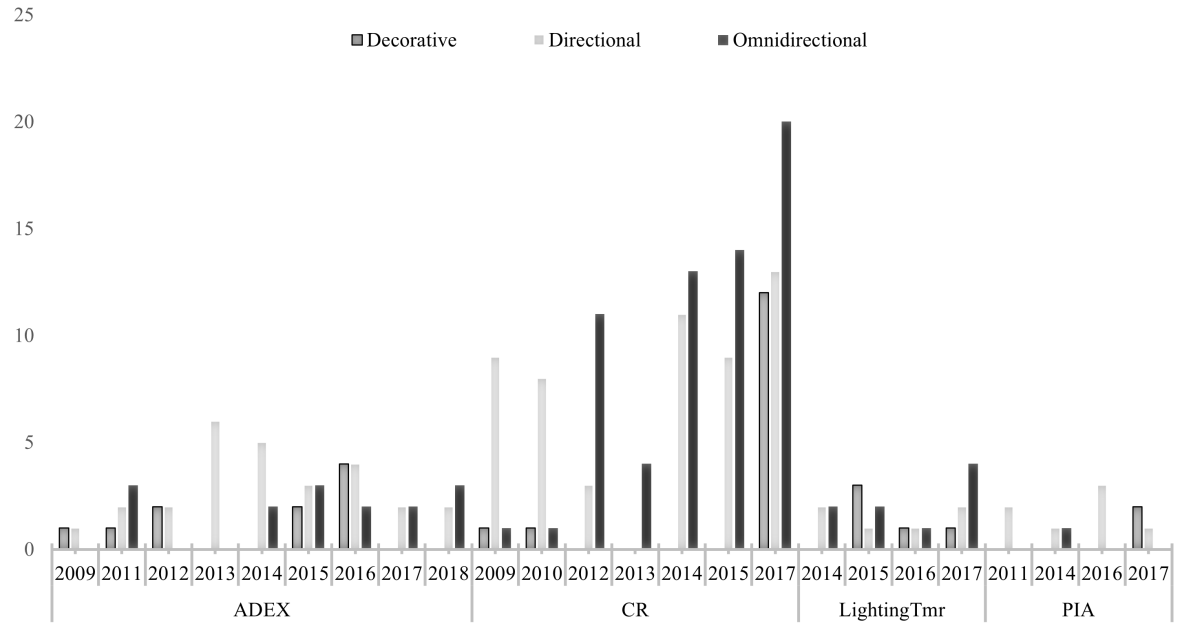
Appendix A: Data Collection on Dependent Variable *Market Acceptance*

We offer details on each data source that contributes to our dependent variable in the following table and graph. The table on top describes each of the four dimensions, while the graph at the bottom shows the number of unique firms and their distribution across the four dimensions over time.

Data Sources	Rating Methodology	Raw Data Format
1. Consumer Reports	An aggregated score capturing millions of consumer reviews that reflect lightbulbs' color, claimed lifetime, and brightness, combined with independent testing	Continuous [0,100]
2. Consortium of Energy Efficiency (CEE)	An industry-wide competition that awards lightbulbs that balance the optimal efficiency and design, managed by several nationwide lightbulb associations and coalitions	Binary [0,1]
3. Architectural SSL Magazine	An industry-wide competition that awards the most innovative lightbulbs based on their attributes, qualities, functionality and/or performance beyond industry standards, judged by a panel of designers and lighting specialists skilled in product evaluation	Binary [0,1]
4. Awards for Design Excellence (ADEX)	A cross-industry competition that awards the best design associated with lightbulbs evaluated by experts from the field	Binary [0,1]

Notes:
1. Consumer Reports is a US-based consumer organization offering independent product testing and consumer-oriented research. We collected data from their *Best Lightbulb of the Year* reports, which rate lightbulbs on a scale of 0 to 100, with 100 being the best-rated lightbulbs. These reports integrate both consumer- and industry-based evaluations.
2-4. We consider the *Lighting for Tomorrow* competition by the CEE, the *Product Innovation Awards* by Architectural SSL Magazine, and the ADEX Award to be valid and representative sources for industry ratings on lightbulbs. To collect data from these agencies, we contacted each of them and obtained raw data on their past winning firms.



Note: "CR" denotes Consumer Reports; "Lighting Tmr" denotes Lighting Tomorrow by CEE. The y-axis represents the total unique firms ranked by the market intermediary in a given lighting segment in the focal year. Because some firms may have several lines of products in one lighting segment, even the unique number of firms ranked by the same intermediary within the same segment can vary over time with the changing market dynamics in terms of product proliferation and concentration.

