Why the light bulb is no longer a textbook example for price elasticity: Results from choice experiments and demand modeling research

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Abstract

An internet search for textbook examples of "price elasticity" invariably delivers the following demand equation: "the quantity of light bulbs demanded is an inverse function of the price of light bulbs" (i.e., as the price of light bulbs rises, the quantity of light bulbs demanded falls). However, is it really that simple? Recent research from California suggests that the demand for light bulbs has become increasingly more complex, as new lighting technologies serving multiple applications with varying efficiency levels have become more readily available due to changes in policies, standards, supply side business models, and ultimately consumer demand. This paper will present the results of consumer intercept surveys completed with nearly 1,000 randomly selected shoppers in 200 lighting retail stores. Data from these surveys formed the inputs to a series of choice experiments and demand models. Preliminary results suggest that while changes in light bulb purchases remain largely influenced by price, there are a number of other factors that explain customer choice – such as, whether the light bulb was a planned or "impulse" purchase, how many light bulbs are needed at the time of purchase, what type of light bulb was used prior to the purchase of a replacement, what task or application the light bulbs is being used for, and how often the light bulbs will used. Understanding and quantifying the influence of these other factors can help inform lighting policy and program design to more effectively address non-price barriers.

Introduction

Light bulbs are no longer the commodity product that they once were. Residential lighting is both a large category of electrical demand (10–15 % of residential demand in the United States) and a market is undergoing a rapid transformation. Within the past decade, incandescent bulbs have lost their status as the near universal choice for lighting technology. In California, compact fluorescent lamp (CLF) are becoming the preferred technology for some applications and light emitting diode (LED) lamps are now in 1.3 %. This market transformation is part due to energy efficiency programs that promote the adoption of relatively efficient CFL and LED bulbs[1]. The success that energy programs have had in transforming the lighting market has generated a new set of issues for efficiency program planners and evaluators. The lighting market is full of choices. Calculating the basic price elasticity of demand ignores the complex substitution options that consumers have.

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1. In addition, legislation was passed in the United States that will have substantial influence on the sale of lighting for general purpose use, beginning in 2012 and carrying forward through 2014. Per the Energy Independence and Security Act of 2007 (EISA), the U.S. prohibits manufacture or importation of general purpose lamps that fail to meet specific efficacy requirements based on their range of light output (measured in lumens). The regulation took effect in January 2012 for lamps with light output in the range typically generated by 100 Watt traditional incandescent lamps (1,490–2,600 lumens). In January 2013, the regulation affected lamps with light output in the range traditionally generated by 75 Watt traditional incandescent lamps, and will continue to phase in until January 2014 for lamps with light output in the range typically generated by 40 and 60 Watt traditional incandescent lamps. EISA does not prohibit sale of lamps that have already been manufactured or imported prior to the date on which the regulation takes effect. Through California Assembly Bill 1109, the California Lighting Efficiency and Toxics Reductions Act (also passed in 2007), the state of California adopted the same efficacy requirements as EISA but began each phase of the regulation one year earlier in California than the rest of the U.S. (i.e., AB 1109 affected lamps with light output in the 1,490–2,600 lumen range starting in in January 2011). AB 1109 also does not prohibit sale of lamps that have been manufactured or imported prior to the date on which the regulation takes effect.

The California Public Utility Commission (CPUC) engaged DNV KEMA Energy and Sustainability (DNV KEMA) to quantify the impacts that efficiency programs have in the California residential lighting market. Two of DNV KEMA's activities for the CPUC include: (1) recording available lamp products by retail channel and (2) estimating the change in market shares of lamp technology due to the program influence. DNV KEMA sampled 200 retail stores throughout California. At each location, DNV KEMA conducted a shelf inventory and a series of customer intercept surveys. The shelf inventories record a census of available lighting products. The intercept surveys record both revealed and stated preferences on customers and attributes about purchase decisions. DNV KEMA designed the intercept survey instrument to produce data for discrete choice model of customer choice. The discrete choice model estimates market shares for each technology by lamp style. Discrete choice models frame the probability of a customer choosing a lamp as a response to the factors that influence the customer's decision process. This paper primarily reports on the intercept survey.

The organization of this paper is as follows. The paper first discusses an innovative approach to developing the stated preference data that discrete choice models require. This discussion also reports on the effectiveness of the data collection approach. Next, the paper gives a preliminary description of the data.[2] The subsequent sections describe the discrete choice model framework and preview the results.

Intercept Survey Design

DNV KEMA conducted a series of intercept surveys to capture preferences for lamp technologies. The interviewers talked to both purchasers (i.e., customers who have lamps in their basket) and non-purchasers. When a customer buys a lamp, the customer typically buys the lamp for a specific application, such as replacing a recently burned out lamp. Knowing the intended application for lamp purchase is useful information. This information informs the discrete choice model that a lamp has a higher utility for particular application.

