Free to Choose? A Comparison of a Nested Logit Model with a Billing Regression Model and Self-Report Analysis in a Commercial Impact Evaluation

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ABSTRACT

Impact evaluations are often limited to a single method for estimating program impacts, with billing regressions and self-report analysis being two of the mostly widely used. However, neither of these methods is designed to simulate the actual customer decision process for choosing to purchase energy efficient equipment. Given the increasing importance placed on behavioral economics in the evaluation field, this is potentially a serious omission. One alternative for addressing this is the nested logit model, which has been designed specifically to simulate the customer decision-making process by estimating the probability of choosing among several options, with each option being characterized by its attributes (e.g., cost, rebate, bill savings, etc.). Once the model is estimated, the parameters are changed to simulate the likelihood of purchasing the same energy efficient equipment in absence of any efficiency program (e.g., no program awareness, rebates, audits, etc.). By using the nested logit model to simulate customer behavior with and without the program, the overall influence of the program on purchases of energy efficient equipment is estimated.

This paper provides the results of a nested logit model developed to evaluate several small commercial efficiency programs in California using phone survey data from a large sample of program participants and non-participants. In addition to being one of the few times a nested logit model has been used in an impact evaluation, the study also compares the results of the nested logit model with impact results obtained independently using a self-report free ridership analysis for the same programs.

Introduction

A common approach for estimating net impacts of energy efficiency programs is to use a battery of survey questions to create a 'self-report' estimate of free ridership. With the self-report method, participants in an efficiency program are asked a series of questions relating to their equipment purchase process to determine the influence that the program had in ultimately getting the customer to make an energy efficient equipment purchase. These 'stated preference' survey data are then scored to develop a measure of free ridership and/or spillover and to calculate a net-to-gross ratio.

The self-report method has the advantage of being relatively easy to implement and can be applied to virtually any measure promoted in an energy efficiency program. A weakness of the self-report approach is the potential for biased results, as it relies on respondents remembering equipment purchase decisions that occurred in the past. Additionally, for commercial projects the purchase decision may have occurred over months or even years, which makes disentangling the influence of a utility rebate program from other possible influences especially challenging.

An alternative to the self-report method is a nested logit discrete choice model that estimates the probability of a customer making a high efficiency equipment purchase. This model is based on 'revealed preference' data that reflect purchases that the customer actually made under observable market conditions. While the nested logit has the advantage of relying on actual market data, it has substantial data collection requirements and its application is limited to certain measures. Because of these limitations, the nested logit model is used much less frequently then the self-report method in estimating net impacts.1

A recent impact evaluation in California provided a unique opportunity to use both the self-report and nested logit approaches and then compare the resulting net impact estimates. This research was the result of the 2006-08 impact evaluation covering the nonresidential high impact measures (HIM) for lighting across multiple programs targeting small commercial customers. The lighting measures were offered by programs implemented by Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), Southern California Gas (SCG), San Diego Gas and Electric (SDG&E) and third party implementers for the 2006-2008 program cycle. The evaluation was conducted by the Small Commercial Contract Group Evaluation Team[2] under the rules specified in the CPUC EM&V Protocols and the CPUC Energy Division (ED).

Although the full impact evaluation covered several HIM groups and included multiple impact estimation methods, this paper focuses on a small component of this study, namely the lighting net-to-gross analysis using both the self-report and the nested logit model.

Analysis Methods

Self-Report Approach

With the self-report method, one topic of considerable debate has been designing the appropriate questions to minimize potential biases. An additional issue that has received considerable attention is determining how responses should be weighted to develop a single measure of free ridership. Since historically there has been no consensus on consistent methods, comparisons across programs (and even evaluations of the same program over different evaluations) have been difficult.

To help impose some consistency on how the self-report method is applied, the CPUC Energy Division convened a committee of evaluators to develop a standard framework for the measurement of net-to-gross ratios for residential and small commercial programs in a systematic and consistent manner using the self-report approach. The approach was designed to comply with the Evaluation Protocols. With the assistance of its technical consultants and evaluators, the Energy Division developed the *Guidelines for Estimating Net-To-Gross Ratios Using the Self-Report Approaches* (Guidelines), which provided more detailed guidance than was available in the California Evaluation Protocols. (Include both documents in references)

To develop the self-report estimates of free ridership, a phone survey was fielded that targeted commercial customers and collected data on recent equipment purchases that were made through the 2006-08 California small commercial rebate programs. Individuals who were involved in the decision-making process at each small commercial site were interviewed to measure the program's influence on respondents' decision-making. The survey obtained highly structured responses concerning the probability that the household or firm would have installed the same measure(s) at the same time in the absence of the program. The survey also included open-ended and closed-ended questions that focused on the household's or firm's motivation for installing the efficiency measure. These questions covered all the requirements provided in the Guidelines, such as multiple questions; efficiency level; likelihood of adoption; timing and quantity; and consistency checks.

