical methods. I found that Pepco residential customers reduced their average electricity consumption by 1.73% in response to the activation of the AMI meters and the rollout of the EMTs. The measured impact is statistically significant at the 1% level. This impact was estimated after controlling for potential confounding factors such as...
weather conditions, changes in economic activity and customer participation in demand side management (DSM) programs.

The second part of my testimony presents an analysis of Pepco's Conservation Voltage Reduction (CVR) Program encompassing seven substations. The voltage levels were reduced by 1.5% at these substations, which included 68 feeders serving approximately 57,600 residential and non-residential customers. The program also included seven control substations to compare with the CVR substations (treatment substations). I undertook a regression analysis to compare the usage levels of treatment and control group customers to determine whether the CVR treatment resulted in statistically significant conservation and peak demand impacts. I found that CVR has led to a year-around conservation impact of 1.4% for residential customers. The availability of hourly AMI-sourced data has enabled the calculation of residential summer peak demand savings—that reduction impact is 1.1%. Both impacts are statistically significant at the 1% level. The non-residential year-around conservation impact is 0.9%; but it is not statistically significant at the conventional levels. However, this impact is an unbiased estimate of the mean impact and has a sign and magnitude which have been very consistent across different specifications. This indicates that the non-residential customers have seen a reduction in their usage due to CVR, but due to the sample size and the heterogeneity of the non-residential customers, more precise reduction estimates are not possible at this time. The non-residential peak impact is 2.5% and it is statistically significant, but beyond the expected range of a 1.5% CVR reduction. Therefore, I recommend that 0.9% be used
as the reduction estimate for both non-residential conservation and peak demand impacts at this time.

Q5. What is the purpose of your Direct Testimony in this case?

A5. The purpose of my testimony is twofold. First, I present the estimated impact of Pepco’s AMI-enabled EMTs on residential energy consumption. A copy of the EMT study report is included as Schedule (AF)-2. Second, I present the result of Pepco’s CVR Program on monthly energy consumption and on peak demand for residential and non-residential customers. A copy of the CVR study report is included as Schedule (AF)-3. Company Witness Lefkowitz has described Pepco’s EMT and CVR programs in her testimony.

Q6. Have you previously testified before the Maryland Public Service Commission (Commission) on behalf of Pepco?

A6. Yes, I have in Case No. 9207.

Q7. How is your testimony organized?

A7. My testimony is organized into three sections. The first and current section provides an overview of my background and summarizes the objective of my testimony. The second section introduces my analysis of Pepco’s EMT Program and presents the findings. The third section introduces my analysis of Pepco’s CVR Program and presents the findings.

Energy Management Tool Program Impacts

Q8. Please provide a brief description of Pepco’s EMT Program.

A8. Pepco began deploying AMI to its customers during June 2011 and the deployment was completed by year-end 2013. As it deployed and activated AMI,
Pepco also developed and deployed a portfolio of EMT that provide residential customers with information about their electricity usage and help them to make better informed choices about their electricity consumption. Pepco constructed the EMT in a variety of ways to increase the likelihood of reaching customers. Customers are provided access to the My Account web portal, which allows customers to review their hourly usage of electricity, view user-friendly charts comparing their monthly energy consumption to prior periods, projected bills, tips on energy conservation, and several other useful analytics on their electricity consumption patterns. After the activation of AMI 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.

Pepco has also created multiple information campaigns, approved by the Commission through Maillog No. 128704 and Maillog No. 147014, including the following:

- 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 available on-line and through mailed materials.
- Mass media advertising related to the availability of new Pepco tools to help consumers save energy.
Customer education related to the Peak Energy Savings Credit (PESC) Program, including energy savings tips and ideas for reducing energy during the summer.

- Community meetings and events that involved presentations.
- Individual customer service representative discussions and demonstrations of My Account.
- Customer education handouts.
- News coverage including Pepco press releases, articles and TV coverage of AMI activation and other energy management tools enabled by AMI.

Company Witness Lefkowitz's testimony contains additional details regarding Pepco's AMI-enabled EMT initiative.

Each customer had its own unique AMI activation date that marks the beginning of information flow from Pepco to customers which would help each customer to make better-informed electricity consumption choices.

Q9. Please summarize the modeling process you used for estimating the impact of EMT on residential energy consumption.

A9. Besides EMT, several factors influence residential electricity usage, including individual customer lifestyles, the state of the economy, weather, time, and Pepco DSM programs. The process I used for estimating the effect of EMT (called the "treatment" in the literature on impact evaluation) was to net out the effect of these other factors on electricity consumption and attributing the remaining change to the treatment.
It is theoretically possible that besides the factors listed above, there are other variables which influence energy consumption. But there is no data on those factors. I call them unobservable factors. To isolate the effect of these unobservable factors, I include a control group of customers drawn from an adjacent service territory described below. This allows me to build a difference-in-differences (DiD) model, where the change in the control group’s monthly usage over time is netted from the change in the treatment group’s monthly usage over time, to derive a net estimate of the treatment impact. Such a data set, which consists of treatment and control customers whose usage is measured over time, is called a panel data set.

I use the following regression equation to estimate the EMT impact:

\[
\ln(kWh_{it}) = \beta_0 + \beta_1 \cdot \ln \text{Employment}_t + \beta_2 \cdot \text{Time Trend}_t + \beta_3 \\
* \text{EMT Impact}_{it} + \sum_{m=1}^{12} (\beta_{4m} \cdot \text{D Month}_t + \beta_{5m} \cdot \text{D Month}_t \cdot \text{THI}_it) \\
+ \sum_{k=1}^{K} \beta_{6k} \cdot \text{DSM}_{kt} + \beta_7 \cdot \text{DLC}_{it} + \beta_8 \cdot \text{CVR}_{it} + \epsilon_{it}
\]

Where:

- \(kWh_{it}\) : Average daily consumption for household \(i\) in month-year \(t\)
- \(\ln \text{Employment}_t\) : Logarithm of total non-farm employment
- \(\text{Time Trend}_t\) : Monthly trend variable
- \(\text{EMT Impact}_{it}\) : Indicator that the customer has access to the EMTs
- \(\text{D Month}_t\) : Month specific impact common to all households
- \(\text{D Month}_t \cdot \text{THI}_it\) : Month specific impact of the Temperature Humidity Index
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1. $DSM_{it}$: Flag indicating that a customer is participating in a DSM program

2. $DLC_{it}$: Flag indicating that the customer is part of the utility's summer DLC program

3. $CVR_{it}$: Flag indicating that the customer is on a feeder that is receiving CVR

4. $\epsilon_{it}$: Independently and identically distributed error term, clustered by household

This regression model is estimated using the Fixed Effects (FE) estimation routine, which allows each customer's unique energy lifestyle effect to be accounted for in the model, while still supporting the derivation of an unbiased estimate of the impact of EMTs on the average customer.

Q10. How did you select the control group?

A10. I used Pepco's affiliated Maryland utility, Delmarva Power & Light Company's (Delmarva Power) Maryland customers as the control group, prior to their receiving AMI-enabled EMT treatment in 2014. I compared the usage patterns of Delmarva Power Maryland customers and Pepco Maryland customers during the time period of January 2010 through September 2014 and found that they are quite similar. Once EMTs became available to Delmarva Power Maryland customers, I removed their data from the study dataset. This began to happen in January 2014, but roughly 32% of customers still had not received EMT treatment by September 2014.

Figure 1 illustrates the average daily consumption by Pepco and Delmarva Power Maryland residential customers.
Q11. Please summarize the data you used in estimating your econometric model.

A11. The base dataset I used to estimate the econometric model was customer billing data for all residential customers in Pepco. The data spans almost five years from January 2010 through September 2014. I mapped bills to months to create a panel dataset, where the individual customer was the “cross-sectional” aspect of the dataset and the month was the time element of the dataset. I also received weather data, employment data, and data on utility program flags which I processed and merged-in to the master dataset. The utility programs I received data for were participation in direct load control, participation in EmPOWER Maryland energy efficiency programs, and participation in Pepco’s first phase of CVR deployment.

I also received data on customers who participated in the initial Opower Home Energy Report Program (an EmPOWER Maryland funded program) and also on net energy metering (NEM) customers. Because the objective of my analysis is to isolate the impact of EMT on customers’ electricity usage, customers receiving the Opower
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reports were excluded from the dataset, since they have already been provided separate comparative information reports on their energy usage before the roll-out of the EMT. Similarly, NEM customers were also excluded from the dataset as their energy consumption behavior is potentially different from that of an average customer. Observations that contained data anomalies were also excluded from the analysis. The final dataset comprised roughly 433,000 treatment customers and contained 18.5 million energy consumption observations.

Q12. **What is the outcome of your econometric analysis?**

A12. My analysis finds that Pepco customers have reduced their average daily consumption by 1.73% after the activation of the AMI meters and the roll-out of the EMTs. This impact is statistically significant at the 1% level.

This reduction in usage can be attributed to the different ways Pepco informed its customers about their energy usage. This included the multiple rounds of communication from Pepco about the deployment of AMI meters, providing access to detailed information on their electricity use through My Account and on monthly electricity bills. Concurrent implementation of dynamic pricing may have also increased customers' awareness and 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 is derived after controlling for the effect of observable variables such as weather conditions, economic activity, and DSM program participation, as well as controlling for the effect of unobservable variables by including the control group.
All of the estimated coefficients of the model have the expected signs and magnitudes.

**Conservation Voltage Reduction Program Impacts**

Q13. Please provide an overview of conservation voltage reduction.

A13. The key engineering principle of the CVR operation is that many types of electrical equipment operate more efficiently in the lower half of their designed operating voltage range than in the upper half. Therefore, if the voltage along the distribution feeder is reduced but maintained above the minimum voltage ranges specified by the Code of Maryland Regulations (COMAR) 20.50.07.02., this voltage reduction has the potential to produce considerable energy savings at low cost with no actions required by customers. Field research and engineering studies have shown that the reduction in distribution service voltage yields energy savings from residential and commercial loads. Note that there is a variation in the results due to end-use mix, weather conditions, and distribution system configuration. The availability of voltage data through Pepco’s recently installed AMI System has enabled Pepco to implement CVR and to monitor customer voltage levels to verify that voltage levels remain within the COMAR standards.

Q14. Please provide an overview of Pepco’s CVR program.

A14. Pepco initiated its CVR Program during August 2013. The voltage levels were reduced by 1.5% (treatment) at seven substations. At the same time, another seven substations which were judged to be similar based on engineering and load research characteristics were selected to serve as a control group for comparative purposes without CVR. Because CVR was implemented at the substation level, all customers on substations, both residential and non-residential, received CVR
treatment. Please refer to Company Witness Lefkowitz’s Testimony for additional information regarding the CVR Program.

Q15. Have previous studies indicated an expected level of reduction due to CVR?

A15. Several engineering studies have demonstrated that the implementation of CVR leads to decreased consumption at the customer meter, but there is no consensus on a “CVR Factor,” which is the quantity of energy that is reduced for a specific reduction in voltage. Prior studies have indicated a relatively wide range of potential CVR factors, varying from 0.5 to slightly over 1.

Q16. Please explain your methodology.

A16. I used a DiD analysis through a panel data regression approach to estimate the impact of CVR on energy conservation and peak demand. The DiD analysis compares the usage of the treatment and control group customers before and after the CVR treatment, while accounting for other factors that could potentially confound the estimated impact such as weather conditions, DSM program participation, AMI activation, and calendar time. Analytically, this approach is very similar to the approach I used for estimating the impact of EMT.

For the DiD approach to be accurate, the treatment and control groups must be generally similar. The roll-out of CVR did not follow a formal randomized control trial (RCT) protocol. This means that the customers in the treatment and control groups are not randomized, but that they are assigned ex post, through pairing treatment substations with control substations. The DiD approach isolates the true impact of the treatment by netting the differences in the treatment and control group load profiles before and after the treatment period.
The DiD analysis was conducted through a panel data regression approach to account for other factors that could potentially confound the estimated CVR impact. The most important factor to account for in this regression is the impact of weather conditions on the electricity usage of the customers. If there is a usage reduction in the treatment period, it is important to ensure that the reduction is not due to milder weather conditions (resulting in less air conditioning or electric heating load), before attributing this reduction to the CVR implementation. This analysis used a temperature humidity index (THI) which combines dew point and dry bulb temperatures into one variable. Customer participation and enrollment in utility demand-side management programs was accounted for, as the participants of these programs reduce their electricity usage after the installation/implementation of DSM measures. As in the EMT regressions, the panel data regressions used the Fixed Effects (FE) estimation routine to ensure that the estimated coefficients from the resulting model were unbiased.

The impact of CVR may vary between residential and non-residential customers, for both peak hours and conservation savings. Residential and non-residential customers have different types of consumption. For example, non-residential customers may be more likely to have motor load, which may respond differently the CVR.

With respect to a CVR impact during peak hours versus a conservation impact, peak hours may have more compressor load due to increased usage of air conditioning. Similar to how motor load may respond differently the CVR than other load, compressor load may also respond differently to CVR.
Because of the potential for different ways that residential, non-residential, peak and all-hours load may respond to CVR, my analysis is broken down between peak and all other hours. Furthermore, within the peak and conservation analyses, residential and non-residential customers are analyzed separately.

Q17. Please explain your specific methodology for the energy conservation analysis.

A17. To estimate the energy conservation impact of CVR, I used monthly billing data. This is because hourly data were only available for three months prior to CVR treatment. To understand the true conservation impact, it is important to have multiple seasons of pre-treatment data.

The final regression equation used for the energy conservation analysis is as follows:

\[
\ln(\text{kWh}_{it}) = \beta_0 + \beta_1 \times \text{TreatPeriod}_{it} + \beta_2 \times \text{CVR}_{it} + \beta_3 \times \text{THI}_{it} + \beta_4 \times \text{AMI}_{it} \\
+ \sum_{m=1}^{12} (\beta_{4m} \times \text{monthm}_{it} + \beta_{5m} \times \text{monthm}_{it} \times \text{THI}_{it}) + \beta_6 \times \text{DSM}_{it} + \nu_i + \epsilon_{it}
\]

Where:

- \(\ln(\text{kWh}_{it})\) is the natural logarithm of average daily consumption for household \(i\) in month \(t\).
- \(\text{TreatPeriod}_{it}\) is a flag indicating that the start of the CVR treatment period.
- \(\text{CVR}_{it}\) is a flag indicating that the customer has received the CVR treatment.
- \(\text{THI}_{it}\) is the impact of the Temperature Humidity Index on usage.
- \(\text{AMI}_{it}\) is a flag indicating that a customer’s AMI meter has been activated.
- \(\text{monthm}_{it}\) is the month-specific impact common to all households.
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1 \[ monthm_t \times THI_{1t} \] Month specific impact of the Temperature Humidity Index

2 \[ DSM_{it} \] Indicator that a customer is participating in DSM program

3 \[ \nu_i \] Customer fixed effect

4 Q18. Please explain your specific methodology for estimating the impact of CVR on peak demand.

A18. To estimate the peak demand impact, I used hourly AMI data. I am able to use hourly data for the peak demand analysis because the Pepco system peaks during the summer and AMI data for the pre-treatment period were available for the summer months.

As the system peak happens when temperature and humidity are high, in the peak demand analysis I used only the hottest days of the summer, which were defined in this analysis as being days where the average (THI) between 2 pm and 7 pm was greater than 77, which equates to about 85 degrees Fahrenheit, depending upon humidity levels. A THI cutoff of 77 creates a balance between including only very hot days, while still establishing sufficient days for a robust analysis. The THI cutoff of 77 resulted in 78 weekdays and 29 weekend days available to use for analysis. The hours of 2 pm to 7 pm were used to be consistent with PJM’s capacity market peak definition during the summer. I created models for weekdays, weekends, and all days to investigate if there was a difference in impact due to the characteristics of weekends vs. weekdays.
The final regression equation used for the peak demand analysis is as follows:

$$\ln(kWh_{it}) = \beta_0 + \beta_1 * TreatPeriod_i + \beta_2 * CVR_{it} + \beta_3 * THI_{t}$$

$$+ \sum_{m=6}^{10} (\beta_{4m} * monthm_t + \beta_{5m} * monthm_t * THI_{t})$$

$$+ \beta_6 * DSM_{it} + \beta_6 * v_i + \varepsilon_{it}$$

Where:

1. $\ln(kWh_{it})$: Natural logarithm of average hourly consumption for household $i$ in day $t$
2. $TreatPeriod$: Flag indicating the start of the treatment period
3. $CVR_{it}$: Flag indicating that the customer has received the CVR treatment
4. $THI_{t}$: Impact of Temperature Humidity Index on usage
5. $monthm_t$: Month specific impact common to all households
6. $monthm_t * thi_{it}$: Month specific impact of the Temperature Humidity Index
7. $DSM_{it}$: Indicator that a customer is participating in DSM program
8. $v_i$: Customer fixed effect
9. $\varepsilon_{it}$: Independently and identically distributed error term, clustered by household

Q19. What data did you use for your econometric analysis?

A19. The study required a comprehensive data compilation effort. While the datasets for the conservation and peak demand analyses differ in structure, they are still built with similar building blocks. For all customers, I compiled billing data,
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hourly consumption data, weather data (dew point and dry bulb temperatures), AMI meter activation date, participation in DSM programs, Opower participation, and NEM status.