The intercept survey asks respondents a series of questions that explore the buying situation and a series that asks the respondent to play a stated preference game. The first series includes questions to understand the application use, the market segment and housing and household characteristics. What makes this survey innovative is its use of an iPad to customize a stated preference game to what is in the respondent's basket. The remainder of this section describes the variables available to the lamp choice model and the stated preference game.

APPLICATION USE

The intended application use a lamp should help explain lamp choice. Consumers may accept a CFL twister, for example, in basement but strongly prefers an incandescent for use in a desk lamp. For consumers that intend to install their purchase within the next week, the intercept survey yields the following variables for the lamp choice model:

- **Installation room** – e.g., living room, kitchen.
- **Fixture type** – e.g., ceiling, table lamp.
- **Dimmable required** – whether the lamp will be in a fixture with controls for dimming.

MARKET SEGMENTATION

The intercept asks a series of questions to understand whether the respondent is making a *targeted* or *opportunistic* purchase. Consumers that target their shopping to a particular store to buy a particular lamp will react differently to prices than an opportunistic shopper. The targeted shopper will be relative price inelastic compared to the consumer that decides to buy a lamp only after seeing the lamp is on sale. The lamp choice model reflects the different price elasticities through *market segmentation*. The intercept survey yields the following variables that describe the market segmentation of the consumer:

- **Targeted store** – whether the respondent intend to buy lamps at this store.
- **Targeted style** – whether the respondent intended to buy the lamp style.
- **Targeted technology** – whether the respondent intended to buy the lamp technology.

HOUSING AND HOUSEHOLD CHARACTERISTICS

The choices consumers make vary with the structure and size of the consumer's housing and household structure. Highly educated consumers may be, for example, more likely to buy LED or CFL lamps. The intercept survey yields the following variables to understand housing size and household structure:

- **Bedrooms** – number of bedrooms in the house.
- **Bathrooms** – number of bathrooms, with half baths as ½, in the house.
- **Occupants** – number of people who live in the household year round.
- **Education** – highest level of education completed.
- **Household income** – household income in categories.

STATED PREFERENCE

The last component of the intercept survey consists of two parts:

- **Preference ranking** – the survey instrument (an iPad) presents a set of lamp alternatives. Each alternative is reasonable substitute for the other alternatives. Figure 1 is an illustration showing the actual text and images for A-lamp or Twisters. The survey instrument shows only alternatives that a consumer is likely in the retail channel where the survey takes place. For example, a respondent will not see a LED lamp as part of the choice set in the discount channels as discount channel stores typically do not stock LED lamps. Also note:
  - Purchasers taking the survey see the lamp that is in their basket as one of the choices. This prevents the stated preference from being completely hypothetical.

2. The data collection is approximately 70 % complete as of February 10, 2012. The final paper will reflect the results of the full data collection effort.

Figure 1. Lamp Preference Ranking in the Survey Instrument.

- – The instrument shows randomized prices that are consistent with the typical prices by retail channel.

- **Price quantity response** – the survey instrument takes the preferred choice from the ranking exercise and asks the respondent how many would lamps would he or she buy. The instrument than varies the price up and down and asks again for the quantity that the respondent would buy. This result is the quantity a consumer would buy at three price points. This information is useful for calculating the demand response to price.

Intercept Survey Collection Performance

There are three targets that the interview team needed to meet to be successful. First, the team needed to conduct the intercept surveys in a reasonable amount of time to prevent survey fatigue. Surveys that take much more than five minutes to complete can lead to poor response quality. Second, the team needed to capture a large proportion of purchasers. The lamp choice model uses attributes about the purchase decision to explain choice. The interviews with non-purchasers do not result in a rich set of explanatory variables. Third, the stated preference game needed to result in not one technology that clearly dominating all other technologies. One technology dominating all others results in a mode that cannot be estimated.

Table 1 shows the average intercept survey response times by retail channel. The results show that the interview team was able to keep the response times near or under five minutes for most of the retail channels. The purchaser surveys take longer than the non-purchaser surveys since the interviewers only ask lighting application questions to purchasers. The hardware, home improvement, mass merchandise and membership club channel stock a much greater variety of lamps than other channels. As a result, the stated preference games contain more options and appear to take longer to play. That the grocery channel purchaser survey took on average of over six minutes to complete is not a source of concern. As show in Figure 2, the interview team found only a few lamp purchasers in the grocery channel.