Appendix B: Additional Tables on the Contingency Tests

Table 1 Contingency Tests: OLS Regression as an Alternative Model

	(1)	(2)	(3)	(4)
Pace	-0.0130*	-0.0162**	-0.0164**	-0.0142*
	(0.00647)	(0.00624)	(0.00632)	(0.00604)
Pioneering Experience	0.00243	0.00235	0.00236	0.00236
	(0.00149)	(0.00137)	(0.00137)	(0.00137)
Brand Recognition	1.046	0.818	1.057	1.048
	(0.543)	(0.590)	(0.538)	(0.543)
Regulatory Influence	0.0532*	0.0538*	0.0382	0.0533*
	(0.0258)	(0.0257)	(0.0235)	(0.0258)
Lifetime Duration	-0.00617	-0.00612	-0.00580	
	(0.00688)	(0.00694)	(0.00692)	
Lifetime Duration Deviation				-0.00591
				(0.00898)
Pace × Pioneering Experience	-0.0000265			
	(0.0000750)			
Pace × Brand Recognition		0.115*		
		(0.0565)		
Pace × Regulatory Engagement			0.00752***	
			(0.00157)	
Pace × Lifetime Duration Deviation				-0.0000691
				(0.000747)
Constant	-6.123	-6.219	-6.110	-6.331
	(5.733)	(5.711)	(5.666)	(5.715)
Observations	3660	3660	3660	3660
R^2	0.292	0.295	0.294	0.292

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Standard errors are included in parentheses and clustered at firm level. All models in this table follow the same specification in Model 2 of Table **??**. Control variables are abbreviated but included across all models.

Table 2 Zero-inflated Negative Binomial With Regulatory Engagement Lagged

	(1)	(2)	(3)	(4)
Pace	-0.0661***	-0.0787***	-0.0875***	-0.0922***
	(0.0180)	(0.0182)	(0.0181)	(0.0187)
Regulatory Engagement (9-Month Ago)	0.0421***			
	(0.0106)			
Pace × Regulatory Engagement (9-Month Ago)	0.0131*			
	(0.00526)			
Regulatory Engagement (6-Month Ago)		0.0293**		
		(0.0108)		
Pace × Regulatory Engagement (6-Month Ago)		0.0135**		
		(0.00504)		
Regulatory Engagement (3-Month Ago)			0.0279**	
			(0.0103)	
Pace × Regulatory Engagement (3-Month Ago)			0.0131**	
			(0.00494)	
Regulatory Engagement (2-Month Ago)				0.0292**
				(0.00991)
Pace × Regulatory Engagement (2-Month Ago)				0.0138**
				(0.00452)
Observations	2553	2917	3381	3547

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Standard errors are included in parentheses and clustered at firm level. All models in this table follow the same specification in Model 5 of Table **??**, with the exception that *Regulatory Influence* is lagged by 2, 3, 6, and 9 months across various models.

Table 3 Robustness Checks With Outliers Removed: The Lenient Method

	(1)	(2)	(3)	(4)
Pace	-0.110***	-0.0773***	-0.0839***	-0.0769***
	(0.0223)	(0.0171)	(0.0169)	(0.0169)
Pioneering Experience	0.00461***	0.00542***	0.00546***	0.00553***
	(0.000493)	(0.000424)	(0.000418)	(0.000424)
Brand Recognition	0.779***	0.518***	0.783***	0.791***
	(0.115)	(0.139)	(0.117)	(0.116)
Regulatory Engagement	0.0720***	0.0714***	0.0410***	0.0723***
	(0.00831)	(0.00823)	(0.00969)	(0.00840)
Lifetime Duration	-0.0468***	-0.0460***	-0.0460***	
	(0.0112)	(0.0112)	(0.0111)	
Lifetime Duration Deviation				-0.0214
				(0.0142)
Pace × Pioneering Experience	0.000358**			
	(0.000114)			
Pace × Brand Recognition		0.123***		
		(0.0348)		
Pace × Engagement			0.0143***	
			(0.00402)	
Pace × Lifetime Duration Deviation				-0.00744**
				(0.00263)
Constant	-16.70***	-19.59***	-20.67***	-20.08***
	(3.169)	(3.272)	(2.884)	(3.193)
Zero Inflation: Firm-level	0.0203***	0.0258***	0.0261***	0.0230***
	(0.00256)	(0.00324)	(0.00327)	(0.00281)
Constant	-7.472***	-9.312***	-9.437***	-8.349***
	(0.784)	(1.067)	(1.080)	(0.893)
ln(alpha)	0.633***	0.657***	0.649***	0.652***
	(0.135)	(0.133)	(0.134)	(0.132)
Observations	3661	3661	3661	3661

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Standard errors are included in parentheses and clustered at firm level.