For the conservation analysis, the master dataset I created was based on monthly billing data from September 2012 through August 2014. One full year of pre-treatment period data (September 2012 – August 2013) and one full year of post-treatment data (September 2013 – August 2014) were used for this analysis. For the peak demand analysis, the master dataset included hourly AMI data for hours-ending 15-19 (June – August). Since the peak demand impact estimation relates to the summer months, three months of pre-treatment data (June - August 2013) and three months of post-treatment data (June – August 2014) were used. Table 1 summarizes the impacts estimated and time periods used in the study.

Table 1: CVR Impacts Estimated and Time Periods Used in the Analysis

<table>
<thead>
<tr>
<th>Impact</th>
<th>Dataset</th>
<th>Analysis Variable</th>
<th>Pre-treatment Period (*)</th>
<th>Post-treatment Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Impact</td>
<td>Hourly AMI Dataset</td>
<td>Hourly Usage (HE 15-19) on days with average peak THI&gt;77</td>
<td>June - August 2013</td>
<td>June - August 2014</td>
</tr>
</tbody>
</table>

(*) August 2013 is partially a pre-treatment month.

Because the objective of this analysis was to isolate the impact of CVR on customer electricity usage, similar to the EMT analysis, customers receiving the Opower Home Energy Reports were excluded from the dataset. Similarly, customers with NEM status were also excluded from the dataset. (Load from NEM customers was excluded from the analysis because of its load masking effect.)
A small number of observations that contained data anomalies were also excluded from the dataset. The final datasets are comprised of roughly 94,000 residential customers and 8,700 non-residential customers.

Q20. **How did you select the control group?**

A20. To select the control group, I relied on the expertise of Pepco’s engineering and load research teams. This became necessary because Pepco’s CVR program was not designed as a randomized control trial. This implies that the customers in the treatment and control groups have not been randomly assigned to their respective groups; rather Pepco 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, and vintages. Moreover, since all the treatment and control substations are in the Pepco service territory, many factors which may affect consumption, such as rates and economic factors, are similar between treatment and control substations.

I determined that the residential treatment and control group load profiles are very similar to each other in terms of their shape and levels. This implies that the residential control group customers represent the “but-for” usage of the residential treatment customers (in the absence of the CVR treatment) well.

For the non-residential customer load profiles, I determined that they are very similar to each other in terms of their shape but they differ somewhat in terms of the level of usage between the treatment and control groups. Treatment customers are
slightly larger than the control group customers, on average. This difference does not introduce a bias in the impact estimates as it is accounted for by the fixed effects estimation routine.

Q21. What is the estimated impact of CVR on energy conservation?

A21. I find that a 1.5% reduction in voltage levels due to CVR implementation results in a 1.4% usage reduction for residential customers. This number is statistically significant at the 1% level. This implies a CVR factor of 0.93 (1.4% divided by 1.5%), which is in the range suggested by previous studies. For the non-residential customers, the CVR conservation impact was estimated to be 0.9%, resulting in a CVR factor of 0.6 (0.9% divided by 1.5%), but this impact is not statistically significant at conventional levels. However, the measured non-residential impact is still an unbiased estimate of the mean impact and has a sign and magnitude which are robust across different model specifications. Additionally, this estimate is within the lower range of estimates of prior studies. This indicates that the non-residential customers have seen a reduction in their usage due to CVR, but due to the sample size and the heterogeneity of the non-residential customers, a more precise reduction estimate is not possible at this time.

Q22. What is the estimated impact of CVR on peak demand?

A22. The results of the peak demand 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 1% level and implies a residential peak demand CVR factor of 0.73 (1.1% divided by 1.5%), which is in the range suggested by previous studies.
Identifying the non-residential peak demand impact has been more challenging due to the small sample size and the heterogeneity of the non-residential customers. A non-residential peak demand impact of 2.5% was found after the CVR implementation. While this impact is statistically significant, it is beyond the expected range of a 1.5% CVR reduction. This implies that there are other unobservable effects which are at work for non-residential customers, which are not captured in the analysis. Therefore, I recommend that 0.9% be used as the reduction estimate for both non-residential conservation and peak demand at this time. This implies a non-residential peak demand CVR factor of 0.6 (0.9% divided by 1.5%), which is in the range suggested by previous studies.

Q23. Are the CVR and EMT impacts that you have estimated likely to persist in the future?

A23. CVR savings are likely to persist because they are the direct result of the reduced voltage level. EMT savings are likely to persist if Pepco continues with the EMTs and refreshes them so that customers stay engaged with their energy use patterns by taking advantage of new innovations in behavioral economics and digital technologies.

Q24. Does this conclude your Direct Testimony?

A24. Yes, it does.
Dr. Ahmad Faruqui leads a consulting practice focused on understanding and managing the way customers use energy. His clients include utilities, commissions, equipment manufacturers, technology developers, and energy service companies. The practice encompasses a wide range of activities:

- **Rate design.** The recent decline in electricity sales has generated an entire crop of new issues that utilities must address in order to remain profitable. A key issue is the under-recovery of fixed costs and the creation of unsustainable cross-subsidies. To address these issues, we are creating alternative rate designs, testing their impact on customer bills, and sponsoring testimony to have them implemented. We are currently undertaking a large-scale project for a large investor-owned utility to estimate marginal costs, design rates, and produce a related software tool, working in close coordination with their internal executives. We have created a Pricing Roundtable which serves as virtual think tank on addressing the risks of under-recovery in the face of declining growth. About 18 utilities are a part of the think tank.

- **Demand forecasting.** We help utilities to identify the reasons for the slowdown in sales growth, which include utility energy efficiency programs, governmental codes and standards, distributed general, and fuel switching brought on by falling natural gas prices and the weak economic recovery. We present widely on the issue and are researching new methods for forecasting peak demand, such as the use of quantile regression.

- **Demand response.** For several clients in the United States and Canada, we are studying the impact of dynamic pricing. We have completed similar studies for a utility in the Asia-Pacific region and a regulatory body in the Middle East. We also conduct program design studies, impact evaluation studies, and cost-benefit analysis, and design marketing programs to maximize customer enrollment. Clients include utilities, regulators, demand response providers, and technology firms.

- **Energy efficiency.** We are studying the potential role of combined heat and power in enhancing energy efficiency in large commercial and industrial facilities. We are also carrying out analyses of behavioral programs that use social norming to induce change in the usage patterns of households.

- **New product design and cost-benefit analysis of emerging customer-side technologies.** We analyze market opportunities, costs, and benefits for advanced digital meters and associated infrastructure, smart thermostats, in-home displays, and other devices. This includes product design, such as proof-of-concept assessment, and a comparison of the costs and benefits of these new technologies from several vantage points: owners of that technology, other electricity customers, the utility or retail energy provider, and society as a whole.
In each of these areas, the engagements encompass both quantitative and qualitative analysis. Dr. Faruqui’s reports, and derivative papers and presentations, are often widely cited in the media. The Brattle Group often sponsors testimony in regulatory proceedings and Dr. Faruqui has testified or appeared before a dozen state and provincial commissions and legislative bodies in the United States and Canada.

Dr. Faruqui’s survey of the early experiments with time-of-use pricing in the United States is referenced in Professor Bonbright’s treatise on public utilities. He managed the integration of results across the top five of these experiments in what was the first meta-analysis involving innovative pricing. Two of his dynamic experiments have won professional awards, and he was named one of the world’s Top 100 experts on the smart grid by Greentech Media.

He has consulted with more than 50 utilities and transmission system operators around the globe and testified or appeared before a dozen state and provincial commissions and legislative bodies in the United States and Canada. He has also advised the Alberta Utilities Commission, the Edison Electric Institute, the Electric Power Research Institute, FERC, the Institute for Electric Efficiency, the Ontario Energy Board, the Saudi Electricity and Co-Generation Regulatory Authority, and the World Bank. His work has been cited in publications such as The Economist, The New York Times, and USA Today and he has appeared on Fox News and National Public Radio.

Dr. Faruqui is the author, co-author or editor of four books and more than 150 articles, papers, and reports on efficient energy use, some of which are featured on the websites of the Harvard Electricity Policy Group and the Social Science Research Network. He has taught economics at San Jose State University, the University of California at Davis and the University of Karachi. He holds a an M.A. in agricultural economics and a Ph. D. in economics from The University of California at Davis, where he was a Regents Fellow, and B.A. and M.A. degrees in economics from The University of Karachi, where he was awarded the Gold Medal in economics.

AREAS OF EXPERTISE

- **Innovative pricing.** He has identified, designed and analyzed the efficiency and equity benefits of introducing innovative pricing designs such as three-part rates, including fixed monthly charges, demand charges and time-varying energy charges; dynamic pricing rates, including critical peak pricing, variable peak pricing and real-time pricing; time-of-use pricing; and inclining block rates.

- **Regulatory strategy.** He has helped design forward-looking programs and services that exploit recent advances in rate design and digital technologies in order to lower customer bills and improve utility earnings while lowering the carbon footprint and preserving system reliability.
Cost-benefit analysis of advanced metering infrastructure. He has assessed the feasibility of introducing smart meters and other devices, such as programmable communicating thermostats that promote demand response, into the energy marketplace, in addition to new appliances, buildings, and industrial processes that improve energy efficiency.

Demand forecasting and weather normalization. He has pioneered the use of a wide variety of models for forecasting product demand in the near-, medium-, and long-term, using econometric, time series, and engineering methods. These models have been used to bid into energy procurement auctions, plan capacity additions, design customer-side programs, and weather normalize sales.

Customer choice. He has developed methods for surveying customers in order to elicit their preferences for alternative energy products and alternative energy suppliers. These methods have been used to predict the market size of these products and to estimate the market share of specific suppliers.

Hedging, risk management, and market design. He has helped design a wide range of financial products that help customers and utilities cope with the unique opportunities and challenges posed by a competitive market for electricity. He conducted a widely-cited market simulation to show that real-time pricing of electricity could have saved Californians millions of dollars during the Energy Crisis by lowering peak demands and prices in the wholesale market.

Competitive strategy. He has helped clients develop and implement competitive marketing strategies by drawing on his knowledge of the energy needs of end-use customers, their values and decision-making practices, and their competitive options. He has helped companies reshape and transform their marketing organization and reposition themselves for a competitive marketplace. He has also helped government-owned entities in the developing world prepare for privatization by benchmarking their planning, retailing, and distribution processes against industry best practices, and suggesting improvements by specifying quantitative metrics and follow-up procedures.

Design and evaluation of marketing programs. He has helped generate ideas for new products and services, identified successful design characteristics through
customer surveys and focus groups, and test marketed new concepts through pilots and experiments.

- **Expert witness.** He has testified or appeared before state commissions in Arkansas, California, Colorado, Connecticut, Delaware, the District of Columbia, Illinois, Indiana, Iowa, Kansas, Michigan, Maryland, Ontario (Canada) and Pennsylvania. He has assisted clients in submitting testimony in Georgia and Minnesota. He has made presentations to the California Energy Commission, the California Senate, the Congressional Office of Technology Assessment, the Kentucky Commission, the Minnesota Department of Commerce, the Minnesota Senate, the Missouri Public Service Commission, and the Electricity Pricing Collaborative in the state of Washington. In addition, he has led a variety of professional seminars and workshops on public utility economics around the world and taught economics at the university level.

**EXPERIENCE**

**Innovative Pricing**

- **Report examining the costs and benefits of dynamic pricing in the Australian energy market.** For the Australian Energy Market Commission (AEMC), developed a report that reviews the various forms of dynamic pricing, such as time-of-use pricing, critical peak pricing, peak time rebates, and real time pricing, for a variety of performance metrics including economic efficiency, equity, bill risk, revenue risk, and risk to vulnerable customers. It also discusses ways in which dynamic pricing can be rolled out in Australia to raise load factors and lower average energy costs for all consumers without harming vulnerable consumers, such as those with low incomes or medical conditions requiring the use of electricity.

- **Whitepaper on emerging issues in innovative pricing.** For the Regulatory Assistance Project (RAP), developed a whitepaper on emerging issues and best practices in innovative rate design and deployment. The paper includes an overview of AMI-enabled electricity pricing options, recommendations for
designing the rates and conducting experimental pilots, an overview of recent pilots, full-deployment case studies, and a blueprint for rolling out innovative rate designs. The paper's audience is international regulators in regions that are exploring the potential benefits of smart metering and innovative pricing.

- **Assessing the full benefits of real-time pricing.** For two large Midwestern utilities, assessed and, where possible, quantified the potential benefits of the existing residential real-time pricing (RTP) rate offering. The analysis included not only “conventional” benefits such as avoided resource costs, but under the direction of the state regulator was expanded to include harder-to-quantify benefits such as improvements to national security and customer service.

- **Pricing and Technology Pilot Design and Impact Evaluation for Connecticut Light & Power (CL&P).** Designed the Plan-It Wise Energy pilot for all classes of customers and subsequently evaluated the Plan-It Wise Energy program (PWEP) in the summer of 2009. PWEP tested the impacts of CPP, PTR, and time of use (TOU) rates on the consumption behaviors of residential and small commercial and industrial customers.

- **Dynamic Pricing Pilot Design and Impact Evaluation: Baltimore Gas & Electric.** Designed and evaluated the Smart Energy Pricing (SEP) pilot, which ran for four years from 2008 to 2011. The pilot tested a variety of rate designs including critical peak pricing and peak time rebates on residential customer consumption patterns. In addition, the pilot tested the impacts of smart thermostats and the Energy Orb.

- **Impact Evaluation of a Residential Dynamic Pricing Experiment: Consumers Energy (Michigan).** Designed the pilot and carried out an impact evaluation with the purpose of measuring the impact of critical peak pricing (CPP) and peak time rebates (PTR) on residential customer consumption patterns. The pilot also tested the influence of switches that remotely adjust the duty cycle of central air conditioners.

- **Impact Simulation of Ameren Illinois Utilities’ Power Smart Pricing Program.** Simulated the potential demand response of residential customers enrolled to real-time prices. Results of this simulation were presented to the Midwest ISO’s Supply Adequacy Working Group (SAWG) to explore alternative ways of
introducing price responsive demand in the region.

- **The Case for Dynamic Pricing: Demand Response Research Center.** Led a project involving the California Public Utilities Commission, the California Energy Commission, the state’s three investor-owned utilities, and other stakeholders in the rate design process. Identified key issues and barriers associated with the development of time-based rates. Revisited the fundamental objectives of rate design, including efficiency and equity, with a special emphasis on meeting the state’s strongly-articulated needs for demand response and energy efficiency. Developed a score-card for evaluating competing rate designs and applied it to a set of illustrative rates that were created for four customer classes using actual utility data. The work was reviewed by a national peer-review panel.

- **Developed a Customer Price Response Model: Consolidated Edison.** Specified, estimated, tested, and validated a large-scale model that analyzes the response of some 2,000 large commercial customers to rising steam prices. The model includes a module for analyzing conservation behavior, another module for forecasting fuel switching behavior, and a module for forecasting sales and peak demand.

- **Design and Impact Evaluation of the Statewide Pricing Pilot: Three California Utilities.** Working with a consortium of California’s three investor-owned utilities to design a statewide pricing pilot to test the efficacy of dynamic pricing options for mass-market customers. The pilot was designed using scientific principles of experimental design and measured changes in usage induced by dynamic pricing for over 2,500 residential and small commercial and industrial customers. The impact evaluation was carried out using state-of-the-art econometric models. Information from the pilot was used by all three utilities in their business cases for advanced metering infrastructure (AMI). The project was conducted through a public process involving the state’s two regulatory commissions, the power agency, and several other parties.

- **Economics of Dynamic Pricing: Two California Utilities.** Reviewed a wide range of dynamic pricing options for mass-market customers. Conducted an initial cost-effectiveness analysis and updated the analysis with new estimates of avoided costs and results from a survey of customers that yielded estimates of likely participation rates.
• **Economics of Time-of-Use Pricing:** A Pacific Northwest Utility. This utility ran the nation's largest time-of-use pricing pilot program. Assessed the cost-effectiveness of alternative pricing options from a variety of different perspectives. Options included a standard three-part time-of-use rate and a quasi-real time variant where the prices vary by day. Worked with the client in developing a regulatory strategy. Worked later with a collaborative to analyze the program's economics under a variety of scenarios of the market environment.

• **Economics of Dynamic Pricing Options for Mass Market Customers** - Client: A Multi-State Utility. Identified a variety of pricing options suited to meet the needs of mass-market customers, and assessed their cost-effectiveness. Options included standard three-part time-of-use rates, critical peak pricing, and extreme-day pricing. Developed plans for implementing a pilot program to obtain primary data on customer acceptance and load shifting potential. Worked with the client in developing a regulatory strategy.

• **Real-Time Pricing in California** - Client: California Energy Commission. Surveyed the national experience with real-time pricing of electricity, directed at large power customers. Identified lessons learned and reviewed the reasons why California was unable to implement real-time pricing. Catalogued the barriers to implementing real-time pricing in California, and developed a program of research for mitigating the impacts of these barriers.

• **Market-Based Pricing of Electricity** - Client: A Large Southern Utility. Reviewed pricing methodologies in a variety of competitive industries including airlines, beverages, and automobiles. Recommended a path that could be used to transition from a regulated utility environment to an open market environment featuring customer choice in both wholesale and retail markets. Held a series of seminars for senior management and their staffs on the new methodologies.