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1 For another example of a nested logit model applied to an impact evaluation, see Seiden and Platis (1999) where a nested logit model is used to estimate free riders and free drivers in a gas furnace program.

2 The Small Commercial Contract Group Evaluation Team was led by Itron and included ECONorthwest, KEMA, PA Consulting, Summit Blue, and Robert Thomas Brown Company.

The net-to-gross ratio (NTGR) algorithm derived four separate measurements of free ridership from different inquiry routes. The first measurement consisted of responses to a series of yes/no questions that measured the impact of the program on the quantity, efficiency, and timing of the purchase. The second measurement consisted of a 0-10 scale that asked the likelihood that the respondent would have purchased the same high efficiency measure in the absence of the program. The third measurement combined responses to the quantity and timing questions with responses to a statement that asked respondents to rate on a 0-10 scale if, in the absence of the program, they would have paid the additional rebate amount in order to purchase the high efficiency equipment on their own. The final measurement combined responses to the quantity and timing questions with participant responses, using a 0-10 scale, to whether they agreed that the program was a critical factor in their decision to purchase the high efficiency equipment. In cases where responses were inconsistent among the four measurements, an analyst reviewed responses to open-ended questions that asked for clarification of the inconsistency, and recoded the four measurements as needed.

These four measurements were averaged to derive the final free-ridership estimate at the measure level.

Nested Logit Modeling Approach

In addition to the self-report approach, a discrete choice modeling approach was developed to provide an independent estimate of net impacts for linear fluorescent and high bay measures. The nested logit model is designed to estimate the probability of choosing any outcome within a specified decision process. For this study, the choice structure was limited to selected lighting options and a 'no purchase' option, as shown in the decision tree depicted in Figure 1. For this model, the decision tree focused on four possible options: purchasing high efficiency lighting (T8 or T5), choosing standard efficiency lighting (T10/T12) or making no lighting purchase at all.

The decision tree structure has two levels: 1) choice of efficiency level [standard/high], and 2) equipment chosen [T10/T12, T8, T5, no purchase]. The equipment choices of T10/T12 and no purchase are nested in the standard efficiency portion of the tree while the T8 and T5 equipment choices are in the high efficiency nest of the tree. This tree structure was found to be the most logical organization of the equipment alternatives as comparable lighting options are grouped together.