Table 4 Robustness Checks With Outliers Removed: The Stringent Method

	(1)	(2)	(3)	(4)
Pace	-0.125***	-0.121***	-0.121***	-0.107***
	(0.0304)	(0.0269)	(0.0249)	(0.0232)
Pioneering Experience	0.00480***	0.00520***	0.00529***	0.00530***
	(0.000526)	(0.000415)	(0.000414)	(0.000416)
Brand Recognition	0.793***	0.498***	0.812***	0.796***
	(0.115)	(0.148)	(0.116)	(0.115)
Regulatory Engagement	0.0708***	0.0701***	0.0412***	0.0706***
	(0.00824)	(0.00821)	(0.0106)	(0.00821)
Lifetime Duration	-0.0436***	-0.0428***	-0.0427***	
	(0.0111)	(0.0111)	(0.0111)	
Lifetime Duration Deviation				-0.0255
				(0.0149)
Pace × Pioneering Experience	0.000223			
	(0.000151)			
Pace × Brand Recognition		0.144**		
		(0.0452)		
Pace × Regulatory Engagement			0.0142**	
			(0.00507)	
Pace × Lifetime Duration Deviation				-0.00597
				(0.00347)
Constant	-12.12***	-20.02***	-15.37***	-17.22***
	(3.170)	(3.142)	(3.185)	(3.135)
Zero Inflation: Firm-level	0.0193***	0.0206***	0.0193***	0.0195***
	(0.00245)	(0.00256)	(0.00242)	(0.00243)
Constant	-7.083***	-7.543***	-7.097***	-7.166***
	(0.731)	(0.780)	(0.717)	(0.725)
ln(alpha)	0.623***	0.621***	0.615***	0.626***
	(0.137)	(0.135)	(0.135)	(0.134)
Observations	3532	3532	3532	3532

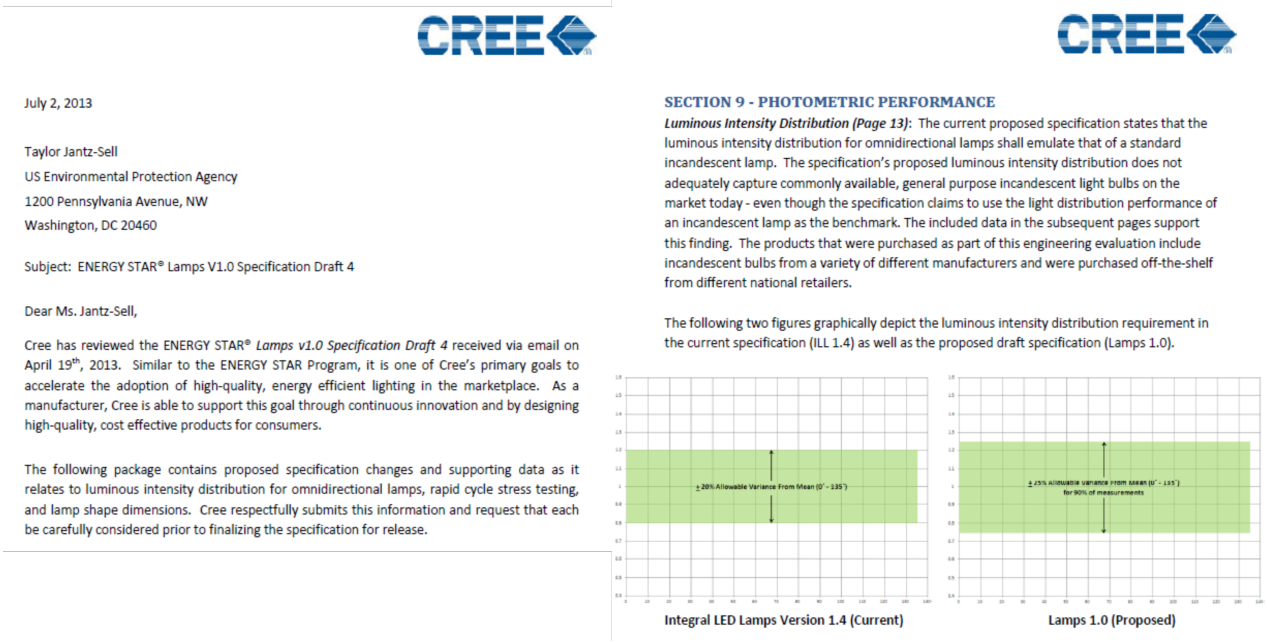
Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Standard errors are included in parentheses and clustered at firm level.