• **Tools for Electricity Pricing** - Client: Consortium of Several U.S. and Foreign Utilities. Developed Product Mix, a software package that uses modern finance theory and econometrics to establish a profit-maximizing menu of pricing products. The products range from the traditional fixed-price product to time-of-use prices to hourly real-time prices, and also include products that can hedge customers' risks based on financial derivatives. Outputs include market share,
gross revenues, and profits by product and provider. The calculations are performed using probabilistic simulation, and results are provided as means and standard deviations. Additional results include delta and gamma parameters that can be used for corporate risk management. The software relies on a database of customer load response to various pricing options called StatsBank. This database was created by metering the hourly loads of about one thousand commercial and industrial customers in the United States and the United Kingdom.

- **Risk-Based Pricing - Client: Midwestern Utility.** Developed and tested new pricing products for this utility that allowed it to offer risk management services to its customers. One of the products dealt with weather risk; another one dealt with risk that real-time prices might peak on a day when the customer does not find it economically viable to cut back operations.

### Demand Response

- **National Action Plan for Demand Response: Federal Energy Regulatory Commission.** Led a consulting team developing a national action plan for demand response (DR). The national action plan outlined the steps that need to be taken in order to maximize the amount of cost-effective DR that can be implemented. The final document was filed with U.S. Congress in June 2010.

- **National Assessment of Demand Response Potential: Federal Energy Regulatory Commission.** Led a team of consultants to assess the economic and achievable potential for demand response programs on a state-by-state basis. The assessment was filed with the U.S. Congress in 2009, as required by the Energy Independence and Security Act of 2007.

- **Evaluation of the Demand Response Benefits of Advanced Metering Infrastructure: Mid-Atlantic Utility.** Conducted a comprehensive assessment of the benefits of advanced metering infrastructure (AMI) by developing dynamic pricing rates that are enabled by AMI. The analysis focused on customers in the residential class and commercial and industrial customers
under 600 kW load.

- **Estimation of Demand Response Impacts: Major California Utility.** Worked with the staff of this electric utility in designing dynamic pricing options for residential and small commercial and industrial customers. These options were designed to promote demand response during critical peak days. The analysis supported the utility’s advanced metering infrastructure (AMI) filing with the California Public Utilities Commission. Subsequently, the commission unanimously approved a $1.7 billion plan for rolling out nine million electric and gas meters based in part on this project work.

### Smart Grid Strategy

- **Development of a smart grid investment roadmap for Vietnamese utilities.** For the five Vietnamese power corporations, developed a roadmap to guide future smart grid investment decisions. The report identified and described the various smart grid investment options, established objectives for smart grid deployment, presented a multi-phase approach to deploying the smart grid, and provided preliminary recommendations regarding the best investment opportunities. Also presented relevant case studies and an assessment of the current state of the Vietnamese power grid. The project involved in-country meetings as well as a stakeholder workshop that was conducted by Brattle staff.

- **Cost-Benefit Analysis of the Smart Grid: Rocky Mountain Utility.** Reviewed the leading studies on the economics of the smart grid and used the findings to assess the likely cost-effectiveness of deploying the smart grid in one geographical location.

- **Modeling benefits of smart grid deployment strategies.** Developed a model for assessing benefits of smart grid deployment strategies over a long-term (e.g., 20-year) forecast horizon. The model, called iGrid, is used to evaluate seven distinct smart grid programs and technologies (e.g., dynamic pricing, energy storage, PHEVs) against seven key metrics of value (e.g., avoided resource costs, improved reliability).

- **Smart grid strategy in Canada.** The Alberta Utilities Commission (AUC) was
charged with responding to a Smart Grid Inquiry issued by the provincial government. Advised the AUC on the smart grid, and what impacts it might have in Alberta.

- Smart grid deployment analysis for collaborative of utilities. Adapted the iGrid modeling tool to meet the needs of a collaborative of utilities in the southern U.S. In addition to quantifying the benefits of smart grid programs and technologies (e.g., advanced metering infrastructure deployment and direct load control), the model was used to estimate the costs of installing and implementing each of the smart grid programs and technologies.

- Development of a smart grid cost-benefit analysis framework. For the Electric Power Research Institute (EPRI) and the U.S. DOE, contributed to the development of an approach for assessing the costs and benefits of the DOE's smart grid demonstration programs.

- Analysis of the benefits of increased access to energy consumption information. For a large technology firm, assessed market opportunities for providing customers with increased access to real time information regarding their energy consumption patterns. The analysis includes an assessment of deployments of information display technologies and analysis of the potential benefits that are created by deploying these technologies.

- Developing a plan for integrated smart grid systems. For a large California utility, helped to develop applications for funding for a project to demonstrate how an integrated smart grid system (including customer-facing technologies) would operate and provide benefits.

**Demand Forecasting**

- Comprehensive Review of Load Forecasting Methodology: PJM Interconnection. Conducted a comprehensive review of models for forecasting peak demand and re-estimated new models to validate recommendations. Individual models were developed for 18 transmission zones as well as a model for the RTO system.
• Analyzed Downward Trend: Western Utility. We conducted a strategic review of why sales had been lower than forecast in a year when economic activity had been brisk. We developed a forecasting model for identifying what had caused the drop in sales and its results were used in an executive presentation to the utility's board of directors. We also developed a time series model for more accurately forecasting sales in the near term and this model is now being used for revenue forecasting and budgetary planning.

• Analyzed Why Models are Under-Forecasting: Southwestern Utility. Reviewed the entire suite of load forecasting models, including models for forecasting aggregate system peak demand, electricity consumption per customer by sector and the number of customers by sector. We ran a variety of forecasting experiments to assess both the ex-ante and ex-post accuracy of the models and made several recommendations to senior management.

• U.S. Demand Forecast: Edison Electric Institute. For the U.S. as a whole, we developed a base case forecast and several alternative case forecasts of electric energy consumption by end use and sector. We subsequently developed forecasts that were based on EPRI's system of end-use forecasting models. The project was done in close coordination with several utilities and some of the results were published in book form.

• Developed Models for Forecasting Hourly Loads: Merchant Generation and Trading Company. Using primary data on customer loads, weather conditions, and economic activity, developed models for forecasting hourly loads for residential, commercial, and industrial customers for three utilities in a Midwestern state. The information was used to develop bids into an auction for supplying basic generation services.

• Gas Demand Forecasting System - Client: A Leading Gas Marketing and Trading Company, Texas. Developed a system for gas nominations for a leading gas marketing company that operated in 23 local distribution company service areas. The system made week-ahead and month-ahead forecasts using advanced forecasting methods. Its objective was to improve the marketing company's profitability by minimizing penalties associated with forecasting errors.
Demand Side Management

- The Economics of Biofuels. For a western utility that is facing stringent renewable portfolio standards and that is heavily dependent on imported fossil fuels, carried out a systematic assessment of the technical and economic ability of biofuels to replace fossil fuels.

- Assessment of Demand-Side Management and Rate Design Options: Large Middle Eastern Electric Utility. Prepared an assessment of demand-side management and rate design options for the four operating areas and six market segments. Quantified the potential gains in economic efficiency that would result from such options and identified high priority programs for pilot testing and implementation. Held workshops and seminars for senior management, managers, and staff to explain the methodology, data, results, and policy implications.

- Likely Future Impact of Demand-Side Programs on Carbon Emissions - Client: The Keystone Center. As part of the Keystone Dialogue on Climate Change, developed scenarios of future demand-side program impacts, and assessed the impact of these programs on carbon emissions. The analysis was carried out at the national level for the U.S. economy, and involved a bottom-up approach involving many different types of programs including dynamic pricing, energy efficiency, and traditional load management.

- Sustaining Energy Efficiency Services in a Restructured Market - Client: Southern California Edison. Helped in the development of a regulatory strategy for implementing energy efficiency strategies in a restructured marketplace. Identified the various players that are likely to operate in a competitive market, such as third-party energy service companies (ESCOS) and utility affiliates. Assessed their objectives, strengths, and weaknesses and recommended a strategy for the client’s adoption. This strategy allowed the client to participate in the new market place, contribute to public policy objectives, and not lose market share to new entrants. This strategy has been embraced by a coalition of several organizations involved in the California PUC’s working group on public purpose programs.
- Organizational Assessments of Capability for Energy Efficiency - Client: U.S. Agency for International Development, Cairo, Egypt. Conducted in-depth interviews with senior executives of several energy organizations, including utilities, government agencies, and ministries to determine their goals and capabilities for implementing programs to improve energy end-use efficiency in Egypt. The interviews probed the likely future role of these organizations in a privatized energy market, and were designed to help develop U.S. AID's future funding agenda.

- Enhancing Profitability Through Energy Efficiency Services - Client: Jamaica Public Service Company. Developed a plan for enhancing utility profitability by providing financial incentives to the client utility, and presented it for review and discussion to the utility's senior management and Jamaica's new Office of Utility Regulation. Developed regulatory procedures and legislative language to support the implementation of the plan. Conducted training sessions for the staff of the utility and the regulatory body.

Advanced Technology Assessment

- Competitive Energy and Environmental Technologies - Clients: Consortium of clients, led by Southern California Edison, Included the Los Angeles Department of Water and Power and the California Energy Commission. Developed a new approach to segmenting the market for electrotechnologies, relying on factors such as type of industry, type of process and end use application, and size of product. Developed a user-friendly system for assessing the competitiveness of a wide range of electric and gas-fired technologies in more than 100 four-digit SIC code manufacturing industries and 20 commercial businesses. The system includes a database on more than 200 end-use technologies, and a model of customer decision making.

- Market Infrastructure of Energy Efficient Technologies - Client: EPRI. Reviewed the market infrastructure of five key end-use technologies, and identified ways in which the infrastructure could be improved to increase the penetration of these technologies. Data was obtained through telephone interviews with equipment manufacturers, engineering firms, contractors, and end-use customers.
TESTIMONY

Arizona


California


Qualifications and prepared testimony before the Public Utilities Commission of the State of California, on behalf of Southern California Edison, Edison SmartConnect™ Deployment Funding and Cost Recovery, exhibit SCE-4, July 31, 2007.


Colorado


Connecticut

Testimony before the Department of Public Utility Control, on behalf of the Connecticut Light and Power Company, in its application to implement Time-of-Use, Interruptible Load Response, and Seasonal Rates-Submittal of Metering and Rate Pilot Results-Compliance Order No. 4, Docket no. 05-10-03RE01, 2007.

District of Columbia

Direct testimony before the Public Service Commission of the District of Columbia on behalf of Potomac Electric Power Company in the matter of the Application of Potomac Electric Power Company for Authorization to Establish a Demand Side Management Surcharge and an Advance Metering Infrastructure Surcharge and to Establish a DSM Collaborative and an AMI Advisory Group, case no. 1056, May 2009.

Illinois


Testimony before the State of Illinois—Illinois Commerce Commission on behalf of Commonwealth Edison Company regarding the evaluation of experimental residential real-time pricing program, 11-0546, April 2012.


Indiana

Direct testimony before the State of Indiana, Indiana Utility Regulatory Commission, on behalf of Vectren South, on the smart grid. Cause no. 43810, 2009.

Kansas


Maryland

Direct testimony before the Public Service Commission of Maryland, on behalf of Potomac Electric Power Company and Delmarva Power and Light Company, on the deployment of Advanced Meter Infrastructure. Case no. 9207, September 2009.
Prepared direct testimony before the Maryland Public Service Commission, on behalf of Baltimore Gas and Electric Company, on the findings of BGE’s Smart Energy Pricing (“SEP”) Pilot program. Case No. 9208, July 10, 2009.

**Minnesota**


**Nevada**


Prepared direct testimony before the Public Utilities Commission of Nevada on behalf of Nevada Power Company d/b/a NV Energy, in the matter of the application for approval of a cost of service study and net metering tariffs, Docket No. 15-07, July 31, 2015.

**New Mexico**

Direct testimony before the New Mexico Regulation Commission on behalf of Public Service Company of New Mexico in the matter of the Application of Public Service Company of New Mexico for Revision of its Retail Electric Rates Pursuant to Advice Notice No. 507, Case No. 14-00332-UT, December 11, 2014.

**Oklahoma**


**Pennsylvania**

REGULATORY APPEARANCES

Arkansas


Delaware


Kansas


Ohio


Texas

Presented before the Public Utility Commission of Texas, “Direct Load Control of Residential Air Conditioners in Texas,” at the PUCT Open Meeting, Austin, Texas, October 25, 2012.

PUBLICATIONS

Books


**Technical Reports**

*Quantifying the Amount and Economic Impacts of Missing Energy Efficiency in PJM’s Load Forecast,* with Sanem Sergici and Kathleen Spees, prepared for The Sustainable FERC Project, September 2014.


*The Costs and Benefits of Smart Meters for Residential Customers,* with Adam Cooper, Doug Mitarotonda, Judith Schwartz, and Lisa Wood, prepared for Institute for Electric Efficiency, July


Electrotechnologies for Multifamily Housing. With Omar Siddiqui. EPRI TR-106442, Volumes 1 and 2. Electric Power Research Institute, September 1996.


Articles and Chapters

“An Economist’s Dilemma: To PV or Not to PV, That Is the Question,” Electricity Policy, March 2016. http://www.electricitypolicy.com/Articles/an-economists-dilemma-to-pv-or-not-to-pv-that-is-the-question


http://www.fortnightly.com/fortnightly/2014/08/smart-default?/page=0%2C0&authkey=e5b59c3e26805e2c6b9e469cb9c1855a9b0f18c67bbe7d8d4ca08a8abd39c54d

“Quantile Regression for Peak Demand Forecasting,” with Charlie Gibbons, SSRN, July 31, 2014.

“Study Ontario for TOU Lessons,” Intelligent Utility, April 1, 2014.
http://www.intelligentutility.com/article/14/04/study-ontario-tou-lessons?quicktabs_11=1&quicktabs_6=2

http://ssrn.com/abstract=2411832

“Charting the DSM Sales Slump,” with Eric Schultz, Spark, September 2013.
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http://www.fortnightly.com/fortnightly/2012/12/demand-growth-and-new-normal?page=0%2C1&authkey=4a6cf0a67411ee5e7c2aee5da4616b72fde10e3fbe215164cd4e5dbd8e9d0c98
Available at SSRN: http://ssrn.com/abstract=2029150


http://www.electricenergyonline.com/?page-show_article&mag=76&article=618

"Dynamic Pricing of Electricity and its Discontents" with Jennifer Palmer, Regulation, Volume 34, Number 3, Fall 2011, pp. 16-22.

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"Are LDCs and customers ready for dynamic prices?" with Jürgen Weiss, Fortnightly's Spark, August 25, 2011.


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http://www.fortnightly.com/archive/puf_archive_1110.cfm


http://www.sciencedirect.com/science/article/pii/S0360544209003387

http://www.utilityweek.co.uk/news/news_story.asp?id=123888&title=Dynamic+tariffs+are+vital+for+smart+meter+success


http://www.cato.org/pubs/regulation/regv31n4/v31n4-noted.pdf

http://www.fortnightly.com/exclusive.cfm?o_id=94


http://www.drgcoaition.org/resources/other/Pricing_Programs_TOU_and_RTP.pdf


“Reforming electricity pricing in the Middle East,” with Robert Earle and Anees Azzouni, Middle East Economic Survey (MEES), December 5, 2005.

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Schedule
MD P.S.C. - April, 2016
Impact Evaluation of Pepco Maryland's Portfolio of Energy Management Tools

PREPARED FOR

Pepco Maryland

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This report was prepared for Pepco Maryland by The Brattle Group. All results and any errors are the responsibility of The Brattle Group analytical team.

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Executive Summary

Pepco Holding, Inc. (PHI) has completed the installation of its Advanced Metering Infrastructure (AMI) deployment in four of its five utility service territories. As part of the AMI initiative, smart meters were deployed to virtually all residential customers in the Potomac Electric Power Company Maryland (Pepco MD) service territory, the Potomac Electric Power Company District of Columbia service territory (Pepco DC), the Delmarva Power & Light Company Delaware (DPL DE) service territory, and the Delmarva Power & Light Company Maryland (DPL MD) by year-end 2014. As of the time of writing of this report, there were no New Jersey Commission approved plans for the Atlantic City Electric Company (ACE NJ) to deploy an AMI System in its service territory.

Due to the deployment and activation of AMI, both Pepco and Delmarva Power have developed a portfolio of Energy Management Tools (EMTs) that provide residential customers with detailed information about their electricity usage so they can make well-informed choices about their electricity consumption. The EMTs rely on a wide range of information channels including the utilities’ “My Account” Web portal, detailed bill presentment, educational campaigns, and news coverage regarding the capabilities introduced by smart meters.

This report contains an analysis of the impact of EMTs on customer energy use in the period from January 2012 through September 2014 for the Pepco MD service territory. The tested hypothesis was that the customers reduced their electricity usage in response to the additional energy use information presented to them through EMTs. Specifically, this included multiple rounds of communications from Pepco starting with the deployment of AMI meters and the availability of detailed information on their usage pattern through My Account and detailed monthly electricity bill presentment. Concurrent implementation of dynamic pricing by Pepco MD has also contributed to an increased focus on energy usage through increased messaging related to saving energy, the awareness of tools within My Account and monthly electric bills.

The analysis relied on a comprehensive data compilation effort and used robust analytical methods. The analysis found that Pepco MD residential customers reduced their average daily consumption by 1.73% in response to the activation of the AMI meters and the roll-out of the EMTs. The measured impact is statistically significant at the 1% level. This impact was estimated
after controlling for potential confounding factors such as weather conditions, changes in economic activity and customer participation in demand side management (DSM) programs.
I. Introduction

PHI has completed its AMI System deployment in four of its five utility service territories as of the end of 2014. While residential smart meters were deployed in Pepco MD, Pepco DC, and DPL DE, and DPL MD service territories, there were no approved utility plans for AMI deployment in the ACE NJ service territory as of the time of writing of this report.