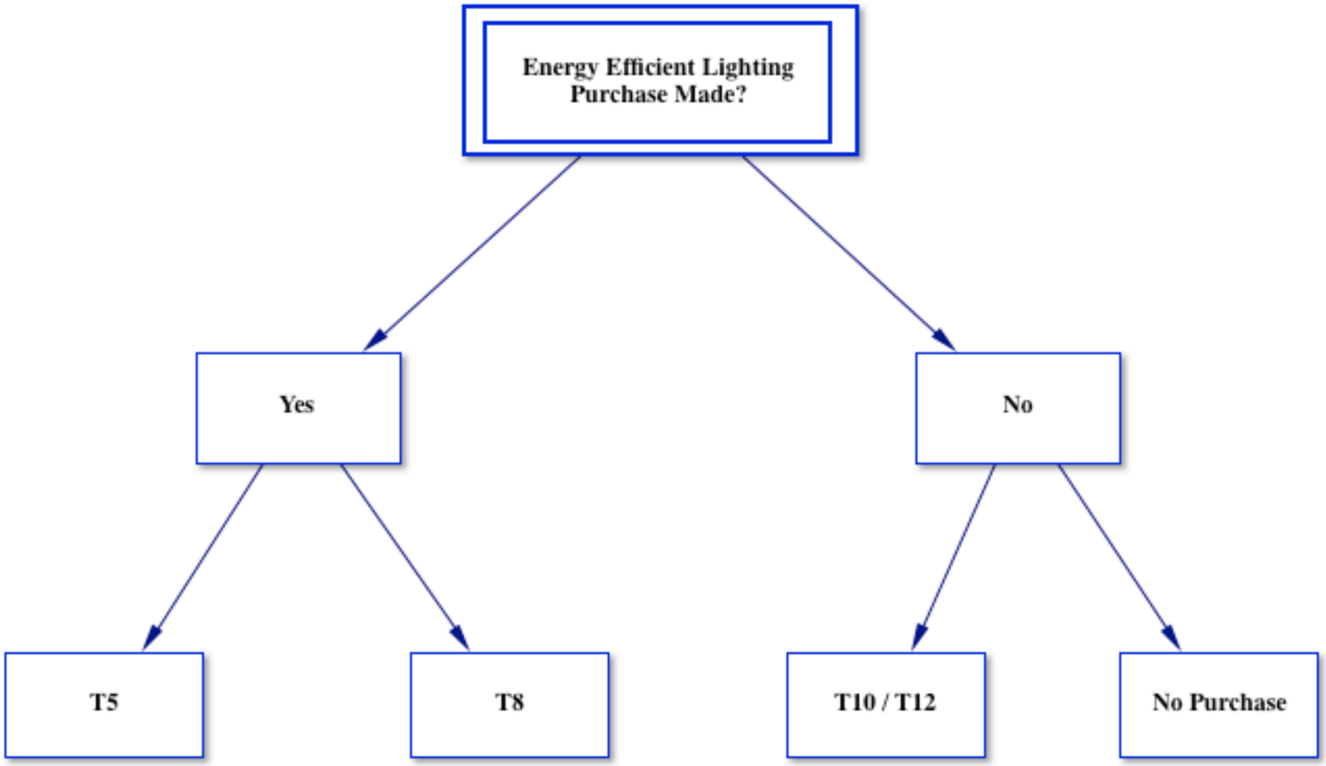

Figure 1. Customer Lighting Purchase Decision Tree

The nested logit model combines customers' responses about their equipment choices and purchase decision process with information on measure costs and savings impacts to estimate the probability that any of the four options of the decision tree might be chosen. It also provides a method for estimating the importance of various equipment and program factors on the equipment choice decision. Additionally, the nested logit model framework provides a way for the benefits of the lower stages of the tree to influence the earlier decisions. In this application, the attributes of the equipment options in the second stage (including energy savings and available rebates) have an influence on whether or not to make any lighting equipment purchase (the first stage). Each decision stage is estimated with the relative benefits of each stage linked to the other stages through an "inclusive value" variable.

The probability of purchasing any given equipment option A (the high efficiency equipment) can also be expressed as the product of two separate probabilities: the probability that a purchase is made (either standard or high efficiency) multiplied by the probability that equipment option A is chosen given that a purchase is made. These two probabilities relate to the two stages of the decision tree shown in Figure 1. In equation form, this can be written as:

$$Prob(EE\ Purchase\ \&\ Equipment\ A) = Prob(EE\ Purchase) \times Prob(Equipment\ A \mid EE\ Purchase)$$

The nested logit model simultaneously estimates the probability of the customer making a purchase (either standard or high efficiency) and the probability that a particular type of equipment is chosen given that the decision to purchase either standard or high efficiency has already been made. Once estimated, the model is used to determine the probability of purchasing high-efficiency equipment in the absence of the program. This is simulated by setting both the rebate and program awareness variables to zero in the model.

One advantage of the nested logit model is that it addresses the entire equipment choice decision for both program participants and nonparticipants using a structure that is consistent with standard microeconomic theory and utility maximization. Additionally, because the model includes both purchasers and nonpurchasers, it eliminates the potential problem of self-selection bias that may occur if only data on purchasers or participants were used. Because the nested logit model simulates the entire decision to purchase energy efficient equipment explicitly and includes observations for customers that choose options outside the program, the problem of self-selection bias is avoided.[3]

To estimate the model, data are needed on purchases for each of the four nodes of the decision tree. Furthermore, to get enough variation in the model to allow estimation, data are needed on customers that made energy efficient lighting purchases outside the rebate programs. Given the maturity of the rebate programs in California, a large amount of phone surveys were required to find customers that had purchased high efficiency lighting but did not receive a rebate from one of the IOUs.