The data include 1,070 intercept interviews: 598 non-purchasers and 472 purchasers. Figure 2 shows the number of observations by retail channel and survey type. The home improvement, mass merchandise and membership club retail channels had substantially more purchaser than non-purchaser surveys. In the grocery, drug and discount channels, interviewers were not as successful in finding purchases. Hardware stores have a near even split between purchasers and non-purchasers.

Finding a low number of purchasers in the grocery and drug channels was a concern prior to conducting the interviews. However, that the interview team was not able to capture a large number of purchasers for these channels is not a large concern. These channels tend to serve a smaller portion of residential lighting market.

Figure 3 shows the number of observations by the preferred lamp technology for each lamp style. The model estimation requires that there is not an alternative completely dominated by all others. That is, the model estimation cannot handle data where a particular alternative is always ranked last. That is not case in these data. CFLs are selected as the highest ranked choice for a-lamps and twisters.

Lamp Choice Model

The price elasticity of demand – the percentage change in quantity due to a percentage change in the price – is a useful concept for understanding the impacts or potential of efficiency programs. Programs incentivize (or penalize) the cost of one product in order to decrease (or increase) the demand of another. The intercept survey asks respondents how they would respond to price. Figure 4 shows estimated price elasticity of demand. The results show a large variation in price elastici-

Table 1. Average intercept survey response times.

		Average Time		
Channel	Stores Completed	Non-Purchasers	Purchasers	All Intercepts
DISCOUNT	29	03:58	04:55	04:14
DRUG	29	03:39	04:21	03:43
GROCERY	28	04:19	06:13	04:25
HARDWARE	29	04:22	05:49	05:05
HOME IMPROVEMENT	28	04:25	05:54	05:21
MASS MERCHANDISE	29	04:30	05:34	05:14
MEMBERSHIP CLUB	28	04:36	05:46	05:23
OVERALL	200	04:11	05:39	04:50

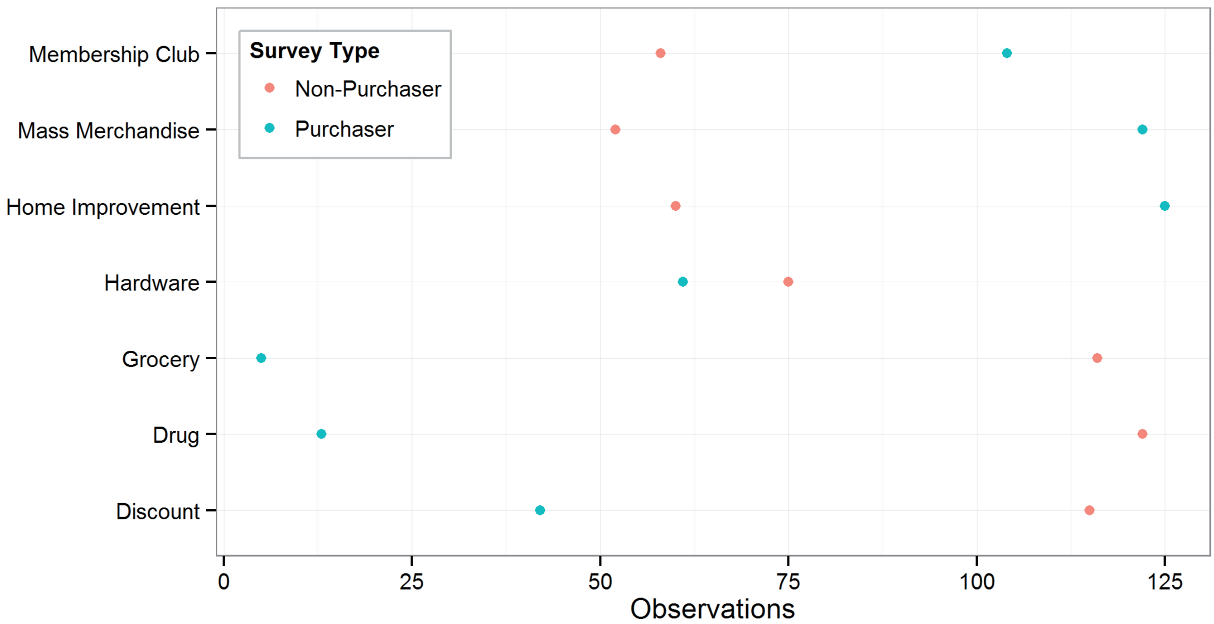

Figure 2. Observations by retail channel and survey type.

ties. The estimates range from perfectly inelastic responses – no quantity as a result of a price change – to very elastic responses where a 10 % change in price will lead to over a 30 % change in demand. The large variation in elasticity values suggests using a more sophisticated methodology to predict the response to program incentives.