Appendix C: Details on the Independent Variable *Regulatory Engagement*

In this section, we provide details on the regulatory process of the Energy Star program on LED lightbulbs. Energy Star is a certification program managed by US governmental regulators to promote energy-efficiency appliances, with lighting being an important component of the program.

Regulatory Process. Energy Star went through several rounds of revisions to modify the standards by which they certify LED lightbulbs. Each round of revision begins with the program administrator posting a tentative draft regarding proposed changes to the previous certification standard, followed by an open call for public opinions during an extended time, which we call the "commentary period". Although all types of stakeholders are eligible to submit letters during the "commentary period", firms directly involved in LED lightbulb manufacturing and distribution are the most active in submitting commentaries. As a next step, the Energy Star program hosts roundtable discussions to which it invites parties of interest; these discussions provide a forum where firms meet with one another, as well as with the regulators, which we call the "discussion period". The process ends with the Energy Star program posting its finalized revision to the previous standards for each segment of the LED lightbulbs, accompanied by its responses to specific requests made by stakeholders during the "commentary period".

Examples of Commentaries. We regard commentaries submitted by firms as valuable resources to understand their engagement during the regulatory process. Because the full texts of all commentaries have been publicly released by the Energy Star program, we can have a full perspective on this process. Below are a few examples of commentaries submitted by firms:



CREE

July 2, 2013

Taylor Jantz-Sell
US Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Washington, DC 20460

Subject: ENERGY STAR® Lamps V1.0 Specification Draft 4

Dear Ms. Jantz-Sell,

Cree has reviewed the ENERGY STAR® *Lamps v1.0 Specification Draft 4* received via email on April 19th, 2013. Similar to the ENERGY STAR Program, it is one of Cree's primary goals to accelerate the adoption of high-quality, energy efficient lighting in the marketplace. As a manufacturer, Cree is able to support this goal through continuous innovation and by designing high-quality, cost effective products for consumers.

The following package contains proposed specification changes and supporting data as it relates to luminous intensity distribution for omnidirectional lamps, rapid cycle stress testing, and lamp shape dimensions. Cree respectfully submits this information and request that each be carefully considered prior to finalizing the specification for release.

CREE

SECTION 9 - PHOTOMETRIC PERFORMANCE

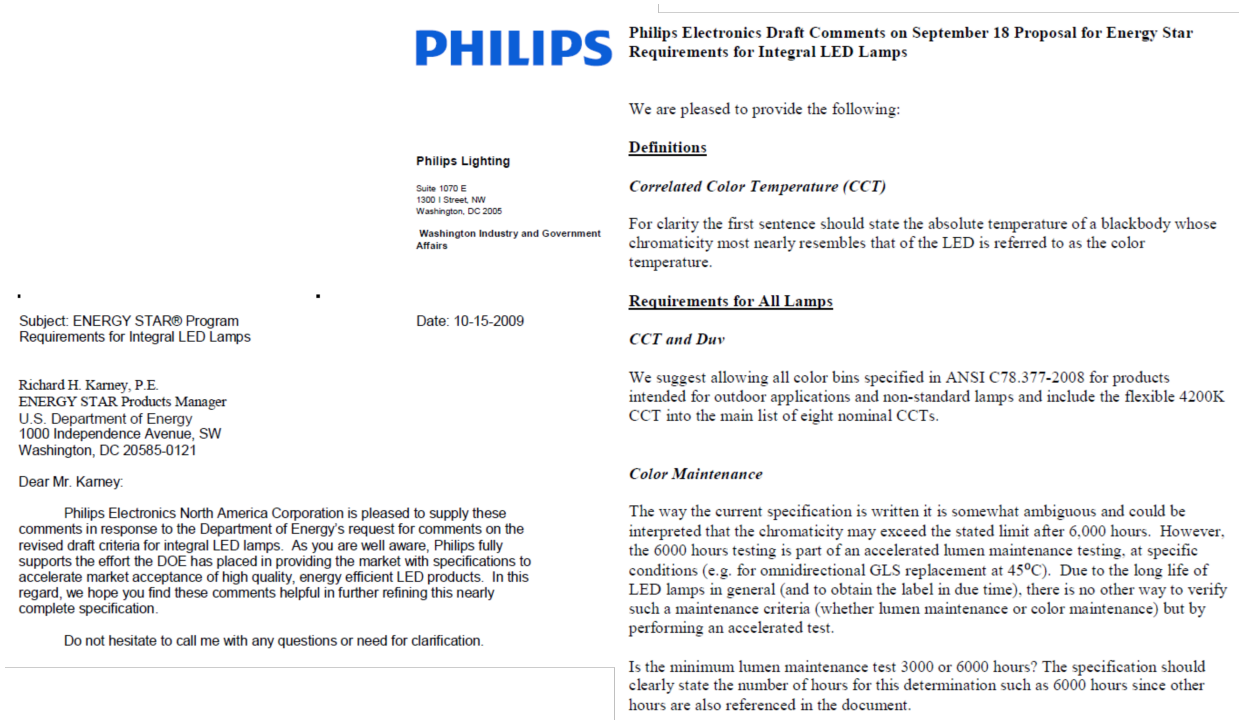
Luminous Intensity Distribution (Page 13): The current proposed specification states that the luminous intensity distribution for omnidirectional lamps shall emulate that of a standard incandescent lamp. The specification's proposed luminous intensity distribution does not adequately capture commonly available, general purpose incandescent light bulbs on the market today - even though the specification claims to use the light distribution performance of an incandescent lamp as the benchmark. The included data in the subsequent pages support this finding. The products that were purchased as part of this engineering evaluation include incandescent bulbs from a variety of different manufacturers and were purchased off-the-shelf from different national retailers.

