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MEMORANDUM

To: Massachusetts Program Administrators and EEAC Consultants

From: Chris Russell, Greg Clendenning, Michael Strom, and Lisa Wright-Wilson, NMR

Subject: LED Incremental Cost Study – Modeling LightTracker LED and Halogen Pricing Data

Date: June 30, 2015

This memo summarizes selected findings from the LightTracker LED, CFL, and halogen pricing data modeling effort and the resulting state-level price forecast through 2020 for LED, CFL, and halogen bulbs. These results are based on light bulb price data from 25 states that lacked LED programs from 2009 to 2014. It is important to note that some of the 16 states lacking LED programs *did* have CFL programs.

Data

LightTracker POS Data

These data were purchased through LightTracker, an initiative of the Consortium for Retail Energy Efficiency Data (CREED) and represent bulb sales data captured at the point-of-sale (POS) for select retail channels for 44 states across six years (2009-2014).[1] A shortcoming of the price data is the absence of home improvement and hardware retail channels, both of which can account for substantial bulb sales in Massachusetts and many other LED program states. In an earlier modeling effort it was estimated that the POS data capture roughly one-quarter of market-level sales in Massachusetts,[2] and consumers very often name these store types as the source of recently purchased bulbs.[3] Therefore, the extent to which the results of the current effort reflect bias that limits their generalizability depends on the *unknown* difference in the concentration of LED sales in reporting and non-reporting channels in the 16 non-program states compared to the excluded program states.

The team performed data cleaning of the POS data in order to refine the data to reflect typical lighting purchases. A key step was removing certain types of specialty bulbs, which included nightlights, appliance, aquarium, black lights, bug lights, string lights, and flashbulb lights. We also cleaned to eliminate possible data reporting error (in the original third party data) by inspecting price per bulb and

[1] The information contained herein is based in part on data reported by IRI through its Advantage service for, and as interpreted solely by LightTracker Inc. Any opinions expressed herein reflect the judgment of LightTracker Inc. and are subject to change. IRI disclaims liability of any kind arising from the use of this information.

[3] NMR Group, Cadmus Group. 2015. *Results of the Massachusetts On-site Lighting Inventory, 2014.* http://ma-eeac.org/wordpress/wp-content/uploads/On-Site-Lighting-Inventory-Final-Results.pdf

bulb count per package—when either of these values were abnormally high or low the Team used the more detailed bulb description to identify whether the data was erroneous.[4] We dropped all records that did not have price information, and we corrected proven bulb count per package error.[5] Last, we cleaned the data of outlier prices (e.g., extremely low or extremely high prices). We identified outliers as bulbs with prices that were more than six standard deviations from the mean bulb price of each bulb type (the data included records for bulb prices that were up to nine standard deviations greater than the mean price of a particular bulb type – LED, CFL, Halogen).

The cleaned POS data still showed a dramatic range in the prices of bulbs ranging from a low of $2 per bulb for halogens to a high of $12 per bulb for LEDs. Importantly, while CFL prices varied little and halogen prices declined rapidly, the price of LEDs counterintuitively increased for much of the study period (plot the average price per bulb and the average price per Watt by year; these graphs show that average price of a bulb tends to jump around from year to year while the average price per Watt declines steadily with the exception of 2011, an aberration that we cannot explain with the data at hand.

Another counterintuitive finding is that LED prices do not differ much between program and non-program states—and in fact average prices for these bulb types were often higher in program areas, at least until 2013 and 2014. The data do not allow us to explain this observation but a hypotheses could be that many program bulbs are sold through channels not represented in the data.

Table 1). During the course of the data cleaning process, the Team found that the higher LED prices were being driven by increased Wattage per bulb. In response, the Team normalized the bulb prices by taking the ratio of average price per bulb to average Wattage. Figure 1, Figure 2, and Figure 3 plot the average price per bulb and the average price per Watt by year; these graphs show that average price of a bulb tends to jump around from year to year while the average price per Watt declines steadily with the exception of 2011, an aberration that we cannot explain with the data at hand.

Another counterintuitive finding is that LED prices do not differ much between program and non-program states—and in fact average prices for these bulb types were often higher in program areas, at least until 2013 and 2014. The data do not allow us to explain this observation but a hypotheses could be that many program bulbs are sold through channels not represented in the data.