One common method is using a discrete choice model to predict market shares. Discrete choice models represent the probability of an outcome as a response to variables that describe the choice. This facilities scenario – what happens if the prices of a particular lamp technology change – in ways that other techniques, such as conjoint analysis do not allow. The discrete choice approach estimates relationships between choices and choice attributes that hold for a variety of scenario testing.

This section describes how to build discrete choice model to predict consumer choices when buying lamps. Discrete choice models are useful to describe a decision making process where the decision maker must choose an alternative rather than an amount. The goal of discrete choice modeling is to approximate how individuals value the alternatives in the market.

The remainder of this section describes the details of building a model for calculating market shares. The following subsection explains the concept of choice sets. The subsequent subsection gives a general model specification. The general specification identifies the likely form and variables that the final model will include. The final subsection outlines an approach for using the lamp choice model to estimate market shares.

CHOICE SETS

The lamp choice model design imposes some structure onto lamp choices to make this problem tractable. The most basic is to ignore lamp branding and package quantity. Trying to pre-

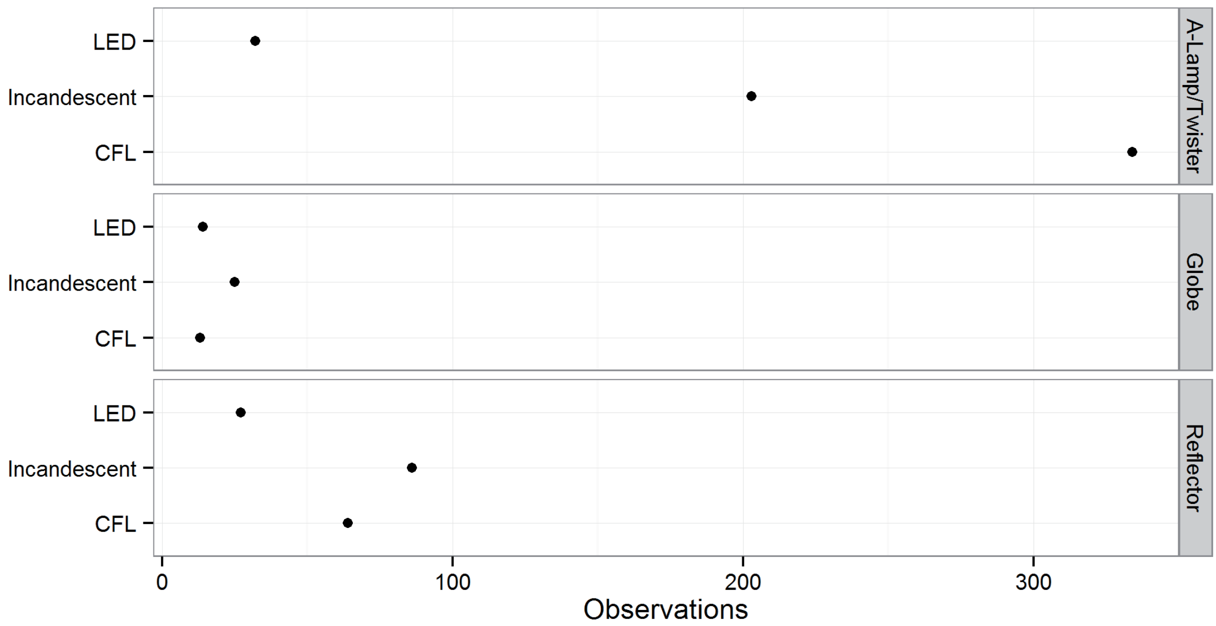

Figure 3. Observations by preferred lamp style and technology.

dict consumer choice around branding adds complexity to the model without any benefit. The choice lamp model ignores the number of lamps in a package. The purchase quantity is the responsibility of a different model. This subsection describes the generalizations of lamps into a choice sets.

The lamp choice model design calls for four separate logit models, one for each of the predominant lamp styles (A-lamp or twister, reflector/flood and globe) plus a separate model for three-way A-lamps or twisters. Choice sets should represent groups of alternatives that are reasonable substitutes. There are separate models by lamp style as lamps from one style are poor substitutes for lamps in another style. Likewise, three-way A-lamps or twisters lamps are very different from standard A-lamps or twisters. Within each choice set, the choice the consumer makes is which technology to buy.

Manufactures produce lamps in a myriad of wattages and brightness levels. To simplify these options into a discrete set of alternatives, Table 2 groups lamps into lumen brightness bins. Most consumers are not aware of lumens as a measure of brightness. However, manufacturers market lamps in terms of incandescent wattage equivalents. The lumen bins provide a useful framework for comparing lamps across technologies and for grouping similar lamps within a technology.