The following two figures graphically depict the luminous intensity distribution requirement in the current specification (ILL 1.4) as well as the proposed draft specification (Lamps 1.0).

Integral LED Lamps Version 1.4 (Current)

Lamps 1.0 (Proposed)

Exhibit 1: This exhibit presents pages 1 and 2 of the comment letter submitted by CREE in April 2013 regarding Energy Star's release of the *Lamps v1.0 Specification Draft 4*. In this letter, CREE began by stating that one of the company's primary goals was to "accelerate the adoption of high-quality, energy-efficient lighting in the marketplace". It then offered a 13-page commentary letter on the technical dimensions of the products such as photometric performance, lumen maintenance, rated life, and dimensional requirements.



PHILIPS

Philips Electronics Draft Comments on September 18 Proposal for Energy Star Requirements for Integral LED Lamps

Philips Lighting

Suite 1070 E
1300 I Street, NW
Washington, DC 2005

Washington Industry and Government Affairs

Subject: ENERGY STAR® Program Requirements for Integral LED Lamps

Date: 10-15-2009

Richard H. Karney, P.E.
ENERGY STAR Products Manager
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-0121

Dear Mr. Karney:

Philips Electronics North America Corporation is pleased to supply these comments in response to the Department of Energy's request for comments on the revised draft criteria for integral LED lamps. As you are well aware, Philips fully supports the effort the DOE has placed in providing the market with specifications to accelerate market acceptance of high quality, energy efficient LED products. In this regard, we hope you find these comments helpful in further refining this nearly complete specification.

Do not hesitate to call me with any questions or need for clarification.

We are pleased to provide the following:

Definitions

Correlated Color Temperature (CCT)

For clarity the first sentence should state the absolute temperature of a blackbody whose chromaticity most nearly resembles that of the LED is referred to as the color temperature.