Along with the AMI deployment and activation, PHI has developed a portfolio of Energy Management Tools (EMTs) that provide residential customers with information about their electricity usage and help them to make better informed choices about their electricity consumption. The EMTs cover a wide range of information outlets including:

1. My Account web portal: customers can log on to My Account and see their hourly usage of electricity, view user-friendly charts comparing consumption to selected periods, i.e. same 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 AMI 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 AMI;
   - 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 Energy Savings Credit, including energy savings tips and ideas for reducing energy during the summer;
   - Community meetings and events that involved presentations, individual discussions and demonstrations of My Account, and providing customer education handouts.

4. News coverage including press releases, articles and TV coverage of AMI activation and other energy management tools enabled by AMI.
This report provides a description of the analysis of whether the residential customers in the Pepco MD service territory have changed their electricity consumption in response to the information provided by EMTs introduced following the AMI activation. Due to the nature of the AMI deployment and activation process, 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 mass media information was available throughout the service territory at the same time. For Pepco MD customers, the AMI activations started in January 2012 and were completed by year-end 2013 with 90 percent of the activations being completed by May 2013.

Each customer had its own unique AMI activation date that marks the beginning of information flow from Pepco MD to customer which would help enable better-informed electricity consumption choices. Our analysis assumes that the “AMI activation” is the “treatment” Pepco MD customers receive, and therefore it identifies the periods before and after AMI-activation as “pre-treatment” and “post-treatment” respectively. Due to the rapid and full-scale nature of the AMI rollout, it was not possible to set aside a control group which would be excluded from receiving the treatment. Moreover, the nature of the local media market and limited geographic area also meant that it would be difficult to shield customers in the control group from hearing about the AMI benefits. Due to this limitation, the analysis considered data from the two PHI jurisdictions, DPL MD and ACE NJ, as potential control groups and selected DPL MD as the control group for this study. Though PHI has also deployed AMI in its DPL MD service territory, these deployments had not started until December 2013, and were not complete by September 2014. The delayed nature of AMI deployment in the DPL MD territory has provided us with sufficient data before the AMI activations and allowed us to use DPL MD as a control group.

This report is organized as follows. Section II details the study objectives, while Sections III and IV describe data and methodology used in this study. Section V presents the results of the analysis and concludes. The Appendix includes the details of the study that are not covered in the main body of this report.
II. Study Objectives

Several studies have demonstrated that residential customers reduce their electricity usage when they have access to information about their consumption patterns and the consequences of their actions in terms of their monthly bills as well as for the environment. With the deployment of AMI, Pepco MD customers had access to multiple Pepco provided channels of information to increase their understanding of their energy use and to inform them of ways to save energy. These channels, as noted previously, include the My Account Web portal, detailed bill presentation, energy awareness ad campaigns, smart meter related communications, and news coverage. Each channel provides customers with different types of electricity usage information with varying degrees of details. The expectation is that being equipped with more detailed and actionable energy use information enables residential customers to change their electricity usage by expanding their awareness of energy usage and costs. As a result of accessing this information, customers better understand how to conserve energy by changing their behavior; learn about the high use periods in a typical day and correspondingly reduce their electricity usage; and invest in more efficient heating and air conditioning or home improvements. These types of changes can lead to sustained reductions in overall electricity usage.

In this study, the hypothesis of residential energy reductions for the Pepco MD residential customers who have had access to EMTs beginning with early 2012 is tested. To determine the resulting change in overall electricity consumption, the energy use of a group of customers who received access to the EMTs was compared with the energy use of customers who had not received access to the EMTs. The comparative analysis accounted for the impact of weather, economic conditions, and other utility energy efficiency program participation.

III. Data

The study required a comprehensive data compilation effort. For each residential customer in the Pepco MD dataset, the following data series were compiled:

- Average daily consumption
- Weather data (dew point and dry-bulb temperatures)
- AMI activation date
- Average monthly all-in electricity rates
- Regional employment levels
- Participation in DSM, Direct Load Control (DLC), and Opower programs
- Net energy metering status
- Participation in the first phase of both Pepco MD and DPL MD's Conservation Voltage Reduction (CVR) deployment

After the compilation of these data series, they were merged into a master dataset spanning nearly five years, January 2010 through September 2014. Because the objective of our analysis is to isolate the impact of EMTs on customers' electricity usage behavior, customers receiving the Opower reports were excluded from the dataset as they have already been accessing detailed information on their energy usage before the roll-out of EMTs. Similarly, net energy metering customers were also excluded from the dataset as their energy consumption behavior is potentially different from that of an average customer. Observations that contained data anomalies were also excluded from the analysis. The final resulting Pepco MD dataset comprised of roughly 433,000 customers and 18.5 million observations.

Similar data were also compiled for the control group over the same time frame. DPL MD residential customers were used as a control group for the Pepco MD analysis, as is described below. DPL MD customers who were involved in the first phase of the DPL MD CVR pilot were dropped from the analysis. The very short period inside of the study window during which these customers was on CVR would make it difficult to control for the CVR impact properly. The DPL MD dataset is comprised of roughly 135,000 to 32,000 customers, as customers are dropped from the analysis as they receive EMT treatment. The DPL MD dataset in total is comprised of roughly and 5.8 million observations.
IV. Methodology

A. Selecting Control Groups

For this study, residential customers in the DPL MD service territory are used as a control group for the residential customers in the Pepco MD service territory. As discussed earlier, the roll-out of the AMI and the derivative rollout of EMTs were not designed as a randomized controlled experiment. Thus, there was no available control group in the design that would represent the "but-for consumption" of the Pepco MD customers in the absence of the EMTs. However, there were two PHI jurisdictions, DPL MD and ACE NJ, which could be considered for the role of a control group in our analysis. DPL MD had started its deployments much later than Pepco MD and had not completed its AMI rollout by September 2014. In ACE NJ there were no plans for AMI deployment as of the writing of this report. Since there were two candidate control groups for the Pepco MD study, the first step involved determining which one of these two jurisdictions looked more similar to Pepco MD in terms of load characteristics, average electricity rates, and local economic conditions.

Our analysis indicated that DPL MD is more similar to Pepco MD in terms of its economic activity levels. Figure 1: below illustrates employment (non-farm jobs) in a proxy metro area for each jurisdiction. Silver Spring-Frederick-Rockville, MD is used for Pepco MD; Salisbury, MD is used for DPL MD; and Atlantic City-Hammonton, NJ is used for ACE NJ. Other economic indicators were considered for the analysis, but employment was chosen as it had the best granularity and is commonly used by PHI in economic modeling. Regional economic indicators were used because economic indicators at the household level were unavailable. Due to the difference in sizes of each metro area, the employment series are standardized to 100% for the first month of the study (January 2010). While DPL MD's employment series is similar to Pepco MD's employment series, ACE NJ's employment series is significantly different than Pepco MD's employment series,
DPL MD also is a more suitable control group in that the geographic distance between the DPL MD and the Pepco MD service territories is significantly less than the distance between the ACE NJ and the Pepco MD service territories. It is clear from Figure 2: Map of PHI Service Territories that the Maryland portion of the DPL service territory is closer than ACE NJ's service territory to the Maryland portion of Pepco's service territory. The significant distance between ACE NJ and Pepco MD indicates that there may be underlying differences between ACE NJ and Pepco MD for which it would be very difficult to control.
We carried out additional checks to further ensure that the DPL MD was a suitable control group for the Pepco MD service territory. First, we compared the average monthly residential usage profile for Pepco MD to the DPL MD average residential usage profile. Though the series do not align perfectly, the overall trends and seasonality are very similar.
Next, to supplement the load profile comparisons, the average electricity prices were compared between the treatment and control jurisdictions over time to be certain that they were not significantly different. Based on the average electricity rate comparison, the rates are slightly lower in the post-AMI period for both jurisdictions, with Pepco MD rates decreasing slightly less in the post AMI period than those of DPL MD. Even then, the difference-in-differences between the rates from these two jurisdictions is negligible.

Figure 4: Average Electricity Rate Comparison Before and After AMI Activation (Pepco MD vs. DPL MD)

<table>
<thead>
<tr>
<th>Period</th>
<th>Pepco MD</th>
<th>DPL MD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-AMI</td>
<td>$0.12630</td>
<td>$0.12952</td>
</tr>
<tr>
<td>Post-AMI</td>
<td>$0.12343</td>
<td>$0.12071</td>
</tr>
<tr>
<td>Difference</td>
<td>-$0.00287</td>
<td>-$0.00880</td>
</tr>
<tr>
<td>Difference in Differences</td>
<td>$0.00593</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Note: As noted above, the AMI activation dates vary by customer. For this comparison, the Post-AMI period was defined as May 2013, which marks the completion of AMI meter activation for 90 percent of the Pepco MD customers.
It is important to note that even though the DPL MD 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 DPL MD customers from the dataset as they received EMTs starting in January 2014. By September 2014, 32% of DPL MD customers had still not received EMT treatment, which resulted in an ample number of customers which 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.

B. Estimating the Impact of Energy Management Tools

After identifying a control group for the Pepco MD analysis, a panel data regression analysis was conducted to estimate the EMT impact (See Appendix E for a primer on panel data analysis). The regression model compares the usage of the treatment and control group customers before and after the AMI activation, while accounting for other factors that could potentially confound the estimated impact. The most important factor to account for in this regression is the impact of weather conditions on the electricity usage of customers. If there is a usage reduction in the treatment period, it is important to ensure that the reduction is not due to milder weather conditions (resulting in less air conditioning or electric heating load), before attributing this reduction to the AMI-enabled EMTs.

Customer participation in other utility programs such as DSM, DLC, and CVR programs was also accounted for, as all of these programs have potential impacts on customers' electricity usage. Other variables that were controlled for include economic activity variables, monthly calendar variables, and a time trend in the model, as all of these variables have potential implications for energy consumption.

The Fixed Effects (FE) estimation routine was used to ensure that the estimated coefficients from the resulting model are unbiased. FE estimation assumes that the unobservable factor in the error term is related to one or more of the model’s independent variables. Therefore, it removes the
unobserved effect from the error term prior to model estimation using a data transformation process. Below is the estimation equation:

\[
\ln(kWh_{it}) = \beta_0 + \beta_1 \cdot \ln_{Employment} + \beta_2 \cdot Time_{Trend_t} + \beta_3 \cdot EMT_{Impact_{it}} \\
+ \sum_{m=1}^{12} (\beta_{4m} \cdot D_{Month_t} + \beta_{5m} \cdot D_{Month_t} \cdot TH_{it}) \\
+ \sum_{k=1}^{K} \beta_{6k} \cdot DSM_{k_{it}} + \beta_7 \cdot DLC_{it} + \beta_8 \cdot CVR_{it} + \varepsilon_{it}
\]

Where:

- \( kWh_{it} \): Average daily consumption for household \( i \) in month-year \( t \).
- \( \ln_{Employment} \): Logarithm of Employment
- \( Time_{Trend_t} \): Monthly trend variable
- \( EMT_{Impact_{it}} \): Indicator that the customer has access to the EMTs
- \( D_{Month_t} \): Month specific impact common to all households
- \( D_{Month_t} \cdot TH_{it} \): Month specific impact of the Temperature Humidity Index
- \( DSM_{k_{it}} \): Indicator that a customer is participating in a DSM program
- \( DLC_{it} \): Indicator that the customer is part of the utility's summer DLC program
- \( CVR_{it} \): Indicator that the customer is on a feeder that is receiving CVR

---

2 This regression model differs slightly from the model filed with the Commission in Case No. 9207, “Filing of Methodologies to Measure Additional Advanced Meter Infrastructure Benefits,” filed Feb. 28, 2014. The updated regression model incorporates indicators and variables, such as Employment, EMT, DSM, DLC, and CVR. This model also differs because the timing of the AMI activation has been unique to each customer, whereas the model submitted to the Commission assumed that the treatment period would begin at the same time for each customer. As indicated in this document, final regression specification can only be determined after empirical work takes place.
This equation was estimated using data on both treatment and control customers before and during the treatment period. The analysis allows for the isolation of a program’s true impact by controlling for any potential biases resulting from (i) differences between control and treatment groups in the pre-treatment period and (ii) any changes in the consumption behavior of the treatment customers between the pre-treatment and treatment periods unrelated to the treatment per se.

V. Results

After estimating the regression equation introduced above, we have found that the Pepco MD customers reduced their average daily consumption by 1.73% after the activation of the AMI 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 Pepco starting with the deployment of AMI meters and being provided access to detailed information on their electricity use through My Account and on monthly electricity bills. Concurrent implementation of dynamic pricing may have also increased customers’ awareness and 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 the DSM program participation. All of the estimated coefficients of the model have the expected signs and magnitudes. The estimation results are provided in Appendix A, Figure A.1.
Glossary of Terms

AMI – Advanced Metering Infrastructure: Systems that measure collect and analyze energy usage from advanced devices such as electricity meters, gas meters, and/or water meters, through various communication media. This infrastructure includes hardware, software, communications, and meter data management software.

CVR – Conservation Voltage Reduction: is a technique for improving the efficiency of the electrical grid by optimizing and lowering voltage on the feeder lines that run from substations to homes and businesses.

DLC – Direct Load Control: A capability that reduces electricity use by providing the system operator, utility, or CSP (Curtailment Service Provider) direct control to remotely shut down or cycle power to individual appliances or equipment on customer premises.

DSM – Demand Side Management: involves reducing electricity use through activities or programs that promote electric energy efficiency or conservation, or more efficient management of electric energy loads.

EMT – Energy Management Tools: refers to PHI provided tools that provide residential customers with information about their electricity usage and help them better understand their energy use and to make informed choices about their electricity consumption. The EMTs rely on a wide range of information outlets including the “My Account” Web portal, detailed bill presentment, educational campaigns, and news coverage regarding the capabilities introduced by smart meters.

FE – Fixed Effects: The fixed-effects model is a model for panel data in which the panel-specific errors are treated as fixed parameters. These parameters are panel-specific intercepts and therefore allow the conditional mean of the dependent variable to vary across panels. The linear fixed-effects estimator is consistent, even if the regressors are correlated with the fixed effects.

GMP – Gross Metropolitan Product: is defined as the market value of all final goods and services produced within a metropolitan area in a given period of time.
Appendix A. Estimation Results

<table>
<thead>
<tr>
<th>Figure A.1 Estimated Regression Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EMT Impact</strong></td>
</tr>
<tr>
<td></td>
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<tr>
<td><strong>In Employment</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>DLC Flag</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>DSM Flag</strong></td>
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<tr>
<td></td>
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<tr>
<td><strong>CVR Flag</strong></td>
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<td></td>
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<tr>
<td><strong>Month Trend</strong></td>
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<td></td>
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<td><strong>February</strong></td>
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<td><strong>March</strong></td>
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<td><strong>May</strong></td>
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<td><strong>August</strong></td>
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<td><strong>September</strong></td>
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<td><strong>October</strong></td>
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<td><strong>November</strong></td>
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<td></td>
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<td><strong>December</strong></td>
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<td></td>
</tr>
<tr>
<td><strong>THI</strong></td>
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<td></td>
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<tr>
<td><strong>February x THI</strong></td>
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<tr>
<td></td>
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<tr>
<td><strong>March x THI</strong></td>
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<td></td>
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<tr>
<td><strong>April x THI</strong></td>
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<tr>
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<tr>
<td><strong>May x THI</strong></td>
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<tr>
<td><strong>June x THI</strong></td>
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<td></td>
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<tr>
<td><strong>July x THI</strong></td>
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<tr>
<td></td>
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<tr>
<td><strong>August x THI</strong></td>
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<tr>
<td></td>
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<tr>
<td><strong>September x THI</strong></td>
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<td></td>
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<tr>
<td><strong>October x THI</strong></td>
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<tr>
<td></td>
</tr>
<tr>
<td><strong>November x THI</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Constant</strong></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Observations 24,188,778  
R-squared 0.206  
Number of Customers 572,659  
Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1
Appendix B. Snapshot of My Account Page
Peak Energy Savings Credit

<table>
<thead>
<tr>
<th>Date</th>
<th>Peak Savings Period</th>
<th>Baseline (kWh)</th>
<th>Use (kWh)</th>
<th>Preliminary Credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>09/20</td>
<td>2 PM - 6 PM</td>
<td>20.00</td>
<td>3.00</td>
<td>$21.25 Preliminary</td>
</tr>
</tbody>
</table>

Peak Energy Savings Credit rewards you for reducing your electricity use. You will see those periods of high demand highlighted in yellow.
Your electric bill - Sep 2014
for the period July 29, 2014 to August 27, 2014

Customer Name
Account number: 
Your service address: 

Bill Issue date: Aug 29, 2014

Summary of your charges
Balance from your last bill $188.41
Changes to electric balance $0.10
Your payment(s) - thank you $189.44
Balance forward as of Aug 29, 2014 $7.07
New electric charges $153.55
Total amount due by Sep 22, 2014 $160.42

After Sep 22, 2014, a Late Payment Charge of $2.40 will be added, increasing the amount due to $162.82.

Information regarding rate schedules and how to verify the accuracy of your bill will be mailed upon request.