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[4] An example of an abnormal bulb count and price per bulb might be a record of 100 LED bulbs per package with the price per bulb being $0.10 per LED—in such a case the Team would use the model description to look up the bulb and find that the bulbs in question are actually string lights. A bulb count of three LED bulbs per package at a price of $10 per bulb would not merit further investigation.

[5] The Team identified extreme bulb per package values and when we were able to use the bulb description to look up and identify a bulb per package error we corrected the value in the data set.

Table 1. Average LED, CFL and Halogen Prices in the POS Data

Year	Price per Bulb in LED Program States n=28	Price per Bulb in Non-LED Program States n=16	Overall Price per Bulb n=44
LED			
2009	$11.92	$11.40	$11.71
2010	$9.24	$8.70	$9.03
2011	$8.60	$8.05	$8.38
2012	$10.03	$9.81	$9.94
2013	$12.28	$12.58	$12.41
2014	$10.25	$11.07	$10.59
CFL			
2009	$2.57	$2.33	$2.47
2010	$2.43	$2.22	$2.36
2011	$2.39	$2.20	$2.35
2012	$2.49	$2.36	$2.48
2013	$2.55	$2.46	$2.53
2014	$2.43	$2.33	$2.40
Halogen			
2009	$5.03	$4.97	$5.05
2010	$5.03	$4.96	$5.14
2011	$4.51	$4.55	$4.68
2012	$3.86	$3.88	$3.92
2013	$2.68	$2.58	$2.65
2014	$2.13	$2.03	$2.09