Requirements for All Lamps

CCT and Duv

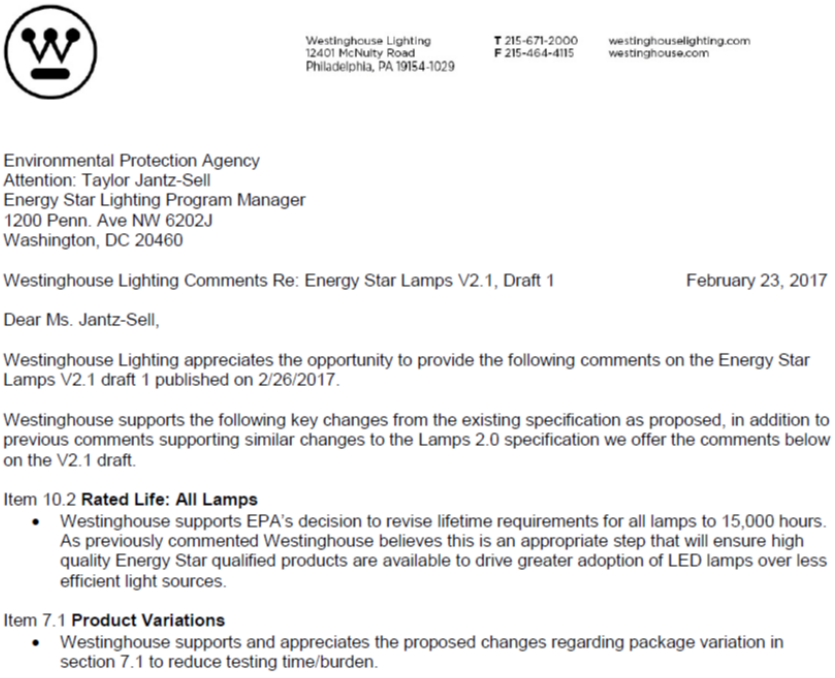
We suggest allowing all color bins specified in ANSI C78.377-2008 for products intended for outdoor applications and non-standard lamps and include the flexible 4200K CCT into the main list of eight nominal CCTs.

Color Maintenance

The way the current specification is written it is somewhat ambiguous and could be interpreted that the chromaticity may exceed the stated limit after 6,000 hours. However, the 6000 hours testing is part of an accelerated lumen maintenance testing, at specific conditions (e.g. for omnidirectional GLS replacement at 45°C). Due to the long life of LED lamps in general (and to obtain the label in due time), there is no other way to verify such a maintenance criteria (whether lumen maintenance or color maintenance) but by performing an accelerated test.

Is the minimum lumen maintenance test 3000 or 6000 hours? The specification should clearly state the number of hours for this determination such as 6000 hours since other hours are also referenced in the document.

Exhibit 2: This exhibit presents the front pages of the comment letter submitted by Philips in October 2009 regarding Energy Star's release of the *Integrated LED Lamps Specification Draft 3*. In this letter, Philips began by stating that it fully supported the goal of Energy Star in "providing the market with specifications to accelerate market acceptance of high quality, energy-efficient LED products". It then offered a 6-page commentary letter on a list of product dimensions such as CCT, CRI, packaging, and certification.



Westinghouse Lighting
12401 McNulty Road
Philadelphia, PA 19154-1029

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F 215-464-4115

westinghouselighting.com
westinghouse.com

Environmental Protection Agency
Attention: Taylor Jantz-Sell
Energy Star Lighting Program Manager
1200 Penn. Ave NW 6202J
Washington, DC 20460

Westinghouse Lighting Comments Re: Energy Star Lamps V2.1, Draft 1 February 23, 2017

Dear Ms. Jantz-Sell,

Westinghouse Lighting appreciates the opportunity to provide the following comments on the Energy Star Lamps V2.1 draft 1 published on 2/26/2017.

Westinghouse supports the following key changes from the existing specification as proposed, in addition to previous comments supporting similar changes to the Lamps 2.0 specification we offer the comments below on the V2.1 draft.

Item 10.2 **Rated Life: All Lamps**

- Westinghouse supports EPA's decision to revise lifetime requirements for all lamps to 15,000 hours. As previously commented Westinghouse believes this is an appropriate step that will ensure high quality Energy Star qualified products are available to drive greater adoption of LED lamps over less efficient light sources.