If you are moving or discontinuing service, please contact Pepco at least three days in advance.

Your smart electric meter is read wirelessly. Visit My Account at pepco.com to view your daily and hourly energy use.

Follow us on Twitter at twitter.com/PepcoConnect.
Like us on Facebook at facebook.com/PepcoConnect.

Return this coupon with your payment made payable to Pepco

611807660 01 AV 0 361 2707660

Customer Name
Address

Account number:
Total amount due by Sep 22, 2014 $160.42
Total amount due after Sep 22, 2014 $162.82

Amount Paid: $  □ □ □ □

PO Box 13608
Philadelphia PA 19101

Dail, tempe a ur e averages: 2013 TME F 2014 TME F

Please tear on the dotted line below:

Schedule (AF)-2
Schedule (AF)-2

Customer Name
Account number:

Your electric bill for the period
July 29, 2014 to August 27, 2014

Details of your Electric Charges
Residential-R

<table>
<thead>
<tr>
<th>Meter Number</th>
<th>Usage (kWh)</th>
<th>Date</th>
<th>Start</th>
<th>Number</th>
<th>Type</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>NXA11</td>
<td>Aug 27</td>
<td>27</td>
<td>29</td>
<td></td>
<td></td>
<td>938</td>
</tr>
</tbody>
</table>

Your meter records hourly use. Total use is the sum of this hourly data
Please visit My Account at pseco.com to view your energy use data.
Your next bill period is scheduled to end on September 29, 2014

Delivery Charges: These charges reflect the cost of bringing electricity to you.
Current charges for 29 days, summer rates in effect.

<table>
<thead>
<tr>
<th>Type of Charge</th>
<th>How we calculate this charge</th>
<th>Amount($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution Services:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer Charge</td>
<td></td>
<td>7.99</td>
</tr>
<tr>
<td>Energy Charge</td>
<td>$0.0489500 \times 1000$</td>
<td>0.92</td>
</tr>
<tr>
<td>Franchise Tax (Delivery)</td>
<td>$0.0005200 \times 1000$</td>
<td>0.59</td>
</tr>
<tr>
<td>Universal Service Charge</td>
<td></td>
<td>0.36</td>
</tr>
<tr>
<td>3rd Resiliency Charge</td>
<td></td>
<td>0.06</td>
</tr>
<tr>
<td>MD Environmental Surcharge</td>
<td>$0.0010500 \times 1000$</td>
<td>0.14</td>
</tr>
<tr>
<td>Empower MD Charge Reg</td>
<td>$0.0003710 \times 1000$</td>
<td>0.11</td>
</tr>
<tr>
<td>Gross Receipts</td>
<td>$2.0408000 \times 1000$</td>
<td>8.32</td>
</tr>
<tr>
<td>Montgomery City Energy Tax Reg</td>
<td>$0.0011500 \times 1000$</td>
<td>10.84</td>
</tr>
<tr>
<td>Administrative Credit Reg</td>
<td>$0.0003913 \times 1000$</td>
<td>0.36</td>
</tr>
<tr>
<td><strong>Total Electric Delivery Charges:</strong></td>
<td></td>
<td><strong>71.66</strong></td>
</tr>
</tbody>
</table>

Electric Summary

| Balance from your last bill | $180.41 |
| Changes to electric balance | $0.10 |
| Payments, Thank you         | $181.41 |
| **Total Payments**          | $181.41 |
| **New Electric Charges**    | $183.35 |
| **Total amount due by**     | $160.42 |
| **Sep 22, 2014**            |         |

☐ Check here to enroll in the Direct Debit Plan

By signing here, you authorize Pseco to electronically deduct the amount of your monthly bill from your checking account each month. The check you signed with this signed authorization will be used to set up Direct Debit. You understand that we will notify you each month of the date and amount of the debit, which will be on or after the due date stated on your monthly bill. You understand that to withdraw this authorization you must call Pseco. You understand that Pseco does not charge for this service, but that your bank may have charges for this service.

Customer Service Centers

Washington DC
701 Ninth St NW (Mon-Fri 8:30am - 5:30pm) 201 West Duke Dr, Rockville (Mon-Fri 10:00am - 2:00pm)
1200 Martin Luther King Ave SE (Mon-Fri 9:00am - 5:00pm) 8300 Old Marboro Pl, Forestville (Mon-Wed, Fri 10:00am - 2:30pm)

Any inquiry or complaint about this bill should be made prior to the due date, in order to avoid late charges.

Electronic Check Conversion - When you provide a check as payment, you authorize us either to use information from your check to make a one-time electronic fund transfer from your account or to process the payment as a check transaction.

Page 2 of 3
Supply Charges: These charges reflect the cost of producing electricity for you. You can compare this part of your bill to offers from competitive suppliers.

Supply Price Comparison Information: The current price for Standard Offer Service (SOS) electricity is 8.64 cents/kWh, effective through Sep 30, 2014. SOS electricity will cost 9.44 cents/kWh, beginning on Oct 1, 2014 through May 31, 2015. The price for SOS electricity after May 31, 2015 has not yet been set. The weighted average price of SOS electricity will be 8.52 cents/kWh through May 31, 2015.

<table>
<thead>
<tr>
<th>Type of charge</th>
<th>How we calculate this charge</th>
<th>Amount($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation Services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Charge</td>
<td>958 KWH x 0.0793200</td>
<td>75.99</td>
</tr>
<tr>
<td>Procurement Cost Adj. Rate</td>
<td>at 0.0014154 per KWH</td>
<td>1.36</td>
</tr>
<tr>
<td>Transmission Services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Charge</td>
<td>958 KWH x 0.0072500</td>
<td>6.90</td>
</tr>
<tr>
<td>Gross Receipts Tax</td>
<td>at 2.0680000%</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Electric Supply Charges:</td>
<td></td>
<td>81.67</td>
</tr>
<tr>
<td>Total Electric Charges - Residential-R</td>
<td></td>
<td>153.35</td>
</tr>
</tbody>
</table>

Your daily electricity use for this bill period. Visit My Account at pepco.com to see your hourly electricity use.
Appendix D. Other AMI related Communication

GET READY TO
TAKE CONTROL
OF YOUR ENERGY USE.

Pepco is installing over 548,000 electric smart meters for its Maryland residential and small business customers between now and December 2012. Once you receive your smart meter, it will measure your energy use periodically throughout the day and Pepco will make your data available to you online. You can get ready by signing up for My Account and creating your own personalized energy profile. After all, when you know how you use energy, you have the power to control it.

GET READY TODAY
by signing up for My Account
at Pepco.com

Have questions?
Call (202) 833-7500 or visit Pepco.com
GET READY TO TAKE CONTROL OF YOUR ENERGY USE

Pepco is currently installing smart meters in homes and businesses throughout Maryland. In the coming months, you will benefit from new energy analysis tools and features on My Account that can help you take better control of your energy use.

If you have not signed up for My Account, visit pepco.com today and click on “First-Time Users.”

TO LEARN MORE
visit takecontrolmaryland.com or call our Smart Meter Information Line at 1-855-NEW-METER (1-855-639-6383)

TO LEARN MORE
visit takecontrolmaryland.com or call our Smart Meter Information Line at 1-855-NEW-METER (1-855-639-6383)

THE POWER TO SAVE ENERGY IS IN YOUR HANDS

Once Pepco installs and activates your new smart meter, you can see detailed information about your daily, weekly, and monthly energy use, including comparison reports to see how and when you use energy by logging on to My Account. Pepco’s online energy analysis tool at pepco.com. These reports will help you make more informed decisions, and allow you to take an active role in managing your energy bills.

How does my home use energy?

When does my home use energy?

View detailed graphs of your actual energy use.

GET READY TODAY by signing up for My Account at pepco.com

pepco Your life, plugged in.
GET READY TO TAKE CONTROL OF YOUR ENERGY USE.

To serve you better, Pepco is installing smart meters in homes and businesses throughout Maryland. If you are registered for My Account, you will be able to access your personalized detailed energy use information as well as money-saving tools to help you better manage your energy use. Sign up today for My Account at pepco.com and get ready to take control of your energy.

TO LEARN MORE
go to takecontrolmaryland.com or call an Energy Advisor at (202) 833-7500

PEPCO CAN HELP YOU SAVE ENERGY.

In the future, your new smart meter will provide you with detailed information about your hourly, daily, weekly, and monthly energy use, and will offer you comparison reports to see how and when you use energy. These reports will help you make more informed decisions, and allow you to take an active role in managing your energy bills.

How does my home use energy?

View detailed graphs of your actual energy use.

GET READY TODAY by signing up for My Account at Pepco.com
ACCESS your SMART METER data!

SIGN UP FOR MY ACCOUNT
Your smart meter data is at your disposal online through MyAccount, our personalized, easy-to-use online tool. MyAccount is an energy audit tool that lets you compare and analyze your energy usage, view and understand where your energy dollars go. You can even pay your bill online if you choose.

HERE'S HOW:
- You'll need the following information before going online: a copy of your last Pepco bill, your property details (size, age, square footage, etc.), property features (heating and cooling systems, types and number of appliances), and your household and appliance details (number of people who reside, types and number of appliances).
- Go online to Pepco.com and click to sign up.
- Fill out the profile information as requested.
- When your profile is complete, your customized information will appear and it's time to start understanding your smart meter data!

Speak to an Energy Adviser at (202) 833-7500

INTRODUCING SMART METERS
ENJOY THESE EXCITING BENEFITS:

- **Detailed Energy Information**
  In the past, you received monthly usage information on your bill or online. Today, you can view daily and hourly energy usage through My Account.

- **Improved Customer Service**
  Smart meters not only help our representatives answer questions about your energy usage but also enable us to better pinpoint where damage and power outages occur on our electrical system. Smart meters also reduce the number of estimated bills.

- **Environmental Benefits**
  Smart meters help Pepco customers to make informed decisions about reducing energy use. This reduces the need for new power plants and the need to burn fossil fuels later in existing power plants during periods of peak demand. Remote meter reading also minimizes the number of vehicles carrying emissions through reduced travel.

The Smart meter project is a long-term initiative. As additional benefits and programs are added, we will let you know so you can take full advantage of the many ways to manage your energy use and costs. These are exciting times as we all work together to reduce efficiency and reduced energy use.

**Take Control**

The data provided by your smart meter is located online through My Account, an energy audit tool that lets you compare and analyze your energy usage to understand where your energy dollars go. Follow this easy 3-step process:

**STEP 1... SIGN UP FOR MY ACCOUNT ONLINE**
It's easy. See how on the back panel of this brochure, or visit Pepco.com.

**STEP 2... REVIEW YOUR ENERGY USAGE DATA**
Once logged into My Account, review your smart meter data by selecting the "Energy Use Analysis" link. This is the data recorded by your smart meter which shows the energy your home or small business used daily and hourly. You can change the date, meter and type of graph to see it in different formats.

**STEP 3... TAKE CONTROL**
Discover your energy use patterns and you can begin to take control. The power is in your hands:
- Pepco.com. This helpful website is dedicated to helping Pepco Maryland customers understand smart meters. Here you'll find detailed information, videos, tutorials and valuable resources to help you get started.
- Use Your Custom My Account Portal. The "My Home" tab allows you to run a Home Energy Analysis Report. The "Find Ways to Save" tab takes you through a series of questions on topics such as heating and cooling, to give you practical ideas for saving. The "Calculate Improvements" tab is filled with tools for finding the most efficient improvement projects.

Still have questions? Speak to an Energy Advisor at (202) 833-7500.

**WHAT IS A SMART METER?**
A smart meter is an electronic meter with two-way communications between your home or small business and Pepco. The meter records your daily energy use to help monitor and take control of your energy use. Your new smart meter actually "reads" the energy used periodically throughout the day, and communicates that information to Pepco. That captured data is available to you online by signing up for My Account.

**WHAT IS SMART METER DATA?**
What happens today when you receive a lower or higher than expected energy bill? You might wonder what changed in your usual pattern. The new smart meter will provide you with detailed information and comparison reports to help you identify when you are using more or less energy during the day, week or the month. This information will also help you make changes that let you take control of your energy bills.

**IS MY SMART METER DATA SAFE?**
We call smart meters "smart" because of the two-way communications capability that enables remote meter reading, outage detection and other automated services. As always, you can be confident that we use the latest technologies to keep your personal data safe and secure, and we never share your account information with outside parties, unless you request us to do so.
TAKE CONTROL
WITH YOUR NEW PEPCO SMART METER.

Get started today by signing up for My Account at pepco.com

Have Questions? Speak to an Energy Advisor at (202) 833-7500

TAKE CONTROL
OF YOUR ENERGY.

Congratulations — You now Have a New Pepco Smart Meter

This will provide you with the ability to learn more about your energy use and become more energy wise. Pepco is installing more than 540,000 new meters across its Maryland service territory. This initiative is part of our ongoing effort to increase efficiency, control costs and enhance the services and conveniences we offer our customers.

Now that your smart meter is activated, you can receive detailed information about your energy use by going online to your MyAccount portal.
ENJOY THESE EXCITING BENEFITS:

- **More Energy Information**
  You now have access to more frequent information about your energy usage through your My Account. In the past, you only received monthly usage information on your bill or online. Today, you can view daily and hourly energy usage information with a single click of the computer mouse. In the future, you will also see a graph of your daily energy use on your printed bill.

- **Fewer Estimated Bills**
  Because this new technology enables Pepco to remotely read your meter, we will be able to reduce the number of estimated bills. Estimated bills can be the result of not having access to the meter, for example, because the meter is indoors or there is severe weather.

- **Enhanced Power Restoration**
  We will have more information to better pinpoint where damage and power outages occur on our electrical system. This is the first step of a larger journey to improve customer service and reliability.

As additional benefits and programs are added, we will let you know so you can take full advantage of the many ways to manage your energy use and costs. There are exciting times as we all work together for greater efficiency and reduced energy use. Pepco stands committed to serving you.

Accurate, Private, Secure.

We recognize that customers expect accurate bills for their energy use. We want you to know that the new electricity metering technology gives us a more precise reading process to ensure it works properly and is accurate. The meters are tested by the manufacturer and when they arrive at Pepco, a sample group of these meters is tested again.

Yesterday, today and tomorrow—protecting your privacy will remain a top priority here at Pepco.

We have always respected the privacy of our customers, recognizing that their account information, including their specific energy use, is personal and private. While this new technology will enable us to learn more about their specific energy use, the privacy protection laws still apply and our customers' energy information will remain strictly confidential.

The data in these systems will be used as the electric information we maintain for use customers today is secure. The only difference is that we use the latest technology to make more detailed data and make it available to the customer. As technology advances, we will move toward a "smart" electrical grid. Pepco will keep pace by implementing new technologies that provide enhanced security measures aimed at protecting these systems and customers' information. And that important work is already under way.

Data provided by these new meters is encrypted and more closely monitored to ensure enhanced our security protection. Most important, Pepco has taken several steps to develop a robust security program to ensure the highest level of data protection:

**Taking Control with My Account.**

You may not have signed up for My Account yet. If not, go to pepco.com and click on "my account" in the Customer Self Service box. The features on your My Account page are designed for you to become aware of your energy usage so that you can make informed decisions about controlling it.

**Existing Features**

For those new to My Account, you can look forward to many resources that are designed for you to take control of your own energy usage. Existing features include:

- **Use Less. Pay Less.** My Account offers a breakdown of your personal energy costs and provides specific recommendations for reducing energy use in your home.
- **Green Bill**—Save time, money and earth by paying your monthly Pepco bill online. It's easy and free to do with Green Bill, a paperless billing system.
- **Calculate & Save**—Time to save more energy? Updated Weather and Energy Before you buy, use My Account's appliance calculations to determine the approximate amount of energy your new appliance could save you.

The New Feature

And soon, a new tool will appear on your account page: a budget and your smart meter information will also appear in your My Account page. This tool uses a new feature called "My Account Analytics," which displays detailed energy usage information so you can better control your monthly energy costs. You'll be able to view your current and past energy costs and make informed decisions about controlling your energy use.

If you are not yet enrolled in My Account, sign up today at pepco.com. You also have the option to set up automatic billing by calling (800) 633-7796 from 7 a.m. to 7 p.m. Monday through Friday, one Energy Advisor can walk you through your usage information.

Schedule (AF): 2
SAVE ENERGY WITH MY ACCOUNT

You can take control with online energy tools.

Benefits include:
- Charts and graphs that show how you’re using energy to help you reduce your energy use
- A tool to view your projected energy cost at any time during the month to help you manage your budget
- The ability to see by day or week when you are using the most energy so you can make small changes around your home to lower your energy use

Start using My Account today.
Visit pepco.com/takecontrol or call us at 1-855-NEW-METER (1-855-639-6383) to receive information about your energy use over the phone or by mail.

pepco
Energy for a changing world.
I'M IN CONTROL OF MY ENERGY USE.

"I go in My Account fairly often because I like to see my daily energy use."
- Richard K., Pepco customer

Take control of your energy use today by signing up for My Account at pepco.com or call us at 1-855-NEW-METER (1-855-639-6383).

TAKING CONTROL OF YOUR ENERGY USE HAS NEVER BEEN EASIER.