The model design does not, however, allow for substitution across brightness bins. Consumers can and do replace a lamp in one brightness level with a lamp in another. However, this is typically not the case. Trying to incorporate substitution across brightness levels into the model would impose additional difficulties in the intercept survey and would result in a more complex model design. The intercept survey prohibits a consumer that is about to buy a high brightness lamp from seeing medium or low brightness lamps. Similarly, the model estimation procedure will use characteristics of high brightness lamps (e.g., price and EUL) across each of the technology alternatives to mirror the intercept survey.

The final aspect of the model structure relates to the retail channel. Not all lamps are available in each retail channel. Consumers in a discount store generally will not have the opportunity to purchase an LED A-lamp for example. The model design reflects the difference in choice set by retail channel through *availability* restrictions. The intercept survey presents only the choices a consumer is likely to see in the retail channel where the survey takes place. Likewise, the model estimation prohibits choices that are not available by retail channel.

GENERAL SPECIFICATION

This subsection presents a general model specification. The particular form of discrete choice models shown in Equation (1) is the logit model. Logit models express the probability of the discrete choice *i* as the exponentiated *utility* of choice *i* over the sum of the exponentiated utilities of all choices.

$$\Pr(i) = \frac{\exp(U_i)}{\sum_{j \in J} \exp(U_j)}$$

Equation (2) gives the general specification for a utility equation that describes the value of a lamp. The final specification depends on an exploration of the intercept survey results and on the results from the model estimation.

$$\begin{aligned} U_j = {} & \beta_{0,j} + \beta_{1,j} Price + \beta_{2,j} EUL + \beta_{3,j} Watts + \beta_{4,j} RoomType \\ & + \beta_{5,j} FixtureType + \beta_{6,j} Education + \beta_{7,j} RetailChannel \end{aligned}$$

where:

U_j is the utility of lamp technology *j;*

$\beta_{0,j}$ is the alternative specific constant for technology *j;*

β_1 to β_3 are the coefficients common to all technologies*;* and

$\beta_{4,j}$ to $\beta_{7,j}$ are the coefficients specific to technology *j*.

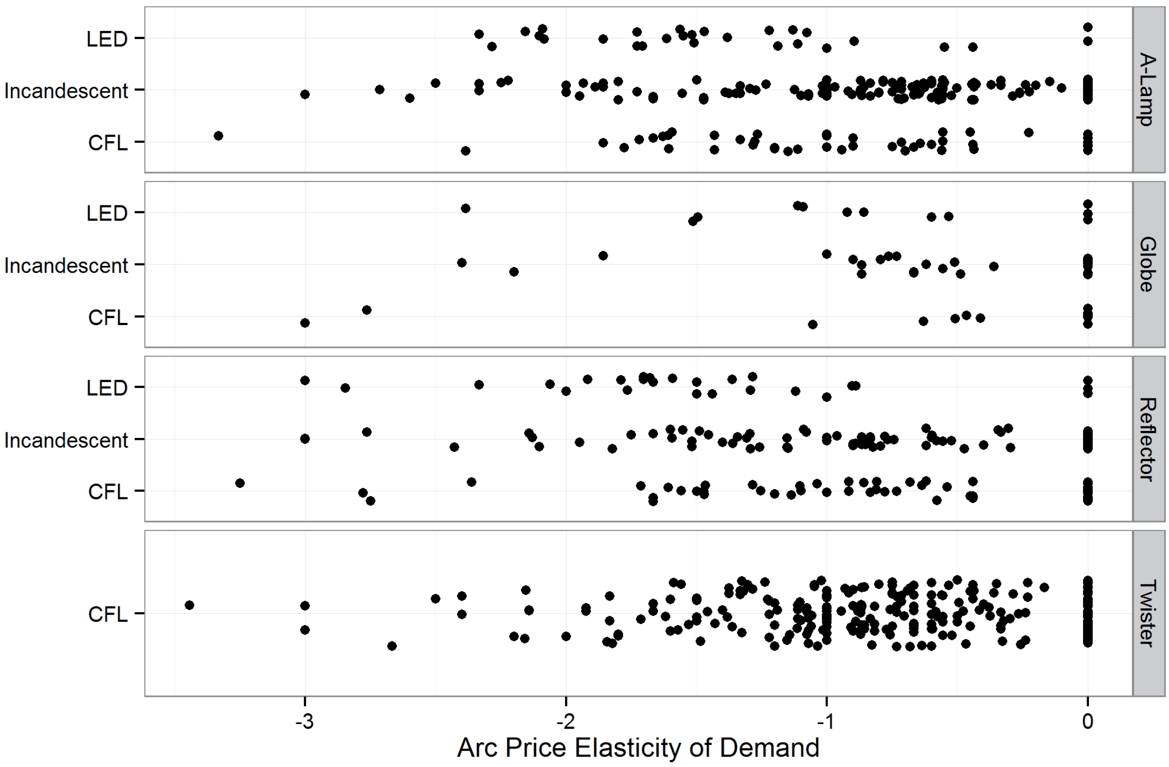

Figure 4. Arc Price Elasticities of Demand for individual responses by lamp style and technology.