Figure 1. The Price of Non-LED program LED bulbs and Price per Watt by Year

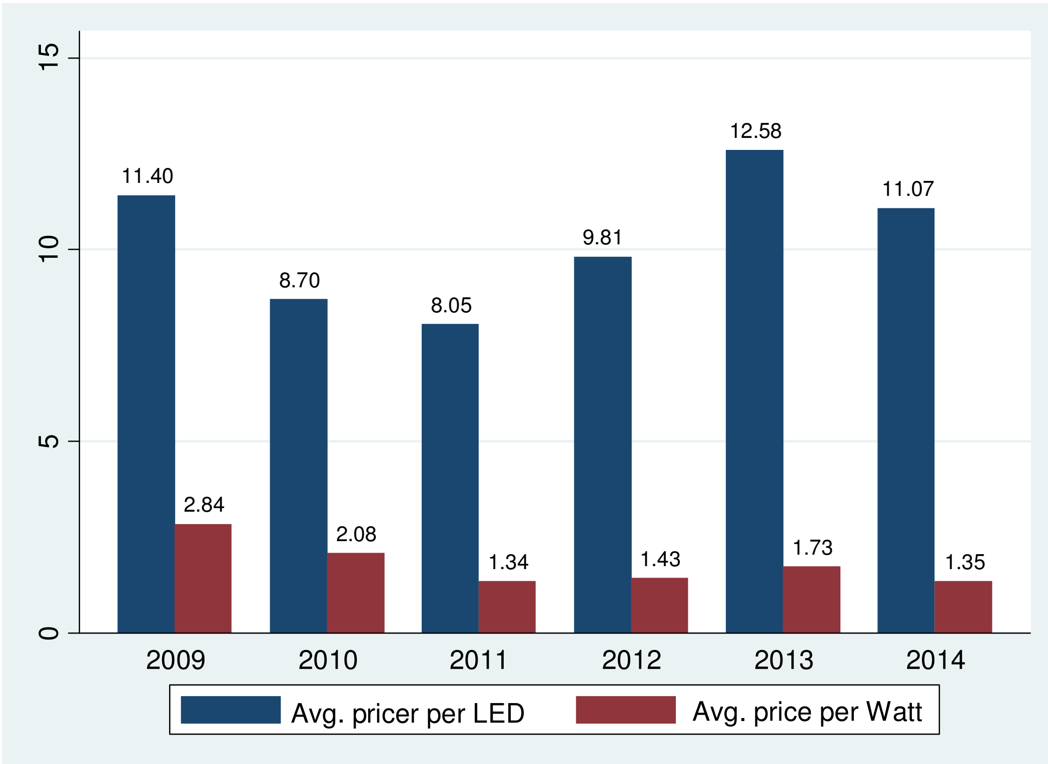


Figure 2. The Price of Non-LED program CFL bulbs and Price per Watt by Year

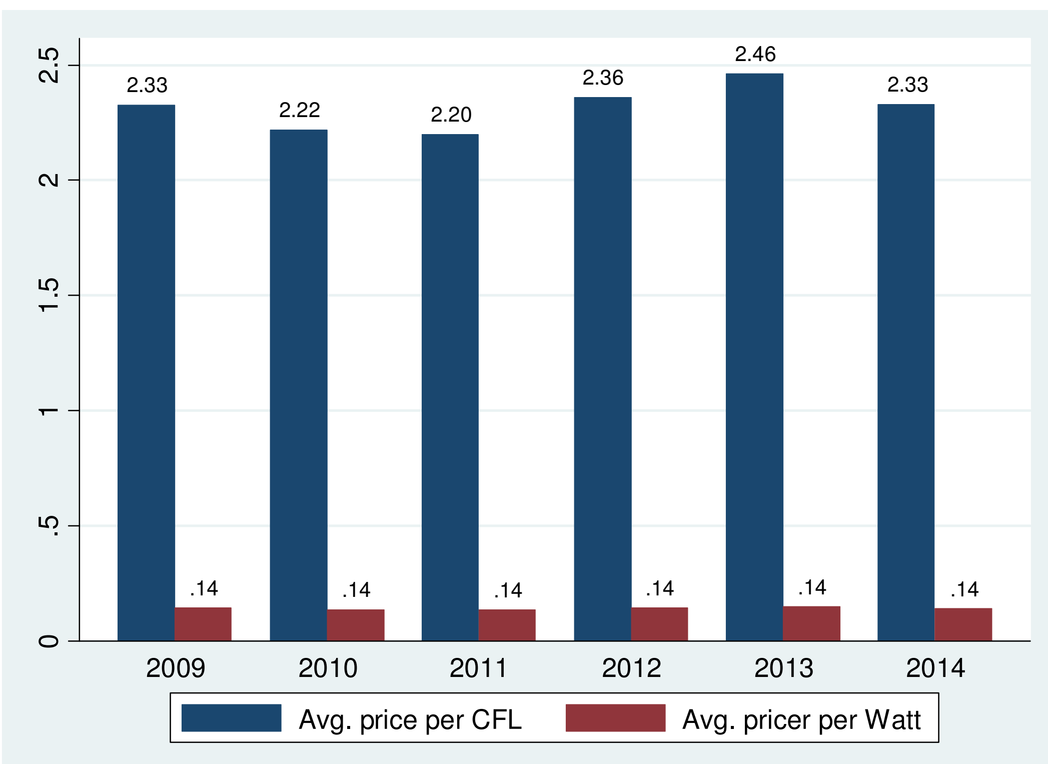
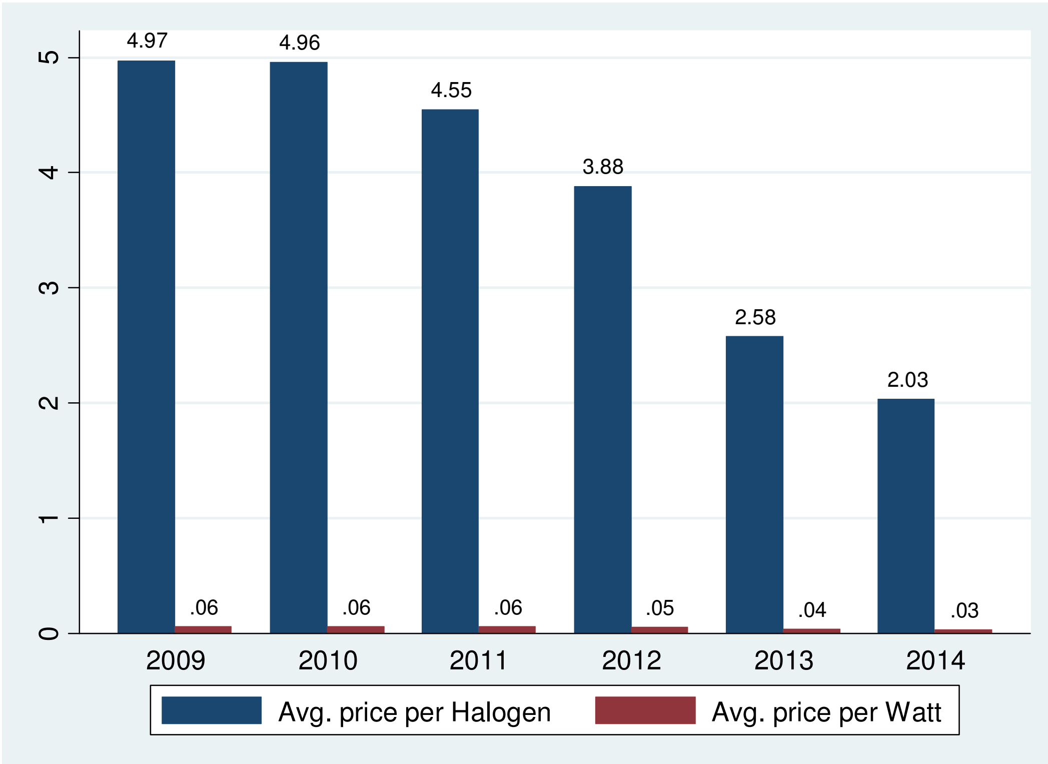