Your personalized energy use data is available online through My Account, your easy-to-use online energy analysis tool. My Account offers a number of features, including:

- Detailed Energy Use
- Bill to Date Information
- View and Pay Your Bill

View these new tools and sign up for My Account today at pepco.com

Don't have a computer? Call us at 1-855-NEW-METER (1-855-639-6383).
Appendix E. A Primer on Panel Data Analysis

A “panel data or cross-sectional time-series” technique involves comparing the same individuals over time as well as comparing different individuals at a given point in time, through regression models. Panel regressions also allow for the testing of a broad range of hypotheses in addition to the estimation of the load impacts, provided that the program is run and measurements are taken over a sufficiently long time period. For example, do the treatment impacts persist over time? Do the treatment impacts vary seasonally?

We selected panel data analysis for the impact evaluation of Pepco MD’s Energy Management Tools. There are several reasons for this decision. First, the EMT treatment has been in effect over several months and yield repeated measurements for the treatment and control groups. Several months’ worth of pre-treatment data are also available for both treatment and control group customers. Given that the repeated measurements are available for both groups before and during the treatment period, a panel data regression can rely upon the variations in the data across individuals, as well as across time, to fit a relationship between dependent and independent variables and as a result yield the most precise impact estimate. Second, panel regression allows for explicitly controlling for the weather variables and removing the impact of weather and seasonality on customers’ usage behaviors. Third, a panel data analysis allows an accounting of the time-invariant unobservable characteristics of individuals that could otherwise introduce biases to the estimation results. These biases could be due to certain socio-demographic and appliance characteristics such as the education level of the head of household, income level, central air conditioning ownership, and so on. If a researcher does not observe, or have reliable data on these characteristics, it is not possible to employ these variables as independent variables even though they have the potential to explain the variation in the dependent variable. Omission of these variables from the regression model leads to an “omitted variable” problem which may result in biased parameter estimates.

One of the key assumptions for a regression model to produce unbiased estimates, the error term, u, must have an expected value of zero given any value of the model’s independent variables (\( E(u | X) = 0 \), zero conditional mean assumption). This implies that the error term must not be

---

3 For a more detailed discussion, see, “Jeffrey Wooldridge (2002), *Econometric Analysis of Cross Section and Panel Data*. Cambridge: The MIT Press,
related to any of the independent variables in the model. However, when an independent variable is omitted from the regression, it is automatically included in the error term. If this omitted variable is related to one of the model’s independent variables, then the error term becomes related to one of the independent variables violating the zero conditional mean assumption and leading to biased parameter estimates.

*Fixed-effects (FE) estimation* assumes that the unobservable factor (in the error term) is related to one or more of the model’s independent variables. Therefore, it removes the unobserved effect from the error term prior to model estimation using a data transformation process. During this process, other independent variables that are constant over time are also removed. This drawback of the FE estimation implies that it is not possible to estimate the impact of variables that remain constant over time, such as ownership of a single-family house.\(^4\)

*Random-effects (RE) estimation* is a reasonable alternative when a researcher is able to explicitly control for all potential independent variables and has a good reason to think that any unobservable variable that may be pooled in the error term is not correlated with any of the model’s independent variables. If this assumption holds, then removing it from the error terms, as in the case with FE estimation, would result in inefficient estimates. Therefore, RE estimator is a more efficient estimator compared to that of FE when the unobserved effect is uncorrelated with independent variables. Moreover, RE estimator has the advantage of allowing for the estimation of variables that remain constant over time. However, it is important to note that if the assumption about the unobservable effect does not hold, then the RE estimator would yield biased parameter estimates.

Most of the time, the primary reason for using panel data is to account for the unobservable time-invariant effects, which are thought to be correlated with the independent variables, using an FE estimator. If this assumption does not hold however, the parameter estimates would be less efficient compared to those that can be estimated using an RE estimator. Fortunately, there is a statistical procedure called the “Hausman test” which is used to assess whether the RE or FE is a

\(^4\) However, it is still possible to estimate the impact of the ownership of a single-family house in the post-treatment period, by interacting the single-family home variable with a post-treatment period indicator variable (which is time-variant).
more suitable estimator for a given panel regression model. The Hausman test is based on estimating a model using both FE and RE and then formally testing for differences in the parameter estimates. Rejection of the Hausman test implies that the RE assumption is not valid; therefore, the researcher should employ the FE routine to obtain unbiased parameter estimates.

\footnote{Some econometric packages, such as STATA, have a routine to calculate the Hausman test.}
A. Faruqui (AF) - 3
Schedule
MD P.S.C. -- April, 2016
Impact Evaluation of Pepco Maryland's Phase I Conservation Voltage Reduction (CVR) Program

PREPARED FOR

Pepco Maryland

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July 2015
This report was prepared for Pepco Maryland by The Brattle Group. All results and any errors are the responsibility of The Brattle Group analytical team.

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Executive Summary

Pepco initiated Phase I of its Conservation Voltage Reduction (CVR) program in August 2013, encompassing seven substations in its Maryland Service Territory. The voltage levels were reduced by 1.5% at these substations, which included 68 feeders serving approximately 57,600 residential and non-residential customers. Pepco Maryland has also identified seven similar control substations to compare with each of the Phase I substations so that the effect of the reduced voltage on the energy usage of the Phase I substations could be assessed. This study compares consumption of the treatment and control groups before and after the implementation of CVR using an econometric study of customer usage. More specifically, a regression analysis was conducted to compare the usage levels of treatment and control group customers to determine whether the CVR treatment resulted in statistically significant conservation and peak demand impacts. The analysis accounts for exogenous factors such as weather, calendar and seasonality impacts as well as utility energy and demand savings programs.

Separate analyses were undertaken to measure peak impacts and conservation impacts. The peak analysis relied on hourly AMI data while the conservation analysis was based on monthly billing data. For both the peak and conservation analyses, models were run separately for residential and non-residential customers, as these two groups have fundamentally different consumption profiles.

The study found that CVR has led to a year-round conservation impact of 1.4% for residential customers. This impact is statistically significant at the one percent level. The availability of hourly AMI-sourced data has enabled the calculation of residential summer peak demand savings – that reduction impact is 1.1% and is also statistically significant at the one percent level. The non-residential year-round conservation impact is 0.9%; but it is not statistically significant at the conventional levels. However, this impact is an unbiased estimate of the mean impact and has a sign and magnitude which have been very consistent across different specifications. This indicates that the non-residential customers have seen a reduction in their usage due to CVR, but due to the sample size and the heterogeneity of the non-residential customers.

\[1\text{ Data derived through the AMI System has also ensured that the voltage levels delivered to customers do not drop below the required Maryland standards.}\]
customers, precise reduction estimates are not possible at this time. The non-residential peak impact is 2.5% and it is statistically significant, but beyond the expected range of a 1.5% CVR reduction. Therefore, it is recommended that 0.9% be used as the reduction estimate for both non-residential conservation and peak demand impacts until additional non-residential data become available. Table 1 summarizes the results of the study.

<table>
<thead>
<tr>
<th>Impact</th>
<th>Residential Customers</th>
<th>Non-Residential Customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation</td>
<td>1.4%</td>
<td>0.9% (insignificant)</td>
</tr>
<tr>
<td>Peak Impact</td>
<td>1.1%</td>
<td>0.9% (modified from 2.5%)</td>
</tr>
</tbody>
</table>

In order to calculate the conservation and peak demand impact of CVR at the 1.5% reduction level, the estimated impacts in Table 1 should be multiplied by the pre-CVR annual weather normalized electricity consumption and summer normalized electric peak demands of the customers affected by the application of CVR to a select substation.

I. Introduction and Background

Pepco Maryland (Pepco MD) initiated its Phase I of Conservation Voltage Reduction (CVR) program on August 1, 2013. The voltage levels were reduced by 1.5% ("treatment") at seven substations, while another seven substations without CVR were selected to serve as a control group for comparative purposes. In this study, we compared the usage levels of the treatment and control group customers to determine whether the CVR treatment resulted in any statistically significant conservation and peak demand impacts.

The key engineering principle of the CVR operation 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).\(^2\) This voltage reduction has the potential to produce considerable energy savings at low cost and without harm to customer end-uses and with no impact to end-use operation. Field research and engineering studies have shown that the

\(^2\) COMAR at 20.50.07.02 specifies the required Maryland voltage delivery levels.
reduction in distribution service voltage yields energy savings for residential and commercial loads. Note that there is a variation in the results due to end-use mix, weather conditions, and distribution system configuration. The availability of voltage data through Pepco’s recently installed Advanced Metering Infrastructure (AMI) System has enabled Pepco to monitor customer voltage levels to verify that voltage levels remain within the Code of Maryland Regulations (“COMAR”) standards while implementing CVR.

Several engineering studies have demonstrated that the implementation of CVR leads to decreased consumption at the customer meter, but there is no consensus on a “CVR Factor,” which is the quantity of energy that is reduced for a specific reduction in voltage. The CVR Factor is calculated as the reduction in consumption divided by the reduction in voltage. For example, a CVR Factor of .85 indicates that a one percent decrease in voltage would lead to a 0.85% decrease in consumption.

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 actually able to achieve the conservation impact that advocates claimed. In the Pepco region, the PJM Interconnection, L.L.C. has relied on temporary voltage reductions to lessen demand during periods of constrained supply. Recently, CVR has received greater interest as it has become more controllable and can be achieved at a lower cost with the deployment of smart meters. Multiple studies have been conducted which seek to understand the impact that CVR has on electricity consumption. Most studies have not estimated a peak demand versus energy conservation impact or a residential versus a non-residential impact.

The majority of previous studies have been engineering studies and not econometric studies. Unlike this Pepco Maryland CVR econometric study, the engineering studies have focused on simulations of consumption reduction due to CVR, and did not use actual customer energy usage data. A 2010 Pacific Northwest National Laboratory (PNNL) study simulated the impact of CVR

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3 The seven treatment substations were selected based upon engineering analysis of actual AMI customers’ voltage readings that indicated that a reduction in operating voltage on the feeders from these substations would not lead to any customers experiencing voltages below the COMAR minimum level.

on 24 feeders which were modeled to be prototypical. These feeders ranged from "light rural" to "heavy urban". Actual load numbers were modeled based on the characteristics of the feeder. The researchers ran a one-year simulation of the system in one minute intervals under standard conditions, and then re-ran the simulation with reduced voltage levels. Each feeder had a different starting voltage, but almost all feeders experienced a reduction in both peak demand and overall energy consumption. Other studies have blended an engineering approach with statistics, but have not implemented a complete difference-in-differences analysis as in this study. A 2007 pilot study by the Northwest Energy Efficiency Alliance (NEEA) found that lowering voltage at a substation by 3% led to a 1.5%-2.5% decrease in energy consumption and a 1.8%-2.6% decrease in demand. The study found a wide range of CVR factors, with CVR factors for energy ranging from 0.3 to 0.86 and CVR factors for demand ranging from 0.55 to 1.12. NEEA's pilot program differed structurally from Pepco Maryland's CVR Phase I program. The NEEA study measured impacts by comparing 24 hours on and 24 hours off, rather than including a control group in the design and comparing before and after treatment data. One notable aspect of NEEA's study is that many utilities participated resulting in a range of impacts, however, the average impacts were estimated to yield a 0.8 CVR factor.

Indianapolis Power & Light Company (IPL) also conducted a similar analysis with short time periods with CVR turned on and compared usage during those periods to CVR off periods. IPL turned CVR "on" for a four-hour period during each of three days in 2012 and "on" for a one-hour period during each of two days in 2013. IPL then compared the drop in usage during those periods compared to the predicted baseline and estimated a CVR factor of 0.7-0.87.

A more recent study by the National Rural Electric Cooperative Association (NRECA) notes that though CVR factors of about 0.8 are often realized, "factors vary widely from substation to substation, feeder to feeder, and especially load to load. Contributions to the overall factor for a utility include consumers' load mix, transformer and conductor characteristics, and voltage

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control schemes as moderated by voltage regulators, line drop compensators, and switched capacitor banks."

Several other utilities in the PJM area have also implemented CVR pilots over the past couple of years. In the winter of 2012, spring of 2013, and summer of 2013, West Penn Power Company (West Penn) implemented tests to understand the impact of CVR on their system. Similar to Pepco MD's CVR program, West Penn reduced voltage by 1.5%\(^8\). West Penn compared usage by turning CVR on for a day, and off for a week (February 2013) and on for a day, off for a day (spring and summer 2013). Notably, West Penn's analysis diverges from the studies above in that it calculates a CVR impact by comparing control and treatment groups using a difference-in-differences approach, which is the same technique used in this study. Ultimately, West Penn found incidences of CVR factors greater than 1, but with an average of 0.86. The study does not break-down residential vs. non-residential when analyzing the initial impacts. A total impact is calculated and then is assigned to each sector based on energy consumption reported in West Penn's FERC Form 1 filing.

Also in PJM, Dominion Virginia Power (Dominion) has tested CVR and found a CVR factor of 0.92\(^10\). Dominion's technique has clear similarities to this study. Using AMI data, Dominion compared consumption from a baseline pre-CVR period to consumption during a period when CVR had been implemented. However, instead of using a regression analysis to estimate the difference-in-differences analysis impact (as is done in this study), Dominion used a day-pairing method to calculate impacts. Dominion first matched individual days from the CVR period to individual days in the pre-CVR period using relevant independent variables identified through regression analysis. Then, the difference in usage between the days is calculated along with a CVR factor for each day-pair. This analysis was also repeated using a control group where the impact identified in the control group differed from the impact in the treatment group. However, Dominion's analysis did not analyze residential and non-residential impacts separately.

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Though not all studies have broken-down residential vs. non-residential and energy vs. peak impacts, there is a clear trend of CVR factors being in the 0.5-1 range, with CVR factors often being close to 1. Table 2 presents the CVR factors from the studies discussed above.

Table 2: Summary of CVR Factors based on Literature Review

<table>
<thead>
<tr>
<th>Study</th>
<th>CVR Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEEA</td>
<td>0.86</td>
</tr>
<tr>
<td>IPL</td>
<td>0.3-1.12</td>
</tr>
<tr>
<td>NRECA</td>
<td>0.7-0.8</td>
</tr>
<tr>
<td>West Penn</td>
<td>0.86</td>
</tr>
<tr>
<td>Dominion Virginia</td>
<td>0.92</td>
</tr>
</tbody>
</table>

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. The main engineering concept is that lower voltage levels cause end-uses to use less energy. 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. Because of the large number of components involved, CVR factors are typically determined for each electric distribution system.

In this study, the conservation and peak demand impact of a 1.5% voltage reduction was empirically determined on 68 feeders connected to seven substations in the Pepco Maryland service territory. To determine the resulting change in overall electricity consumption, the energy use of customers who were connected to substations that received the CVR treatment was compared to the energy use of the control group customers who were connected to substations without CVR. This comparative analysis accounted for the impact of weather and other utility energy and demand savings programs, which can potentially affect customer energy usage. The impacts were estimated separately for residential and non-residential customers, and also for conservation and peak impacts.
II. Data

A. Data Overview

The study required a comprehensive data compilation effort. While the datasets for the conservation and peak analyses differ in structure, they are still built with similar building blocks. For all customers, the following data series were compiled:

- Billing data
- Hourly consumption
- Weather data (dew point and drybulb temperatures)
- Advanced metering infrastructure (AMI) activation date
- Participation in Demand Side Management programs
- Recipients of Opower Home Energy Reports
- Net energy metering (NEM) status

For the *conservation analysis*, the master dataset was based on monthly billing data from September 2012 through August 2014. One full year of pre-treatment period data (Sept. 2012 – Aug. 2013) and one full year of post-treatment data (Sept. 2013 – Aug. 2014) were used for this analysis. For the *peak demand analysis*, the master dataset included hourly AMI data for hours-ending 15-19 (June - August). Since the peak impact estimation relates to the summer months, three months of pre-treatment data (June- Aug. 2013) and three months of post-treatment data (June – Aug. 2014) were used. Table 3 summarizes the impacts estimated and time periods used in our study.

Table 3: CVR Impacts and Time Periods

<table>
<thead>
<tr>
<th>Impact</th>
<th>Dataset</th>
<th>Analysis Variable</th>
<th>Pre-treatment Period (*)</th>
<th>Post-treatment Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Impact</td>
<td>Hourly AMI Dataset</td>
<td>Hourly Usage (HE 15-19) on days with average peak THI&gt;77</td>
<td>June - August 2013</td>
<td>June - August 2014</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tbody>
</table>
Because the objective of this analysis was to isolate the impact of CVR on customer electricity usage, customers receiving the Opower Home Energy Reports were excluded from the dataset. Opower report recipients have been receiving detailed information about their energy usage patterns, and therefore might have made behavioral changes that lead to energy conservation. Similarly, customers with NEM status were also excluded from the dataset as their energy consumption profile is different from that of an average residential customer. A small number of observations that contained data anomalies were also excluded from the dataset. The final datasets are comprised of 93,499 residential customers (46,751 treatment and 46,748 control customers) and 8,740 non-residential customers (3,957 treatment and 4,783 control customers).