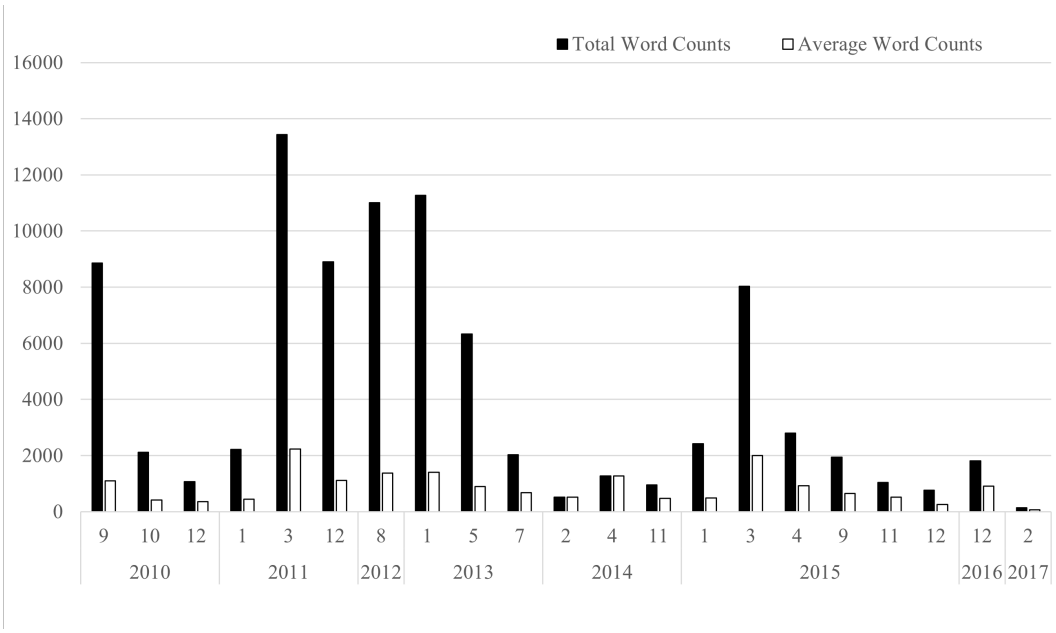
Item 7.1 **Product Variations**

- Westinghouse supports and appreciates the proposed changes regarding package variation in section 7.1 to reduce testing time/burden.

Exhibit 3: This exhibit presents the commentary letter submitted by Westinghouse in February 2017 regarding Energy Star's release of the *Lamps 2.0 Specification Draft 1*. In this 1-page letter, Westinghouse expressed its support for the proposed changes without providing additional comments that would direct the standards in other directions.

We assume that the length of the commentaries and a firm's frequency of submission reflect the amount of regulatory engagement. As shown by a comparison across these examples, firms seeking to change or modify the standards tended to write longer commentary letters (Exhibits 1 and 2), whereas the length of the letters is short among firms that largely supported the regulatory standards (Exhibit 3).

Distribution of Commentaries. We summarize the total/average word counts of all the commentary letters found in each round of the "commentary period" within our study period. With the increasing maturing of regulatory standards on LED lightbulbs over time, there is a steady decrease in the total word counts across all commentaries. Because the average word count of each letter remains stable across our study period, the drop in total word counts is largely driven by a decline in the number of unique firms submitting letters.



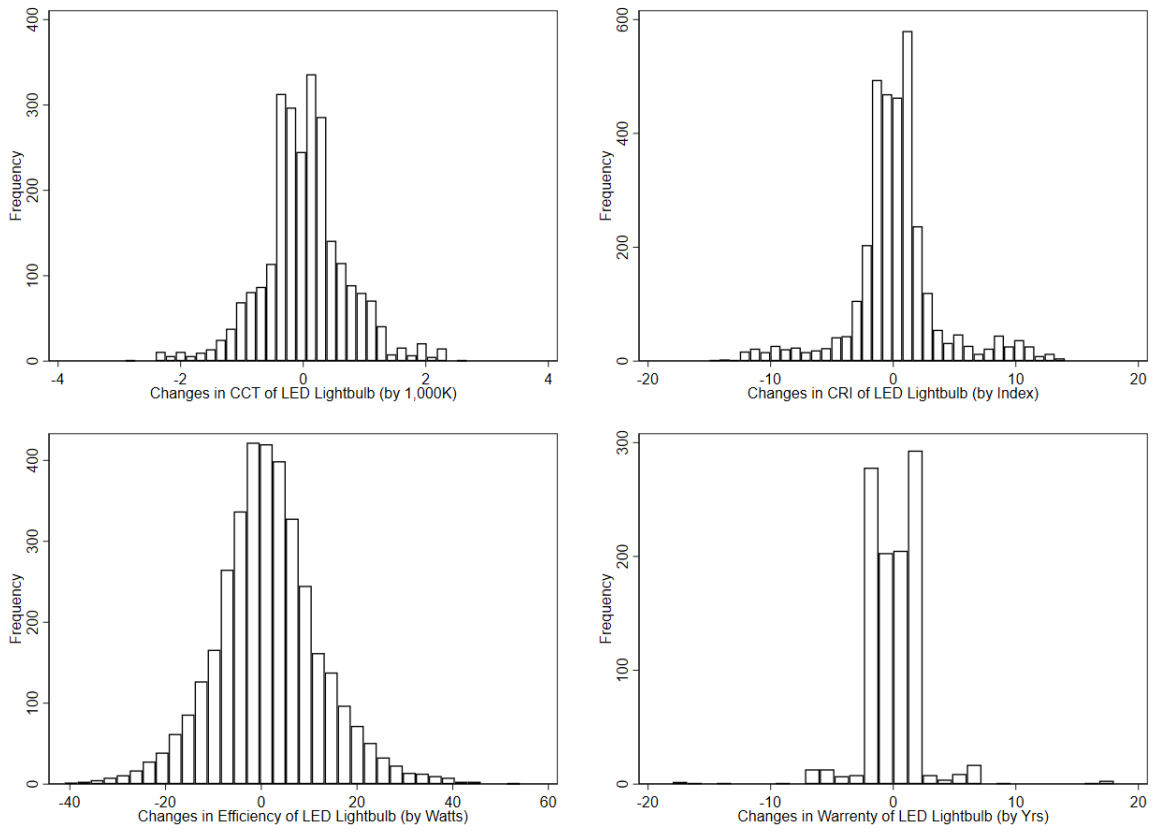
Note: The graph plots the total/average word counts of the letters submitted across all firms in a given month-year.