Figure 3. The Price of Non-LED program Halogen bulbs and Price per Watt by Year



Program Activity

The Team used non-program states only in the models for two reasons. First, we wanted to exclude program subsidized prices in our forecasts and the only way we can be sure that our data do not include subsidized bulbs is by eliminating states with active LED programs. This is also an advantage of this approach over the supplier interview efforts. By eliminating states with active LED programs from the analysis we ensure that we do not bias the data and subsequent analysis. The second reason for estimating a non-program model is to provide estimates of future bulb price without program support. The presence of an LED lighting program therefore(?) was a key aspect of research. The Team utilized and updated the program research conducted during the 2015 Massachusetts Saturation and Stagnation study to determine whether a state has supported LEDs at any point during the 2009-2014 period. If a state did support LEDs at any time during the analysis period they were considered a "program state" and excluded from the non-program models. There were 16 states without active LED programs during the analysis period that were included in the models (Table 2).

Table 2. States without Active LED Residential Lighting Programs from 2009-2014

Alabama	Kentucky	South Dakota
Florida	Louisiana	Tennessee
Georgia	Mississippi	Utah
Idaho	Nebraska	Virginia
Indiana	Ohio	West Virginia
Kansas		

Findings

Table 3 displays the average price per Watt by bulb type for program states, non-program states, and all states combined and also extrapolates the price per Watt to reflect the price equivalent of a 60 Watt incandescent bulb: 10 Watt LED, 13Watt CFL, 43Watt halogen. The price trends per Watt in the POS data are fairly straight forward though there are some points of interest. LED price per Watt declines throughout the program period but does spike in 2013. This is likely due to new technologies such as bulbs that can be controlled by a smart device entering the market and inflating the price per Watt. There is not much movement in CFL price per Watt during the analysis period. It appears that halogen price per Watt is also stagnant but, in reality, the low price of six cents per Watt at the beginning of the analysis period was halved by 2014. Again, it is worth noting that prices in non-program areas for LEDs sometimes fall below those in program areas, which may reflect the types of channels reporting and/or the costs of living in the two types of areas.