B. Selection of Control Group Substations

Pepco Maryland's CVR program was not designed as a randomized control trial. The customers in the treatment and control groups have not been randomly assigned to their respective groups; rather Pepco Maryland 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 Pepco Maryland service territory, many factors which may affect consumption, such as rates and economic factors, are similar between treatment and control substations. Table 4 presents the Treatment-Control substation pairs included in the study. Appendix A contains additional information about how the substations were paired.
### Table 4: Treatment and Control Substation Pairs

<table>
<thead>
<tr>
<th>Treatment Substations</th>
<th>Control Substations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kensington Sub. 193</td>
<td>Linden Sub. 156</td>
</tr>
<tr>
<td>Longwood Sub. 192</td>
<td>Wood Acres Sub. 154</td>
</tr>
<tr>
<td>Montgomery Village Sub. 56</td>
<td>Gaithersburg Sub. 31</td>
</tr>
<tr>
<td>Branchville Sub. 69</td>
<td>Greenbelt Toaping Castle Sub. 173</td>
</tr>
<tr>
<td>Riverdale Sub. 4</td>
<td>Bladensburg Sub. 175</td>
</tr>
<tr>
<td>Camp Springs Sub. 72</td>
<td>St. Barnabas Rd. Sub. 59</td>
</tr>
<tr>
<td>Wildercroft Sub. 178</td>
<td>Lanham Sub. 149</td>
</tr>
</tbody>
</table>

In order to assess the comparability of the treatment and control group substations, *ex-post* comparison was conducted of the treatment and control customer load profiles in the pre-treatment period (for the peak demand analysis). As presented in Figure 1, these comparisons were performed separately by customer type and by time period (peak and off-peak).
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. This implies that the residential control group customers reasonably represents the “but-for” usage of the residential treatment customers (in the absence of the CVR treatment).

For the non-residential customer load profiles, it was determined that they are very similar to each other in terms of their shape but they differ somewhat in terms of the level of usage between the treatment and control groups. Treatment customers use slightly more energy than the control group customers, on average. This difference does not introduce a bias to the impact estimates because it is accounted for by the fixed effects estimation routine; yet points to the greater challenge with the analysis of non-residential customers.
III. Methodology

C. Estimating the Conservation and Peak Demand Impacts of CVR

A Difference-in-Differences (DID) analysis was conducted through the use of a panel data regression approach to estimate the conservation and peak demand impacts of CVR. The DID analysis compares the usage of the treatment and control group customers before and after the CVR treatment, while accounting for other factors that could potentially confound the estimated impact such as weather conditions, DSM program participation, AMI activation, and calendar dummies.

For a difference-in-differences approach to be accurate, the treatment and control groups must be comparable. If the treatment and control groups are not comparable prior to the introduction of treatment, then it will be difficult to isolate the impact of the treatment. The roll-out of CVR was designed as an experimental process, but was not rolled-out as a formal randomized control trial. As discussed earlier, this means that the customers in the treatment and control groups are not randomized, but that they are assigned ex post, through pairing treatment substations with control substations. The DID approach isolates the true impact of the treatment by netting the differences in the treatment and control group load profiles before and after the treatment period. Table 5 presents a simplified demonstration of the DID approach.

<table>
<thead>
<tr>
<th></th>
<th>Treatment Group</th>
<th>Control Group</th>
<th>DID</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-Treatment</strong></td>
<td>Usage= 3 kWh</td>
<td>Usage= 2.5 kWh</td>
<td></td>
</tr>
<tr>
<td><strong>Post-Treatment</strong></td>
<td>Usage= 1.5 kWh</td>
<td>Usage= 2 kWh</td>
<td></td>
</tr>
<tr>
<td><strong>Difference</strong></td>
<td>1.5-3= -1.5 (A)</td>
<td>2-2.5= -0.5 (B)</td>
<td>A-B=-1 kWh</td>
</tr>
</tbody>
</table>

The DID analysis was conducted through a panel data regression approach to account for other factors that could potentially confound the estimated CVR impact. The most important factor to account for in this regression is the impact of weather conditions on the electricity usage of the customers. If there is a usage reduction in the treatment period, it is important to ensure that the reduction is not due to milder weather conditions (resulting in less air conditioning or electric...
heating load), before attributing this reduction to the CVR implementation. This analysis used a temperature humidity index (THI), which combines dewpoint and drybulb temperatures into one variable. Customer participation and enrollment in utility demand side management (DSM) programs was accounted for because the participants of these programs reduce their electricity usage after the installation/implementation of DSM measures. If left unaccounted for in the regression analysis, this would lead to an overstatement of the CVR impact. When monthly data is used, AMI smart meter activation is controlled for. Customers with activated smart meters are able to see detailed usage statistics through Pepco's AMI energy management tools and are likely to reduce usage due to this new information. It is important to include this variable to ensure that the usage reduction due to CVR is measured correctly. The analysis using hourly data did not include the AMI activation variable, as AMI was active for all customers during pre and post treatment periods. Hourly and monthly calendar dummy variables are also included to control for the impact of hour and month specific usage patterns.

The panel data regressions used the Fixed Effects (FE) estimation routine to ensure that the estimated coefficients from the resulting model were unbiased. FE estimation assumes that the unobservable factor in the error term is related to one or more of the model’s independent variables. Therefore, it removes the unobserved effect from the error term prior to model estimation using a data transformation process. Appendix D provides a primer on panel data analysis.

A. Conservation Analysis

As indicated earlier, the year-round conservation impact was estimated using the monthly billing data. AMI data was only available for the treatment and control group substations as of May 2013 and could only yield three months of pre-treatment data for the conservation analysis. Therefore, the monthly consumption data was used, allowing the use of one full year of monthly billing data for each of the pre-treatment and post-treatment periods.

The final regression equation used for the energy conservation analysis is as follows:

\[
\ln(kWh_{it}) = \beta_0 + \beta_1 * \text{TreatPeriod}_{i} + \beta_2 * CVR_{it} + \beta_3 * THI_{t0} + \beta_4 * AMI_{it0}
\]

As of May 2013, Pepco Maryland jurisdiction had completed roughly 90 percent of the AMI activations.
\[ + \sum_{m=1}^{12} (\beta_{4m} \cdot \text{month}_{m_t} + \beta_{5m} \cdot \text{month}_{m_t} \cdot \text{THI}_{i_t}) + \beta_6 \cdot \text{DSM}_{i_t} + v_i + \varepsilon_{i_t} \]

Where:

\( \text{ln}(kWh_{i_t}) \)  
Natural log of average daily consumption for household \( i \) in month \( t \).  

\( \text{TreatPeriod} \)  
Flag indicating that the start of the CVR treatment period  

\( \text{CVR}_{i_t} \)  
Flag indicating that the customer has received the CVR treatment  

\( \text{THI}_t \)  
Impact of Temperature Humidity Index on usage  

\( \text{AM}_{i_t} \)  
Flag indicating that a customer's AMI meter has been activated  

\( \text{month}_{m_t} \)  
Month specific impact common to all households  

\( \text{month}_{m_t} \cdot \text{thi}_{i_t} \)  
Month specific impact of the Temperature Humidity Index  

\( \text{DSM}_{i_t} \)  
Indicator that a customer is participating in DSM program  

\( v_i \)  
Customer fixed effect  

\( \varepsilon_{i_t} \)  
Independently and identically distributed. error term, clustered by household  

It is important to note that the conservation regression equation includes one extra variable, the AMI activation variable, which the peak equation does not have (see below). As noted earlier, with the activation of the AMI meters, the Pepco MD customers have gained access to a portfolio of Energy Management Tools (EMTs). These EMTs provide customers with actionable information on their electricity usage patterns, and as a result yield conservation effects\(^{12}\).

Therefore, it is important to explicitly account for this variable in the analysis to avoid incorrectly attributing the EMT related conservation to CVR.

B. Peak Analysis

The peak analysis used a DID approach on an hourly level to measure peak demand savings from CVR. The hypothesis was that the CVR impact might be different during the high demand hours of the hottest days of the summer compared to the year-round conservation impact, due to different load characteristics.

To test this hypothesis, the peak analysis used only the hottest days of the summer, which were defined in this analysis as being days where the average THI between 2 pm and 7 pm was greater than 77, which equates to about 85 degrees Fahrenheit, depending upon humidity levels. A THI cutoff of 77 creates a balance between including only very hot days, while still establishing sufficient days for a robust analysis. The THI cutoff of 77 resulted in 78 weekdays and 29 weekend days available to use for analysis. The hours of 2 pm to 7 pm were used to be consistent with PJM's capacity market peak definition for summer. Models were run separately for weekdays, weekends, and all days to investigate if there was a difference in impact due to the characteristics of weekends vs. weekdays.

The final equation used for the peak analysis is as follows:

$$\ln(kWh_{it}) = \beta_0 + \beta_1 * \text{TreatPeriod}_i + \beta_2 * CVR_{it} + \beta_3 * \text{THI}_t$$

$$+ \sum_{m=6}^{10} (\beta_{4m} * \text{monthm}_t + \beta_{5m} * \text{monthm}_t * \text{THI}_{it})$$

$$+ \beta_6 * \text{DSM}_{it} + \beta_7 * v_i + \varepsilon_{it}$$

Where:

$\ln(kWh_{it})$ Natural logarithm of average hourly consumption for household $i$ in day $t$

---

13 PJM Open Access Transmission Tariff, Attachment DD, Section 10(a), https://www.pjm.com/media/documents/agreements/tariff.ashx
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TreatPeriod</td>
<td>Flag indicating the start of the treatment period</td>
</tr>
<tr>
<td>CVR&lt;sub&gt;it&lt;/sub&gt;</td>
<td>Flag indicating that the customer has received the CVR treatment</td>
</tr>
<tr>
<td>THI&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Impact of Temperature Humidity Index on usage</td>
</tr>
<tr>
<td>monthm&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Month specific impact common to all households</td>
</tr>
<tr>
<td>monthm&lt;sub&gt;t&lt;/sub&gt; * thi&lt;sub&gt;it&lt;/sub&gt;</td>
<td>Month specific impact of the Temperature Humidity Index</td>
</tr>
<tr>
<td>DSM&lt;sub&gt;it&lt;/sub&gt;</td>
<td>Indicator that a customer is participating in DSM program group k</td>
</tr>
<tr>
<td>v&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Customer fixed effect</td>
</tr>
<tr>
<td>ε&lt;sub&gt;it&lt;/sub&gt;</td>
<td>Independently and identically distributed error term, clustered by household</td>
</tr>
</tbody>
</table>

### IV. Results

#### C. Conservation Analysis

The results of the conservation analysis show that a 1.5% reduction in voltage levels results in a 1.4% usage reduction for residential customers. This number is statistically significant at the one percent level. This implies a CVR factor of 0.93. For the non-residential customers, the CVR conservation impact was estimated to be 0.9%, resulting in a CVR factor of 0.6, but this impact is not statistically significant at conventional levels. However, this impact is still an unbiased estimate of the mean impact and has a sign and magnitude which have been very consistent across different specifications. Additionally, this estimate is within the lower range estimates of prior studies.\(^{14}\) This indicates that the non-residential customers have seen a reduction in their usage due to CVR, but due to the sample size and the heterogeneity of the non-residential

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\(^{14}\) Note that the prior studied mentioned did not contain separate residential vs. non-residential CVR estimates – combining the two estimates from this study would place the overall results in the mid-range of the referenced studies. Approximately 41 percent of Pepco Maryland load is residential and 59 percent of Pepco Maryland load is non-residential – using these percentages suggests that the overall Pepco Maryland CVR factor would be 0.74 for conservation.
customers, a more precise reduction estimate is not possible at this time. Appendix B presents the parameter estimates of the regression equation for the conservation analysis.

D. Peak Demand Analysis

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 and implies a residential peak demand CVR factor of 0.73. Based on the previous studies discussed above, there is not a consensus for a CVR factor for the peak demand. However, prior studies do provide a rough range from 0.5 to greater than 1. There is no consensus on whether the peak CVR factor should be higher or lower than the conservation CVR factor. Some studies, such as the PNNL study discussed previously, have found a higher CVR factor for peak than for conservation. Other studies, such as the NEEA study discussed previously have found the opposite. These differences may be due to differences in distribution system configurations, and weather/load characteristics in different regions. Although there is no clear consensus on a single CVR factor, the CVR factors reported in previous studies are below 1. When CVR factors above 1 are reported, they are only slightly above 1.

Peak demand CVR impact by hour and for weekdays and weekends were also estimated. Weekends and holidays have a slightly higher impact than weekdays, although this difference is relatively small. Table 6 presents the residential peak demand CVR results for all days, weekends and holidays only, and weekday regressions.

---

15 Similarly, it is important to note that prior studies report CVR factors for residential and non-residential customers combined. Approximately 41 percent of Pepco Maryland load is residential and 59 percent of Pepco Maryland load is non-residential – using these percentages suggests that the overall Pepco Maryland CVR factor would be 0.65 for peak.
Identifying the non-residential peak demand impact has been more challenging due to the small sample size and the heterogeneity of the non-residential customers. Results yielded a non-residential peak demand impact of 2.5% after the CVR implementation. While this impact is statistically significant, it is beyond the expected range of a 1.5% CVR reduction. This implies that there are other unobservable effects which are at work for non-residential customers, which are not captured in the analysis. Therefore, it is recommended that 0.99% be used as the reduction estimate for both non-residential conservation and peak demand impacts until additional non-residential data become available. Appendix B presents the parameter estimates of the regression equation for the peak demand analysis.

V. Conclusion

This study has confirmed that the application of CVR to the Pepco Maryland system reduces residential and non-residential annual and peak energy use. The availability of AMI sourced voltage data has enabled Pepco to determine where CVR can be initially deployed without reducing customer voltages below acceptable standards. Over time, the continued monitoring of AMI sourced voltage data will remain an important part of the CVR deployment to help ensure that voltage levels for customers remain in the acceptable range. The availability of AMI sourced hourly data has enabled the study researchers to develop estimates of peak demand reduction capability of CVR for the residential class of service. Monthly sourced AMI data has been used to estimate annual reduction estimates for both residential and non-residential customers. The
estimates that have been developed can be relied on at this time to provide the best indication of the energy and demand impacts of a deployment of CVR to additional substations and feeders on the Pepco Maryland system.\(^\text{16}\)

\(^{16}\) While the voltage level reduction used in the study was 1.5\%, it is expected that a higher level of voltage reduction would provide higher impact scaled by the CVR factor.
Appendix A. Appendix A: Pepco MD’s Control Substation Selection Methodology

In August 2013, Pepco initiated its Phase I Conservation Voltage Reduction (CVR) Program on seven substations in its Maryland Service Territory. These substations were selected based upon engineering analysis of actual AMI customers’ voltage readings that indicated that a reduction in operating voltage on the feeders from these substations would not lead to any customers experiencing voltages below the COMAR minimum level. For 120/240 volt class of services, this limit corresponds to 114 Volts at the customer meter. To support The Brattle Group’s empirical analysis of the CVR program, Pepco MD engineers selected seven similar control stations to each of the Phase I substations so that the effect of the reduced voltage on the energy usage of the Phase I substations could be assessed against the seven substations selected as controls. The substations are shown in the following table.

<table>
<thead>
<tr>
<th>Treatment Substations</th>
<th>Control Substations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kensington Sub. 193</td>
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</tr>
<tr>
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<td>St. Barnabas Rd. Sub. 59</td>
</tr>
<tr>
<td>Wildercroft Sub. 178</td>
<td>Lanham Sub. 149</td>
</tr>
</tbody>
</table>

These substations pairs are generally adjacent to each other and the communities that they serve are similar in nature: similar size homes, similar ages, etc. In the descriptions below, any known differences between the communities are shared, so that any observed differences in usage can be analyzed.

**Kensington and Linden**

These two Montgomery County Substations serve established communities that were largely constructed in the 1940’s and the 1950’s, although many of the homes could have been built as
early as 1900. Many of these homes were built without air conditioning; however, most of these homes had central air added in the 1960's. Any efforts to provide more insulation would, most likely, have been relatively recent. These homes are surrounded by dense tree cover, which may moderate the effect of summer afternoon temperatures on energy usage. These communities are fairly similar in character. Zip Codes: Kensington: 20895, 20902; Linden: 20815, 20910, 20895, 20902.

**Longwood and Wood Acres**

These two Montgomery County Substations serve established communities that were largely constructed in the 1950's, through the 1970's. The older homes would have been built without air conditioning; however, most of these homes would have had central air added in the 1960's. The newer homes would have had air conditioning incorporated in their design. Any efforts to provide more insulation would, most likely, have been relatively recent. These homes are surrounded by dense tree cover, which may moderate the effect of summer afternoon temperatures on energy usage. Between these two substations, the communities served by Wood Acres may tend to be slightly older than the Longwood communities. Zip Codes: Longwood: 20817, 20818, 20854; Wood Acres: 20816, 20818, 20892.

**Montgomery Village and Gaithersburg**

These two Montgomery County Substations serve established communities that were largely constructed in the 1970's, and the 1980's. Most of these homes had air conditioning incorporated in their construction/design. Any efforts to provide more insulation would, most likely, have been relatively recent. These homes have some trees to provide partial shade, which may somewhat reduce the effect of summer afternoon temperatures on energy usage. Between these two substations, the communities served by Montgomery Village may tend to be slightly older than the Gaithersburg communities. Zip Codes: Montgomery Village: 20866, 20879; Gaithersburg: 20877, 20879.

**Branchville and Greenbelt Toaping Castle**

These two Prince George's County Substations serve established communities that were largely constructed in the 1930's, through the 1950's. Most of these homes were built without air conditioning; however, most of these homes would have had central air added in the 1960's and the 1970's. Any efforts to provide more insulation would, most likely, been relatively recent. These homes are surrounded by dense tree cover, which may moderate the effect of summer
afternoon temperatures on energy usage. Much of the community served by Greenbelt Toaping Castle was constructed in a planned community; whereas the community served by Branchville was constructed using conventional techniques of the time. Zip Codes: Branchville: 20737, 20740, 20770; Greenbelt Toaping Castle: 20770, 20771, 20705, 20708.