Table 2. Lamp Brightness by Lamp Style.

Lamp Brightness Category	A-lamp and Twisters	Reflectors/ Floods	Globes	Three Ways
Very High Brightness (>2,099 lm)		X		
High Brightness (1,200–2,099 lm)	X	X	X	
Medium Brightness (700–1,099 lm)	X	X	X	
Low Brightness (65–699 lm)	X	X	X	
Any Brightness				X
Dimmable	X	X	X	

Note that since only the relative utility levels matter, the model sets the alternative specific constant for one of the alternatives to 0.

The design uses a common coefficient across the price, EUL and the wattage for each of the lamps. This reflects that consumers value these attributes independently from the technology. A price increase to one technology will have an equivalent effect to a price increase to an alternative technology.

The remaining coefficients reflect variations in the consumer and how consumers intend to use the lamp. Consumers may prefer incandescent lamps for applications with relatively few hours of use, such as in basement or closet. Highly educated consumers may be more environmental conscience or see a CFL or LED purchase as an investment over longer periods of time. The proposed model specification captures this effect through coefficients specific to consumers' education attainment. Similarly, the model specification accounts for consumers may show retail specific effects with a coefficient particular to a retail channels and technology.

The model specification shown above does *not* address differences in price sensitivities due to income level. This can be handled in one of two ways:

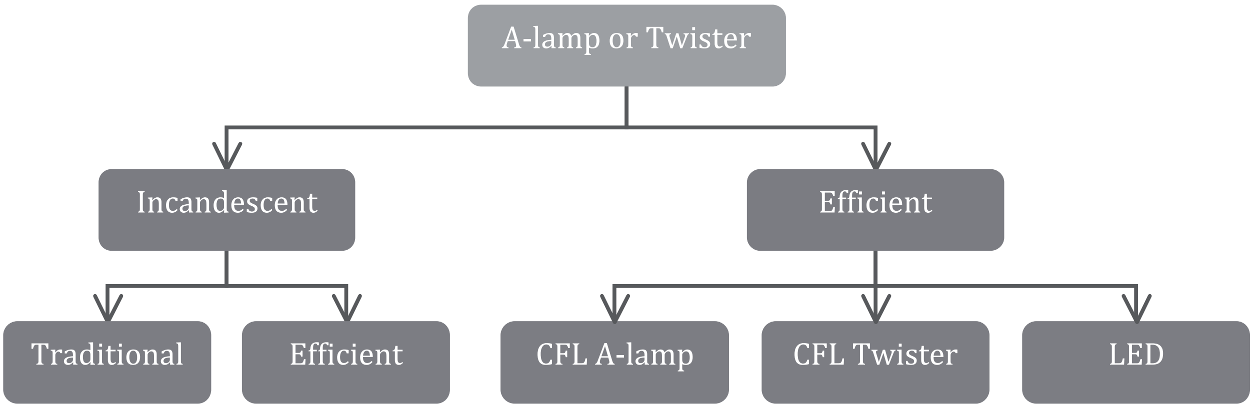

Figure 5. Proposed Nesting Structure.

1. Create price sensitivity coefficient by income groups.
2. Treat the coefficient on price as a random variable. This approach is known a random coefficient or mixed logit model.

Approach 1 is the conceptually and computationally easier approach. The second approach has the potential to represent the price coefficient as a function of variable (e.g., income, occupants, and house structure). DNV KEMA will start with the first approach and move to the second if warranted.

The last element in the specification is a nesting structure. Consumers are *not* likely to substitute equally among all alternatives. Figure 5 shows a proposed nesting structure. The nesting structure says that consumers view incandescent lamps differently than CFL and LED lamps. Consumers find that both incandescent lamp alternatives are good substitutes compared to CFL and LED lamps. A sale on CFL twisters will pull more market share from CFL A-lamps and LED lamp than from incandescent lamps.

DNV KEMA will test the proposed model specification and nesting structure as well as similar alternative specifications during model estimation. The test for a satisfactory model is (1) produces statistically significant result and (2) tells a concise, consistent and coherent story. The first requirement ensures that model truly reflects the underlying data. The second ensures the model has the minimal amount of complexity to reflect how consumers respond to market changes. A model that meets both requirements is a model that is able to answer the impact question of what market shares would have happened in the absence of the program.

ESTIMATING MARKET SHARES

The lamp choice model estimates the probability that an individual will choose a particular alternative from a set of all alternatives. The market share is the sum of applying the model across all individuals in the market by lamp style. Figure 6 shows the process for estimating market shares.