Table 3. Average LED, CFL and Halogen Prices per Watt and Extrapolated price per 60 Watt Incandescent Equivalent Bulb: 10Watt LED, 13Watt CFL, 43Watt Halogen

Year	Price per Watt in Program States n=28	60Watt Equivalent Price in Program States n=28	Price per Watt in Non-Program States n=16	60Watt Equivalent Price in Non-program States n=16	Overall Price per Watt n=44	Overall 60Watt Equivalent Price n=44
LED						
2009	$2.89	$28.91	$2.84	$28.39	$2.87	$28.70
2010	$2.11	$21.15	$2.08	$20.84	$2.10	$21.00
2011	$1.53	$15.33	$1.34	$13.43	$1.46	$14.60
2012	$1.55	$15.50	$1.43	$14.31	$1.50	$15.00
2013	$1.70	$17.00	$1.73	$17.29	$1.71	$17.10
2014	$1.22	$12.25	$1.35	$13.48	$1.28	$12.80
CFL						
2009	$0.16	$2.05	$0.14	$1.86	$0.15	$1.95
2010	$0.15	$1.96	$0.14	$1.78	$0.15	$1.95
2011	$0.15	$1.92	$0.14	$1.76	$0.14	$1.82
2012	$0.15	$1.97	$0.14	$1.87	$0.15	$1.95
2013	$0.15	$2.01	$0.15	$1.94	$0.15	$1.95
2014	$0.15	$1.90	$0.14	$1.83	$0.14	$1.82
Halogen						
2009	$0.06	$2.61	$0.06	$2.60	$0.06	$2.58
2010	$0.06	$2.67	$0.06	$2.64	$0.06	$2.58
2011	$0.06	$2.55	$0.06	$2.56	$0.06	$2.58
2012	$0.05	$2.32	$0.05	$2.32	$0.05	$2.15
2013	$0.04	$1.71	$0.04	$1.63	$0.04	$1.72
2014	$0.03	$1.41	$0.03	$1.34	$0.03	$1.29

The team used a fixed effects panel regression analysis to extrapolate a price trend for the price per Watt by bulb in three separate non-program state models to produce three separate sets of predictions. The estimates are based on models that reflect sales data from 2009-2012, 2009-2013, and 2009-2014. The Team compares the estimated price per Watt to the actual price per Watt for 2014 and then extrapolates the price per Watt out through 2020. Finally we use the extrapolated price per Watt to calculate the price of a bulb equivalent to a 60 Watt incandescent or, in other terms, produces an output of 640 lumens.

The Team began the analysis by running a 2009-2012 model and using the output to forecast out through 2020. The model was a poor predictor of LED 2014 prices and under predicted the actual 2014 LED prices by more than 40%. When these modeled values were extrapolated out to 2020 the LED prices were very low, only $1.71 (Table 4Table 5Table 6). The Team developed a few hypotheses on why the

2009-2012 model was such a poor foundation for extrapolation. First the presence of non-specialty LEDs was not the norm in the channels represented by our data during the years 2009-2010. By restricting the data to 2009-2012 time period we are forecasting a different market that does not incorporate the 'typical' affordable A-line LED.

Table 4. Predicted Wattage Prices for 2014 based on 2009-2012 model

Bulb Type	Non-Program State Average Value	Predicted Value (90% CI)	Difference (predicted-actual)
LED	$1.35	$0.76, ±(0.06)	-$0.59
CFL	$0.14	$0.13, ±(0.01)	-$0.01
Halogen	$0.03	$0.05, ±(0.0023)	$0.02

Table 5. Price per Watt Forecast through 2020 based on 2009-2012 model

Year	LED	CFL	Halogen
2014	$0.76, +(0.06)	$0.13, +(0.01)	$0.05, +(0.002)
2015	$0.60, +(0.06)	$0.13, +(0.02)	$0.05, +(0.003)
2016	$0.46, +(0.06)	$0.13, +(0.02)	$0.05, +(0.003)
2017	$0.36, +(0.06)	$0.13, +(0.02)	$0.05, +(0.003)
2018	$0.28, +(0.06)	$0.13, +(0.02)	$0.04, +(0.004)
2019	$0.22, +(0.06)	$0.13, +(0.03)	$0.04, +(0.004)
2020	$0.17, +(0.06)	$0.13, +(0.03)	$0.04, +(0.004)

Table 6. Example Forecasted Prices for a 640 Lumen Bulb based on a 2009-2012 model

Year	10 Watt LED	13 Watt CFL	43 Watt Halogen
2014	$7.64	$1.75	$2.20
2015	$5.95	$1.74	$2.12
2016	$4.64	$1.73	$2.04
2017	$3.61	$1.72	$1.97
2018	$2.81	$1.72	$1.89
2019	$2.19	$1.71	$1.82
2020	$1.71	$1.70	$1.76