**Riverdale and Bladensburg**

These two Prince George’s County Substations serve established communities that were largely constructed in the 1930’s, through the 1950’s. Most of these homes were built without air conditioning; however, most of these homes would have had central air added in the 1960’s and the 1970’s. Any efforts to provide more insulation would, most likely, been relatively recent. These homes are surrounded by dense tree cover, which may moderate the effect of summer afternoon temperatures on energy usage. These communities are fairly similar in character. Zip Codes: Riverdale: 20737, 20781; Bladensburg: 20722, 20781, 20710, 20781.

**St Barnabas Road and Camp Springs**

These two Prince George’s County Substations serve established communities that were largely constructed in the 1960’s, and the 1970’s. The older homes were built without air conditioning; however, most of these homes would have had central air added in the 1970’s. The newer homes would have had air conditioning incorporated in their design. Any efforts to provide more insulation would, most likely, been relatively recent. These homes have some trees to provide partial shade, which may somewhat reduce the effect of summer afternoon temperatures on energy usage. These communities are fairly similar in character, even though they are not immediately adjacent to each other. Zip Codes: St. Barnabas Road: 20745, 20744, 20748; Camp Springs: 20748, 20746, 20735.

**Wildercroft and Lanham**

These two Prince George’s County Substations serve established communities that were largely constructed in the 1950’s, and the 1960’s. The older homes were built without air conditioning; however, most of these homes would have had central air conditioning added in the 1960’s and the 1970’s. The newer homes would have had air conditioning incorporated into their design/construction. Any efforts to provide more insulation would, most likely, been relatively recent. These homes have some trees to provide partial shade, which may somewhat reduce the effect of summer afternoon temperatures on energy usage. These communities are fairly similar in character. Zip Codes: Wildercroft: 20740, 20737, 20706, 20784; Lanham: 20706, 20784.
## Appendix B. Conservation Results

### A. Residential

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>Variables (continued)</th>
<th>Coefficient</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVR Impact</td>
<td>-0.0144***</td>
<td>(0.00174)</td>
<td>THI</td>
<td>-0.0257***</td>
<td>(0.000408)</td>
</tr>
<tr>
<td>Treatment Period</td>
<td>-0.0719***</td>
<td>(0.00220)</td>
<td>February x THI</td>
<td>-0.117***</td>
<td>(0.00201)</td>
</tr>
<tr>
<td>DSM Flag</td>
<td>-0.0180***</td>
<td>(0.00263)</td>
<td>March x THI</td>
<td>-0.126***</td>
<td>(0.00308)</td>
</tr>
<tr>
<td>AMI Flag</td>
<td>-0.0336***</td>
<td>(0.00199)</td>
<td>April x THI</td>
<td>-0.0354***</td>
<td>(0.00194)</td>
</tr>
<tr>
<td>February</td>
<td>5.028***</td>
<td>(0.0861)</td>
<td>May x THI</td>
<td>0.0862***</td>
<td>(0.00250)</td>
</tr>
<tr>
<td>March</td>
<td>5.815***</td>
<td>(0.144)</td>
<td>June x THI</td>
<td>0.321***</td>
<td>(0.00798)</td>
</tr>
<tr>
<td>April</td>
<td>2.102***</td>
<td>(0.116)</td>
<td>July x THI</td>
<td>0.0485***</td>
<td>(0.000689)</td>
</tr>
<tr>
<td>May</td>
<td>-5.276***</td>
<td>(0.155)</td>
<td>August x THI</td>
<td>0.0113***</td>
<td>(0.000171)</td>
</tr>
<tr>
<td>June</td>
<td>-22.35***</td>
<td>(0.568)</td>
<td>September x THI</td>
<td>-0.0874***</td>
<td>(0.00278)</td>
</tr>
<tr>
<td>July</td>
<td>-2.563***</td>
<td>(0.0550)</td>
<td>October x THI</td>
<td>0.151***</td>
<td>(0.00403)</td>
</tr>
<tr>
<td>August</td>
<td>-</td>
<td>(0.0740)</td>
<td>November x THI</td>
<td>-0.544***</td>
<td>(0.0150)</td>
</tr>
<tr>
<td>September</td>
<td>6.477***</td>
<td>(0.196)</td>
<td>December x THI</td>
<td>-0.0507***</td>
<td>(0.000861)</td>
</tr>
<tr>
<td>October</td>
<td>-9.063***</td>
<td>(0.241)</td>
<td>Constant</td>
<td>4.350***</td>
<td>(0.0185)</td>
</tr>
<tr>
<td>November</td>
<td>26.72***</td>
<td>(0.740)</td>
<td>Observations</td>
<td>1,923,476</td>
<td></td>
</tr>
<tr>
<td>December</td>
<td>2.521***</td>
<td>(0.0430)</td>
<td>R-squared</td>
<td>0.163</td>
<td></td>
</tr>
</tbody>
</table>

Number of servicepoin 86,926

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1
### Non-Residential

<table>
<thead>
<tr>
<th>Variables</th>
<th>Variables (continued)</th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>CVR Impact</td>
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<td>February x THI</td>
<td>-0.0552***</td>
</tr>
<tr>
<td></td>
<td>(0.00867)</td>
<td></td>
<td>(0.00827)</td>
</tr>
<tr>
<td>Treatment Period</td>
<td>-0.0245**</td>
<td>March x THI</td>
<td>-0.0568***</td>
</tr>
<tr>
<td></td>
<td>(0.00989)</td>
<td></td>
<td>(0.0126)</td>
</tr>
<tr>
<td>DSM Flag</td>
<td>0.00189</td>
<td>April x THI</td>
<td>-0.0107</td>
</tr>
<tr>
<td></td>
<td>(0.0104)</td>
<td></td>
<td>(0.00836)</td>
</tr>
<tr>
<td>February</td>
<td>2.378***</td>
<td>May x THI</td>
<td>0.0294***</td>
</tr>
<tr>
<td></td>
<td>(0.354)</td>
<td></td>
<td>(0.0106)</td>
</tr>
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<td>March</td>
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## Appendix C. Peak Results

### A. Residential

#### 1. All Days

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<td>(0.108)</td>
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Observations 8,202,487 8,198,795 8,206,097 8,219,217 8,229,712
R-squared 0.068 0.059 0.054 0.050 0.048
Number of servicepointid 93,350 93,348 93,354 93,368 93,385

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1
## 2. Weekends and Holidays Only

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<th>Variables</th>
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<th>Hour 17</th>
<th>Hour 18</th>
<th>Hour 19</th>
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<td>-0.0123*** (-0.00321)</td>
<td>-0.0108*** (-0.00318)</td>
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<td>13.89*** (0.281)</td>
<td>59.49*** (1.560)</td>
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<td>-2.734*** (0.0507)</td>
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Observations: 2,393,865 2,393,122 2,397,085 2,402,967 2,407,123
R-squared: 0.060 0.054 0.050 0.046 0.040
Number of servicepointid: 93,261 93,241 93,242 93,275 93,316

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
### 3. Weekdays Only

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Observations 5,808,622 5,805,673 5,809,012 5,816,250 5,822,589
R-squared 0.073 0.066 0.059 0.054 0.054
Number of servicepointid 93,322 93,315 93,322 93,331 93,355

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1
## 4. All Hours Pooled

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</tr>
<tr>
<td></td>
<td>(0.0580)</td>
<td>(0.0586)</td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>-0.0999*</td>
<td>-2.148***</td>
<td>-0.133**</td>
</tr>
<tr>
<td></td>
<td>(0.0594)</td>
<td>(0.0426)</td>
<td>(0.0595)</td>
</tr>
<tr>
<td>August</td>
<td>0.855***</td>
<td>-0.860***</td>
<td>1.383***</td>
</tr>
<tr>
<td></td>
<td>(0.0604)</td>
<td>(0.0453)</td>
<td>(0.0620)</td>
</tr>
<tr>
<td>September</td>
<td>3.083***</td>
<td>-4.441***</td>
<td>4.380***</td>
</tr>
<tr>
<td></td>
<td>(0.0596)</td>
<td>(0.0764)</td>
<td>(0.0598)</td>
</tr>
<tr>
<td>October</td>
<td>9.474***</td>
<td>7.058***</td>
<td>2.064***</td>
</tr>
<tr>
<td></td>
<td>(0.0874)</td>
<td>(0.0815)</td>
<td>(0.135)</td>
</tr>
<tr>
<td>THI</td>
<td>0.0655***</td>
<td>0.0479***</td>
<td>0.0670***</td>
</tr>
<tr>
<td></td>
<td>(0.000753)</td>
<td>(0.000469)</td>
<td>(0.000753)</td>
</tr>
<tr>
<td>June x THI</td>
<td>-0.0194***</td>
<td></td>
<td>-0.0174***</td>
</tr>
<tr>
<td></td>
<td>(0.000739)</td>
<td></td>
<td>(0.000747)</td>
</tr>
<tr>
<td>July x THI</td>
<td>0.00395***</td>
<td>0.0276***</td>
<td>0.00394***</td>
</tr>
<tr>
<td></td>
<td>(0.000758)</td>
<td>(0.000542)</td>
<td>(0.000759)</td>
</tr>
<tr>
<td>August x THI</td>
<td>-0.00921***</td>
<td>0.00998***</td>
<td>-0.0162***</td>
</tr>
<tr>
<td></td>
<td>(0.000771)</td>
<td>(0.000579)</td>
<td>(0.000791)</td>
</tr>
<tr>
<td>September x THI</td>
<td>-0.0358***</td>
<td>0.0556***</td>
<td>-0.0531***</td>
</tr>
<tr>
<td></td>
<td>(0.000761)</td>
<td>(0.000963)</td>
<td>(0.000762)</td>
</tr>
<tr>
<td>October x THI</td>
<td>-0.121***</td>
<td>-0.0923***</td>
<td>-0.0285***</td>
</tr>
<tr>
<td></td>
<td>(0.00112)</td>
<td>(0.00105)</td>
<td>(0.00174)</td>
</tr>
<tr>
<td>Constant</td>
<td>-5.047***</td>
<td>-3.421***</td>
<td>-5.165***</td>
</tr>
<tr>
<td></td>
<td>(0.0591)</td>
<td>(0.0366)</td>
<td>(0.0591)</td>
</tr>
</tbody>
</table>

Observations: 41,057,968 11,555,892 29,060,633  
Number of servicepointid: 93,413 93,355 93,391  
R-squared: 0.049 0.047 0.052

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
## B. Non-Residential

### 5. All Hours Pooled

<table>
<thead>
<tr>
<th>Variables</th>
<th>All Days</th>
<th>Weekends and Holiday</th>
<th>Weekdays</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVR Flag</td>
<td>-0.0248* (0.0135)</td>
<td>-0.0364*** (0.0139)</td>
<td>-0.0260* (0.0141)</td>
</tr>
<tr>
<td>Treatment Period</td>
<td>0.0406*** (0.0103)</td>
<td>0.0136 (0.0117)</td>
<td>0.00683 (0.0105)</td>
</tr>
<tr>
<td>DSM Flag</td>
<td>-0.0224 (0.0181)</td>
<td>-0.0464** (0.0203)</td>
<td>-0.0246 (0.0184)</td>
</tr>
<tr>
<td>June</td>
<td>2.729*** (0.182)</td>
<td>3.012*** (0.183)</td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>3.016*** (0.193)</td>
<td>-1.496*** (0.138)</td>
<td>3.440*** (0.195)</td>
</tr>
<tr>
<td>August</td>
<td>5.659*** (0.216)</td>
<td>-0.676*** (0.142)</td>
<td>4.105*** (0.212)</td>
</tr>
<tr>
<td>September</td>
<td>4.189*** (0.191)</td>
<td>-3.005*** (0.229)</td>
<td>4.393*** (0.190)</td>
</tr>
<tr>
<td>October</td>
<td>4.325*** (0.349)</td>
<td>0.982*** (0.350)</td>
<td>5.560*** (0.459)</td>
</tr>
<tr>
<td>THI</td>
<td>0.0734*** (0.00260)</td>
<td>0.00824*** (0.00158)</td>
<td>0.0674*** (0.00256)</td>
</tr>
<tr>
<td>June x THI</td>
<td>-0.0353*** (0.00233)</td>
<td>-0.0379*** (0.00235)</td>
<td></td>
</tr>
<tr>
<td>July x THI</td>
<td>-0.0397*** (0.00248)</td>
<td>0.0187*** (0.00176)</td>
<td>-0.0434*** (0.00249)</td>
</tr>
<tr>
<td>August x THI</td>
<td>-0.0731*** (0.00277)</td>
<td>0.00790*** (0.00182)</td>
<td>-0.0521*** (0.00271)</td>
</tr>
<tr>
<td>September x THI</td>
<td>-0.0560*** (0.00245)</td>
<td>0.0367*** (0.00289)</td>
<td>-0.0549*** (0.00242)</td>
</tr>
<tr>
<td>October x THI</td>
<td>-0.0582*** (0.00446)</td>
<td>-0.0133*** (0.00450)</td>
<td>-0.0714*** (0.00589)</td>
</tr>
<tr>
<td>Constant</td>
<td>-5.324*** (0.203)</td>
<td>-0.484*** (0.123)</td>
<td>-4.835*** (0.200)</td>
</tr>
</tbody>
</table>

Observations: 3,345,265 966,019 2,379,246
Number of servicepointid: 8,680 8,653 8,654
R-squared: 0.009 0.005 0.007

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1
Appendix D. A Primer on Panel Data Analysis

A "panel data or cross-sectional time-series" technique involves comparing the same individuals over time as well as comparing different individuals at a given point in time, through regression models. Panel regressions also allow for the testing of a broad range of hypotheses in addition to the estimation of the load impacts, provided that the program is run and measurements are taken over a sufficiently long time period. For example, do the treatment impacts persist over time? Do the treatment impacts vary seasonally?

The panel data analysis was selected for the impact evaluation of Pepco MD's Phase I CVR program for several reasons for this decision. First, the CVR treatment has been in effect for more than 12 months and, as a result, yielded repeated measurements for the treatment and control groups. Several months' worth of pre-treatment data are also available for both treatment and control group customers. Given that the repeated measurements are available for both groups before and during the treatment period, a panel data regression can rely upon the variations in the data across individuals, as well as across time, to fit a relationship between dependent and independent variables and as a result yield the most precise impact estimate. Second, panel regression allows for explicitly controlling for the weather variables and removing the impact of weather and seasonality on customers' electricity consumption. Third, a panel data analysis allows an accounting of the time-invariant unobservable characteristics of individuals that could otherwise introduce biases to the estimation results. These biases could be due to certain socio-demographic characteristics such as the education level of the head of household, income level, and appliance characteristics, such as central air conditioning ownership, and so on. If a researcher does not observe, or have reliable data on these characteristics, it is not possible to employ these variables as independent variables even though they have the potential to explain the variation in the dependent variable. Omission of these variables from the regression model leads to an "omitted variable" problem which may result in biased parameter estimates.

One of the key assumptions for a regression model to produce unbiased estimates, the error term, \( u \), must have an expected value of zero given any value of the model's independent variables (

---

$E(u \mid X) = 0$, zero conditional mean assumption). This implies that the error term must not be related to any of the independent variables in the model. However, when an independent variable is omitted from the regression, it is automatically included in the error term. If this omitted variable is related to one of the model's independent variables, then the error term becomes related to one of the independent variables violating the zero conditional mean assumption and leading to biased parameter estimates.

**Fixed-effects (FE) estimation** assumes that the unobservable factor (in the error term) is related to one or more of the model's independent variables. Therefore, it removes the unobserved effect from the error term prior to model estimation using a data transformation process. During this process, other independent variables that are constant over time are also removed. This drawback of the FE estimation implies that it is not possible to estimate the impact of variables that remain constant over time, such as ownership of a single-family house.\(^{18}\)

**Random-effects (RE) estimation** is a reasonable alternative when a researcher is able to explicitly control for all potential independent variables and has a good reason to think that any unobservable variable that may be pooled in the error term is not correlated with any of the model's independent variables. If this assumption holds, then removing it from the error terms, as in the case with FE estimation, would result in inefficient estimates. Therefore, RE estimator is a more efficient estimator compared to that of FE when the unobserved effect is uncorrelated with independent variables. Moreover, RE estimator has the advantage of allowing for the estimation of variables that remain constant over time. However, it is important to note that if the assumption about the unobservable effect does not hold, then the RE estimator would yield biased parameter estimates.

Most of the time, the primary reason for using panel data is to account for the unobservable time-invariant effects, which are thought to be correlated with the independent variables, using an FE estimator. If this assumption does not hold however, the parameter estimates would be less efficient compared to those that can be estimated using an RE estimator. Fortunately, there is a statistical procedure called the "Hausman test" which is used to assess whether the RE or FE

\(^{18}\) However, it is still possible to estimate the impact of the ownership of a single-family house in the post-treatment period, by interacting the single-family home variable with a post-treatment period indicator variable (which is time-variant)
is a more suitable estimator for a given panel regression model.\textsuperscript{19} The Hausman test is based on estimating a model using both FE and RE and then formally testing for differences in the parameter estimates. Rejection of the Hausman test implies that the RE assumption is not valid; therefore, the researcher should employ the FE routine to obtain unbiased parameter estimates.

\textsuperscript{19} Some econometric packages, such as STATA, have a routine to calculate the Hausman test.