Although we also have access to recordings of some roundtable discussions, such recordings are only supplementary to the commentaries: not only because the former are not always released but also because those who participated in the "discussion period" are highly similar to those firms submitting letters during the "commentary period". We agree that whether a firm makes greater or lesser efforts is not equivalent to the amount of engagement we captured through commentary letters. That said, we do find a great deal of overlap between firms more involved in the regulatory process and those with greater political capital—at least in our context.

Appendix D: Technological Uncertainties across LED Lightbulbs Dimensions

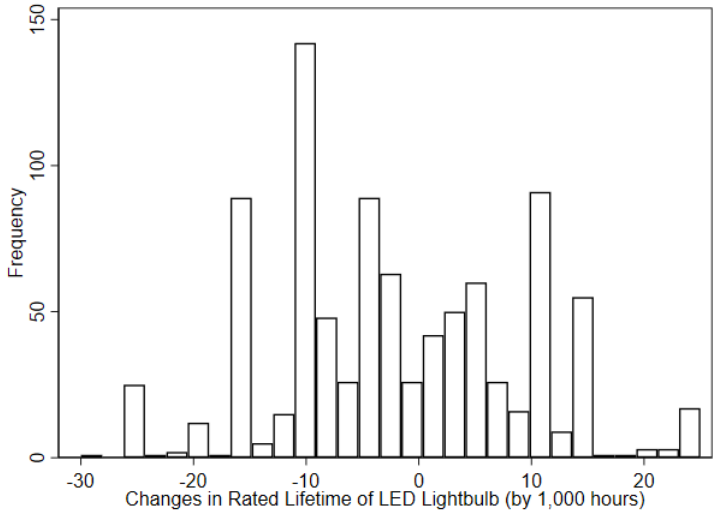
In this section, we explain why lifetime duration represents the product dimension with the most technological uncertainties in the LED lightbulb market. We do so by investigating how firms adapt their LED lightbulbs across different technical attributes and compare patterns across these dimensions. We assume that product dimensions vary by the level of uncertainties involved; the less consensus a product dimension has among market participants, the greater the uncertainty. In other words, we expect firms to reach the least consensus on how they adapt their products from their previous iterations on dimensions that they are least certain about and hence greater heterogeneity across firms.

As shown in the graphs below, we find strong evidence that firms reached the least consensus on how to set the lifetime duration of LED lightbulbs. To be specific, we plot the differences between two adjacent product iterations by the same firm segment across the dimensions of CRI, CCT, efficiency, and warranty. Not only do we find normal distributions across all four dimensions, but we also notice that the bell curves of these distributions tend to peak around zero. These suggest that most firms did not change their products along these dimensions, implying little to no ambiguity was involved in those aspects.



Similar patterns, however, are not observed for how firms changed the lifetime duration of their LED lightbulbs. As shown below, we do not find a normal distribution with the curve, to begin with, especially compared to the shapes graphed for the other dimensions. In addition, judging from the dip in the curve at

zero, it seems that most firms seemed more likely to adjust the lifetime duration of their LED lightbulbs from their previous iterations than to adjust other dimensions. Most importantly, judging from the dispersion of the curve, it seems that when firms did adjust the lifetime duration of their lightbulbs, there was a lack of consensus in terms of how much or in which direction to change (i.e., increase versus decrease).



Taking these results together, we conclude that the lifetime duration of LED lightbulbs involves greater technological uncertainties than other product dimensions—making it a suitable contingency factor for our empirical exploration on product market competition.