Table 1 below shows the breakdown between participant and nonparticipant survey respondents that comprised the sample used in the final model.[4]

Table 1. Survey Sample Points For the Nested Logit Model

Group	Sample
Participants	620
Nonparticipants	3,978
Total	4,598

Nested Logit Model Specification

The nested logit model combines customers' choices of lighting equipment with information on measure costs and savings impacts to estimate the probability that alternative equipment options will be chosen. The model allows both stages of the equipment choice decision (as shown in Figure 1) to be included in one comprehensive model that incorporates the influences of the commercial program rebates.

The nested logit model specification has a dependent variable with a value of either zero or one. Customers are given a value of one indicating their actual equipment choice and a zero for all non-chosen alternatives. The nested logit model specification is defined as:

$$EE\ Choice = \alpha' Rebate + \beta' MeasureCost + \rho' X + \gamma' Y + \delta' Z + \varepsilon$$

The coefficients on *Rebate* and *Measure Cost* apply to all equipment choices. The explanatory variables *X*, *Y*, and *Z* contain choice-specific variables (*Awareness*, *Building Age*, *Square Feet*, *Lease*, *New*) for the T8, T5, and No-Purchase equipment choices, respectively. These coefficients are estimated for three of the four choices, and in this model, the T10/T12 equipment option is treated as the base case and therefore dropped from the estimation.

Table 2 shows the specific variables included in the nested logit model.

3 For a full technical discussion of the nested logit model specification, see *Limited-Dependent and Qualitative Variables in Econometrics* by G. S. Maddala, Cambridge University Press (1992).

4 Additional detail on the participant and nonparticipant surveys, including copies of the survey instruments, are provided in the full impact evaluation report *Small Commercial Contract Group Direct Impact Evaluation Report* Prepared by Itron for the CPUC (February 9, 2010).

Table 2. Description of Model Variables

Variable	Description	Data Type	Source
Rebate	Rebate available to each business for T5 and T8 linear fluorescent; Rebate equals zero for T10/T12 and no- purchase options and for all choices if unaware of EE program.	Continuous	Tracking data, evaluator calcs
Measure Cost	Purchase cost associated with each lighting choice; For no-purchase option, cost is equal to 1/15 of cost of T10/T12 lighting cost as an estimate of annual maintenance cost.	Continuous	Tracking data, evaluator calcs
Awareness	Indicates awareness of EE program.	Binary	Part / Nonpart Survey
Building Age	Age in years of building.	Continuous	Part / Nonpart Survey
Building Sq Ft	Natural logarithm of square feet. Log specification was chosen as way to break collinearity relationship with rebate and measure cost variables, which are based on square feet of facility.	Continuous	Part / Nonpart Survey
Lease	Indicates that the business leases their building.	Binary	Part / Nonpart Survey
New	Indicates whether business is in the new 2006-08 program sample or in the old 2004-05 program sample.	Binary	Part / Nonpart Survey

As discussed above, both the nested logit model and the self-report method were used to estimate net impacts by simulating which high efficiency lighting purchases would have been made in the absence of the rebate program. The final analysis results for both methods are discussed below.

Analysis Results

Self-Report Analysis Results

With the self-report approach, the free ridership calculation is based on a multi-step process that considers a variety of ways in which the program may influence a customer to adopt an energy-efficient measure. Based on the phone survey results, the self-report algorithm derived four separate measurements of free-ridership from different inquiry routes. These four measurements were averaged to derive the final free-ridership estimate at the measure level.

- The first measurement consisted of responses to a series of yes/no questions that measured the impact of the program on the quantity, efficiency, and timing of the purchase.
- The second measurement consisted of a 0-10 scale that asked the likelihood that the respondent would have purchased the same exact high efficiency measure in the absence of the program.
- The third measurement combined responses to the quantity and timing questions with responses to a 0-10 scale that asked the respondents' agreement with the statement that, in the absence of the program, they would have paid the additional rebate amount to buy the high efficiency equipment on their own.
- The final measurement combined responses to the quantity and timing questions with responses to a 0-10 scale that asked respondents' agreement with the statement that the program was a critical factor in their decision to purchase the high efficiency equipment.

In cases where responses were inconsistent among the four measurements, an analyst reviewed responses to open-ended questions that asked for clarification of the inconsistency, and recoded the four measurements if needed.

Table 3 presents the self-report results for linear fluorescent and high bay lighting based on the self-report methodology. In this table, the net-to-gross ratio is presented, which is calculated as one minus the self-report free ridership rate. Results are weighted by both the *ex ante* kWh and kW savings to obtain the overall net-to-gross ratio. The weighted net-to-gross ratio is then applied to the total gross *ex ante* savings to produce the final net *ex post* program impacts for each measure.