The process combines intercept data on choice with shelf self records to form choice sets. The choice sets are the input to the lamp choice model. The details of the algorithm are as follows:

1. **Select purchase records from the intercept survey.** The intercept survey contains data on lamp purchasers. The survey records the retail channel and applications use of purchases and demographics of the purchaser. The intercept survey is the most complete source of information on customers making lighting purchasers by retail channel.

   This step selects records by retail channel and lamp style. These purchase records reflect the distribution of application uses and demographics of purchasers.

   DNV KEMA is currently exploring whether weight the intercept records is necessary.

2. **Draw lamp records from the shelf survey.** The shelf survey data contains data on the lamp prices by lamp technology, shape, retail channel and geographical location. The shelf survey records contain a complete listing of the product attributes (e.g., watts, brightness, and expected life) for each lamp.

   This step draws records from the shelf survey that match the retail channel, lamp style and geographic region of the purchase record. The shelf survey potentially contains a large number of lamps that fit the purchase criteria. The selection process randomly draws (with replacement) a set of records that meet the criteria.

   This technique is known as simulation. The technique samples observed records in order to form the distribution of prices and lamp attributes. A contrasting approach uses the average sales price as the input to the lamp choice model. Sales prices do not tend to follow a normal distribution nor are they always symmetrical around the mean. Figure 7 gives an example of lamp prices using shelf data from fall 2011 in the Home Improvement retail channel. The mean price, shown with a dashed blue line, is close to $0.50 more than the most common price. Using the full distribution of observed prices closely mimics what purchasers encounter in stores and is what survey respondents saw during the stated preference choice ranking.

   Each of the lamp records contains the lamp price, rated life, watts and the amount program discount in the price, if any.

3. **Construct choice sets.** The lamp prices need to reflect prices that are consistent with the scenario. For a scenario with program discounts, this step discounts the price on incen-

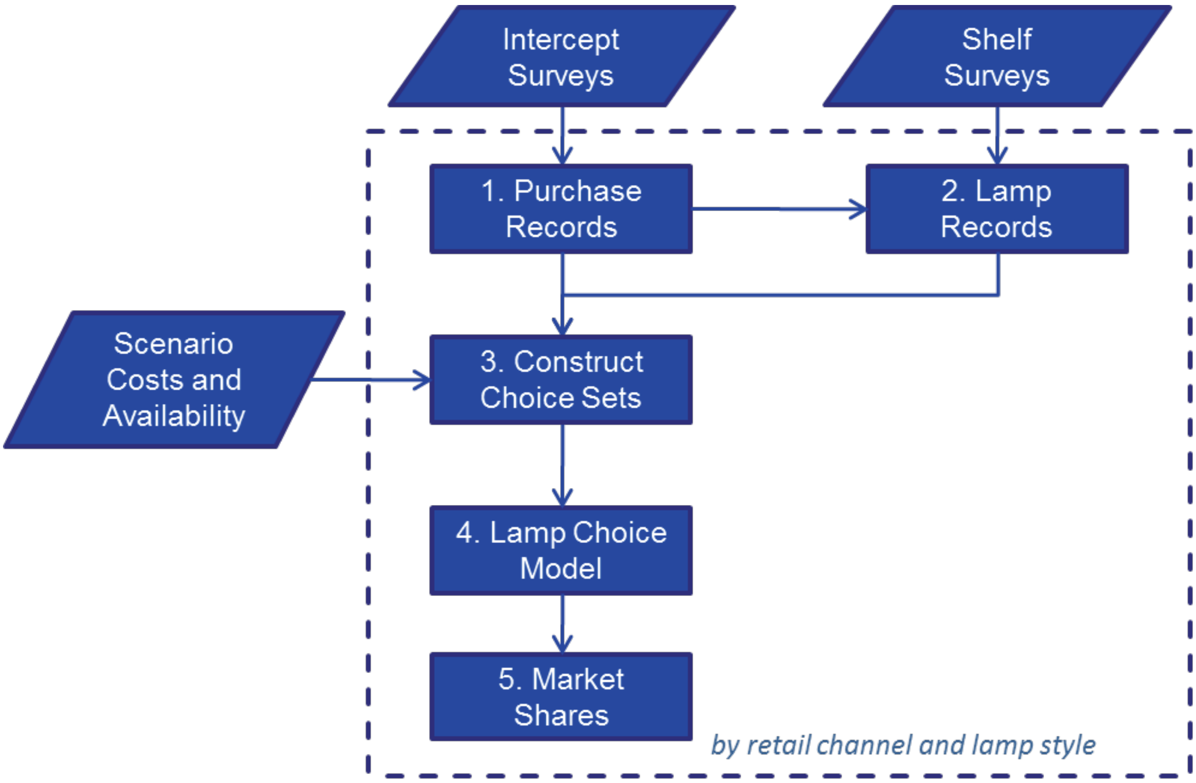

Figure 6. Overview of the market shares calculation.