Table 7 shows the forecasted price per Watts extrapolated from a 2009-2013 model; the estimates are close to the actual 2014 price per Watts. The predicted value of the 2014 LED price per Watt is 14 cents lower than the actual price per Watt and the predicted CFL estimate is exact and the halogen estimate is within a cent of the actual 2014 price per Watt. In our forecast, the predicted price per Watt for LEDs decreases by a little more than half by 2020. When the price per Watt is applied to a 10 Watt LED bulb we see the price drop from an average of $12.08 in 2014 to an average of $5.36 in 2020 (Table 8 and Table 9). Predicted CFL price per Watt shows a slight increase throughout the prediction period while halogen price per Watt continue to decrease and, when extrapolated to a 43 Watt bulb, decreases in price by 48% from 2014 to 2020.

Table 7. Predicted Wattage Prices for 2014 based on 2009-2013 model

Bulb Type	Non-Program State Average Value	Predicted Value (90% CI)	Difference (predicted-actual)
LED	$1.35	$1.21, ±(0.06)	-$0.14
CFL	$0.14	$0.14, ±(0.01)	$0.00
Halogen	$0.03	$0.04, ±(0.0018)	$0.01

Table 8. Price per Watt Forecast through 2020 based on 2009-2013 model

Year	LED	CFL	Halogen
2014	$1.21, +(0.06)	$0.14, +(0.01)	$0.04, +(0.002)
2015	$1.06, +(0.07)	$0.14, +(0.01)	$0.03, +(0.002)
2016	$0.92, +(0.08)	$0.14, +(0.02)	$0.03, +(0.002)
2017	$0.81, +(0.09)	$0.14, +(0.02)	$0.03, +(0.002)
2018	$0.70, +(0.09)	$0.14, +(0.02)	$0.02, +(0.002)
2019	$0.61, +(0.09)	$0.14, +(0.03)	$0.02, +(0.002)
2020	$0.54, +(0.09)	$0.15, +(0.03)	$0.02, +(0.002)

Table 9. Example Forecasted Prices for a 640 Lumen Bulb based on a 2009-2013 model

Year	10 Watt LED	13 Watt CFL	43 Watt Halogen
2014	$12.08	$1.83	$1.66
2015	$10.55	$1.84	$1.49
2016	$9.22	$1.85	$1.34
2017	$8.05	$1.86	$1.20
2018	$7.03	$1.87	$1.07
2019	$6.14	$1.88	$0.96
2020	$5.36	$1.89	$0.87

The final set of forecasted prices is based on a non-program state 2009-2014 model and is the model and forecast the Team recommends. The model under-predicts the price per Watt of LEDs by eight cents while predicting the 2014 price per Watt for CFLs and halogens exactly (Table 10). The forecasted price per Watt for LED decreases by 52% from 2014 to 2020 meaning that the average price of a 10 Watt LED in 2020 would be about $6.17 (Table 11 and Table 12). Predicted CFL price per Watt stays stagnant throughout the prediction period. Halogens continue to decrease in price per Watt through 2020 and the average price per 43 Watt halogen bulb by 2020 should be around $0.64. Note that this approach yields higher price and incremental costs compared to webscraping and supplier interviews, a point we will address in more detail in the forthcoming overall report.

Table 10. Predicted Wattage Prices for 2014 based on 2009-2014 model

Bulb Type	Non-Program State Average Value	Predicted Value (90% CI)	Difference (predicted-actual)
LED	$1.35	$1.27, ±(0.05)	-$0.08
CFL	$0.14	$0.14, ±(0.01)	$0.00
Halogen	$0.03	$0.03, ±(0.0013)	$0.00