Table 3. Free-Ridership Findings by Lighting Measure and Utility

Measure	Utility	Self-Report NTG
Linear Fuorescents	PG&E	73%
	SCE	79%
	SDG&E	87%
	Statewide	79%
High Bay Lighting	PG&E	68%
	SCE	68%
	SDG&E	95%
	Statewide	73%
Combined	Statewide	78%

Nested Logit Model Results

The discrete choice model combines customers' responses about their equipment choices and purchase decision process with information on measure costs and savings impacts to estimate the probability that alternative equipment options will be chosen. Coefficient estimates from the nested logit model are shown in Table 4.

Due to the structure of the nested logit model, the coefficients are not directly interpretable as elasticities or probabilities. The only directly interpretable information on the coefficients is their sign (either positive or negative) and the vast majority of the coefficients have the expected sign. For example, the sign on *Rebate* is positive, indicating that an increase in value of a rebate will increase the probability of taking a particular action (e.g., purchasing energy efficient lighting). Likewise, the sign on the *Measure Cost* variable is negative, indicating that as the cost of a measure increases, the likelihood of choosing that measure decreases. The choice- specific program variable (*Awareness*) also has the expected positive sign for the T8 and T5 options, relative to the T10/T12 base case.

Within the nested logit model, certain coefficient estimates apply to all choices—the *Rebate* and *Measure Cost* variables—and other coefficients are estimated for three of the four choices. Because there are four choices for the nested logit model (T10/T12, T8, T5, No-purchase), there are three sets of such coefficients. For the results shown in Table 4, *T10/T12* represents the base case.

The last two coefficients in Table 4 are the inclusive values (IV) parameters. The IV parameters link the two levels of the nested logit model and are used in such calculations as consumer surplus or perceived benefit of each of the choices. As is common in nested logit model estimation, one of the two IV parameters is fixed (in this case at 1.0) and the other is allowed to vary. The value of the (free) IV parameter must lie between 0 and 1.0 in order for the nested logit model to be consistent with utility maximization. In this case, the value of the free IV parameter, 0.95, is statistically significantly less than 1.0 and greater than 0, thus the nested logit model is consistent with economic theory relating to utility maximization.[5]

5 See Maddala p. 73 for additional discussion on the relationship between the nested logit model and utility maximization.

Table 4. Nested Logit Coefficient Estimates

Variable	Coefficient	Std Err	t-stat	Prob
Rebate	0.00025	0.000002	148.757	< 1%
Measure Cost	-0.00009	0.000001	-131.103	< 1%
Coefficients for T8 Linear Lighting Purchases				
Awareness	0.21772	0.01503	14.486	< 1%
Building Age	-0.02148	0.00018	-118.933	< 1%
Log Square Feet	-0.35321	0.00119	-297.155	< 1%
Lease	-0.61057	0.00924	-66.106	< 1%
New	0.20722	0.01014	20.441	< 1%
Coefficients for T5 Linear Lighting Purchases				
Awareness	0.67203	0.01073	62.62	< 1%
Building Age	-0.01712	0.00023	-73.682	< 1%
Log Square Feet	-0.20427	0.00257	-79.421	< 1%
Lease	-0.47872	0.00739	-64.796	< 1%
New	0.18055	0.00724	24.936	< 1%
Coefficients for No Linear Lighting Purchases				
Awareness	0.86069	0.02490	34.565	< 1%
Building Age	-0.04276	0.00065	-65.524	< 1%
Log Square Feet	0.04482	0.00452	9.907	< 1%
Lease	-0.58096	0.02016	-28.815	< 1%
New	-1.56074	0.02273	-68.677	< 1%
Inclusive Value Parameters				
No EE LL Nest	1	***Fixed Parameter		
EE LL Nest	0.954225	0.00938	101.679	

Once the model is estimated, the coefficient estimates are combined with data on the various equipment choice options to determine the probability that any of the four purchase/equipment options are chosen. After the probabilities are calculated, the net-to-gross ratio is calculated using the change in probability of purchasing high efficiency equipment with and without the program. As shown in the formula below, the net- to-gross ratio is the difference in the probability of purchasing high efficiency equipment with and without the program divided by the probability of purchasing the high efficiency option with the program:

$$NTG = \frac{Prob_{Totalj}^{W} - Prob_{Totalj}^{WO}}{Prob_{Totalj}^{W}}$$

Where :

$Prob_{Totalj}^{W}$ = *Probability of choosing equip option j WITH the Commercial Rebate Program in place*

$Prob_{Totalj}^{WO}$ = *Probability of choosing equip option j WITHOUT the Commercial Rebate Program in place*

Once the equipment purchase probabilities were calculated from the nested logit model results, a simulation was performed using the estimated coefficients from the nested logit model to calculate a net-to-gross ratio for T8 and T5 linear lighting. The simulation exercise examined the change in the probability of purchasing either of these linear lighting options without the rebate associated with the program and without awareness of the program.