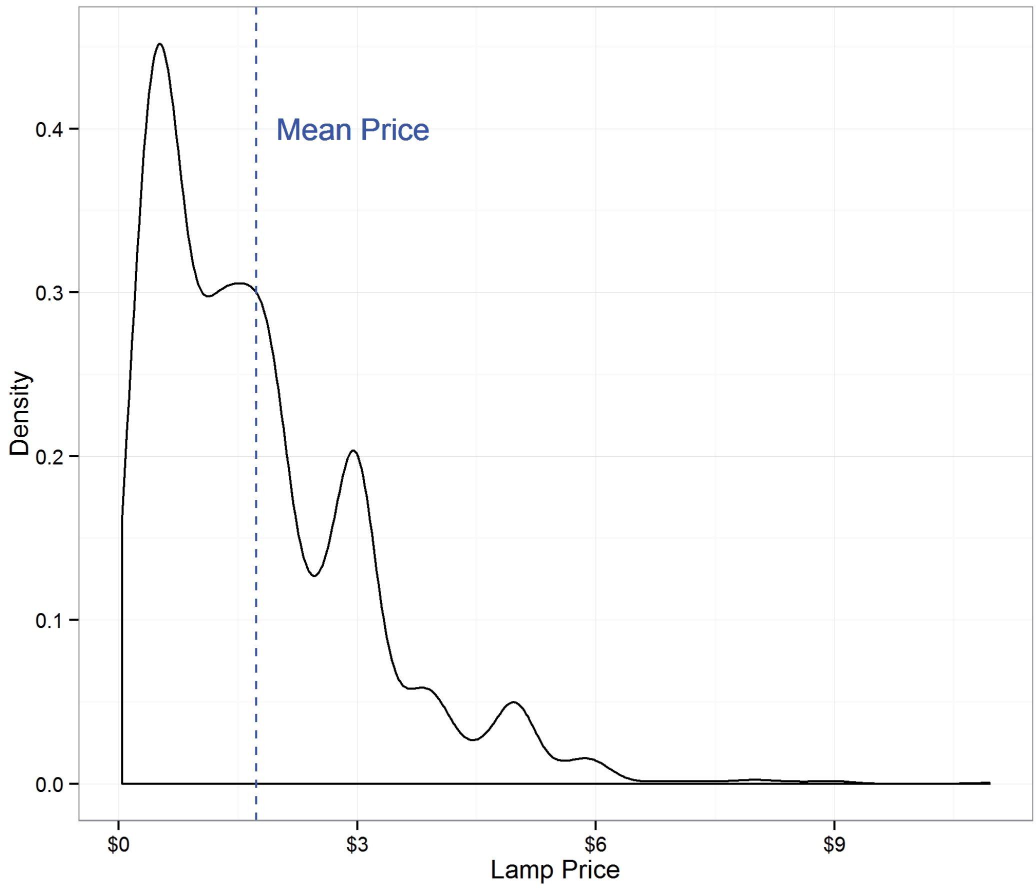

Figure 7. Price distribution and mean price of incandescent A-lamp in Home Improvement.

tivized products. For a baseline scenario, this step removes the discount. In some retail channels, e.g., discount, stores do not regularly stock more expensive lamps as the store caters to very price sensitive customers. Where this is the case, this step marks the alternative as not available for the lamp choice model.

This step results in choice sets for the lamp choice model.

4. **Apply the lamp choice model**. The lamp choice model uses the choice sets developed in step 3 and a set of estimated parameter values as inputs. The model assigns a probability to each alternative for each choice set.

Compute market shares. The market shares are the summation of individual level probabilities computed in step 4 over all records by retail channel and lamp style. The overall market share is the sales weighted average across retail channels by lamp style.

Conclusions

The lamp choice model has clear advantages for both program planners and evaluators. The model looks beyond explaining changes in market shares as solely a response to price. The model formulation recognizes that consumers take a sophisticated view when buying lamps. Consumers are willing to pay for more expensive lamps for applications with high visibility and high hours of usage. However, consumers are not willing to pay a premium for lamps in low usage applications, such as in a closet or basement. The net effect is that light bulbs are no longer the textbook example for price elasticities. The market transformation in the residential lighting market requires a transformation in the tools that program planners and evaluators need to assess the potential and impact of efficiency programs. The lamp choice model offers a framework for planners and evaluators to realistically calculate market shares due to program activity.