Table 11. Price per Watt Forecast through 2020 based on 2009-2014 model

Year	LED	CFL	Halogen
2014	$1.27, +(0.05)	$0.14, +(0.01)	$0.03, +(0.001)
2015	$1.13, +(0.06)	$0.14, +(0.01)	$0.03, +(0.001)
2016	$1.00, +(0.07)	$0.14, +(0.02)	$0.03, +(0.001)
2017	$0.89, +(0.08)	$0.14, +(0.02)	$0.02, +(0.001)
2018	$0.79, +(0.08)	$0.14, +(0.02)	$0.02, +(0.001)
2019	$0.70, +(0.08)	$0.14, +(0.02)	$0.02, +(0.001)
2020	$0.62, +(0.08)	$0.14, +(0.02)	$0.01, +(0.001)

Table 12. Example Forecasted Prices for a 640 Lumen Bulb based on a 2009-2014 model

Year	10 Watt LED	13 Watt CFL	43 Watt Halogen
2014	$12.75	$1.78	$1.48
2015	$11.29	$1.78	$1.28
2016	$10.01	$1.78	$1.11
2017	$8.87	$1.78	$0.97
2018	$7.86	$1.77	$0.84
2019	$6.96	$1.77	$0.73
2020	$6.17	$1.77	$0.64

Future Price Forecasting Models and Results

In order to extrapolate price out to 2020 the Team estimated a series of state level fixed-effects panel regression models using a time and bulb type interaction variable to estimate the average price per Watt. All parts of the interaction term were included in the model so as to not bias the estimate. The fixed-effects model estimates bulb price as a function of time and bulb type. The regression uses the natural logarithm of average price per watt as the dependent variable in order to estimate a log-linear model under the assumption that the relationship between price and time is not linear. The regression form used is as follows:

$$\square(T_{it}) + \beta_2\ \square(\mathrm{BulbType}_{it}) + \beta_3((T_{it}) * [(\mathrm{BulbType}_{it})) +]\delta_i + \varepsilon_{it}$$

Where:

logAverage Price per Watt= Natural logarithm of the State average annual price per Watt by type *i* and year *j*.

$T_{i,j}$=T=Year-2008

BulbType $_{i,j}$=Categorical classification of bulbs (1=LED, 2=CFL, 3=Halogen) with LED as the reference type—meaning that every bulb type coefficient is being compared to the LED. As an example if the CFL coefficient for bulb type is -2.77 it is referencing LEDs—that the CFL is $2.77 less than an LED.

$T_{i,j}$*BulbType $_{i,j}$=Interaction between bulb T and BulbType

$\delta_i =$ State fixed effects that capture time-invariant state specific fixed effects in average bulb price.

$\epsilon_{i,j}$ = Error term clustered by state.

The Team presents the model results in Table 13. All three models showed that time was a significant predictor of price per Watt by bulb type. By adding additional years of data we were able to decrease the standard error around the estimates and increase the precision of the coefficients. All three models showed a close fit between the explained variance (within R-squared) and the explained variance due to independent variable impact on the dependent variable (adjusted R-squared) are virtually identical and above 90%. The reduced standard error and high R-squared values, along with the accurate price per Watt predictions, indicate that the 2009-2014 model is preferred over the other two models.

Table 13. Price Forecast Models

Variables	2009-2012	2009-2013	2009-2014
Intercept	1.23 (0.05)	1.00 (0.04)	0.97 (0.04)
CFL* T	0.25 (0.02)	0.14 (0.02)	0.12 (0.01)
Halogen* T	0.21 (0.02)	0.03 (0.01)	-0.02 (0.01)
CFL	-3.20 (0.06)	-3.00 (0.05)	-2.95 (0.04)
Halogen	-3.98 (0.05)	-3.61 (0.05)	-3.50 (0.04)
T	-0.25 (0.04)	-0.14 (0.01)	-0.12 (0.01)
Additional Details			
Number of States	16	16	16
Number of Observations	192	240	288
Within R-squared	0.994	0.989	0.989
Adjusted R-squared	0.993	0.988	0.988

Conclusions

The Team was successful in predicting state average price per Watt for 2014 by utilizing six years of POS data and recommends the 2009-2014 model and forecast. The data show that the average price of an LED bulb has been increasing over the past six years but we found that bulb price is being driven up by the increased Wattages being offered. By modeling the log average price per Watt we were able to estimate that LED prices will continue to decline and will likely be reduced by a little more than half by 2020. Halogen prices have also dropped dramatically since 2009 and we estimate that the decline will continue.