For the combined programs covered in the evaluation, this method resulted in a net-to-gross ratio estimate of 77%, as shown at the bottom of Table 5. To calculate the net-to-gross ratios, the participant subgroup of linear fluorescent and high bay lighting purchasers was divided into quintiles based on expected kWh savings for each customer, and net-to- gross ratios were calculated for each quintile. A weighted average of the ratios for each quintile was calculated to arrive at the overall program net-to-gross ratio reported below.

Net-to-gross ratios were also calculated separately for linear fluorescent and high bay lighting measures for each IOU and these are shown in Table 5. These were calculated by the same method as described above.

Table 5. Net-to-Gross by IOU for Express Program Participants

Measure	Utility	Nested Logit NTG
Linear Fuorescents	PG&E	64%
	SCE	78%
	SDG&E	68%
	Statewide	73%
High Bay Lighting	PG&E	87%
	SCE	92%
	SDG&E	89%
	Statewide	89%
Combined	Statewide	77%

Table 6 compares the resulting net-to-gross ratios for the self-report and discrete choice methodologies, by lighting technology and utility. Note that the participants included in the model sample are the same ones that participated in the phone survey that produced the self-report net-to-gross estimates described above.

Table 6. Comparison of Self-Report and Discrete Choice Results by Measure and IOU

Measure	Utility	Self-Report NTG	Nested Logit NTG
Linear Fuorescents	PG&E	73%	64%
	SCE	79%	78%
	SDG&E	87%	68%
	Statewide	79%	73%
High Bay Lighting	PG&E	68%	87%
	SCE	68%	92%
	SDG&E	95%	89%
	Statewide	73%	89%
Combined	Statewide	78%	77%

Overall, at the statewide level across both linear fluorescent and high bay lighting measures, net savings are within 1% of each other for the two methods (the self-report method results in slightly higher overall net savings). Statewide, the self-report values for linear fluorescents are 6% higher; for high bay lighting, discrete choice values are 16% higher. The linear fluorescent values for both approaches are based on a larger sample size, so it might be expected that there is more variation among the high bay lighting results.

One possible explanation for the different estimates obtained from the self-report and the discrete choice approaches is the level at which each of these estimates was developed. For the discrete choice model, a single model was run statewide that combined both measures across all IOUs. The model results were then used to calculate separate weighted net-to-gross ratios by measure and IOU. In the case of high bay lighting, the rebates were higher on average (20%) than those for linear fluorescents, which lead to the higher net-to-gross ratios (relative to T8s) when using the discrete choice model results. In contrast, the self-report was done separately for each customer (and therefore separately by IOU and measure). Consequently, one might expect variability when comparing results at the IOU and measure level between the two methods. As mentioned, when comparing a weighted net-to-gross ratio statewide across both measures, the ratios differ by only one percent.

Because the overall values differ by only one percent, the original impact study recommended that the self-report results be used for all measures, as this provided a consistent approach applied to all the lighting measures in this evaluation. While the nested logit model results were not used in the final impact estimates, they did help corroborate the results derived from the self-report results for the linear fluorescent and high bay lighting measures.

Summary and Conclusions

Both the self-report analysis method and the discrete choice model were used to develop estimates of net impacts for the same commercial energy efficiency programs. Although the methods were conducted independently (and did not rely on each other), the net impact estimates were quite similar for linear fluorescent and high bay lighting. At the state level, the estimated net-to-gross ratios only differed by 1% between the two methods for both measures combined.

The consistency of the results across the two methods helps address a primary concern with the self-report method, namely that the results may not be accurate due to the challenges associated with collecting these type of data from customers. Concerns along these lines often focus on customers' ability to remember accurately their decision process for purchasing the equipment, especially if the decision was made over a long period of time. In this study, the nested logit helps corroborate the self-report results, thereby providing more confidence in the final net-to-gross estimates for these measures.

References

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