The Downward Spiral of Compact Fluorescent Lamps in the Pacific Northwest – an Overestimation of the Saturation Point or Natural Fluctuations in the Adoption Path?

by

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Abstract

In 2008, 25 million Compact Fluorescent Lamps (CFLs) were sold in the Pacific Northwest. This number dropped to 15 million by 2011, far below 27 million as predicted with the ‘S’ curve and historic data\(^1\). The adoption path used to model the CFLs is a form of a logistic curve, commonly used to model new product adoption, from introduction to saturation (Meade and Islam). Using an ‘S-curve’ or logistic function worked adequately to model CFL sales prior to the economic decline of 2009. Also, in theory, the tail end of the adoption curve should be predicable with the passage of Energy Independence and Security Act of 2007 (EISA). The lighting standards, phased in between January 1, 2012 and 2015, in the legislation should ensure a relatively high CFL saturation rate. However, the precipitous decline in sales between 2009 and 2011 suggests a more ominous future of the CFL.

Multiple possibilities may explain the overestimation. First, is that a key diffusion model assumption, the ‘saturation’ point, has been overvalued. Currently, the diffusion model assumes a maximum saturation with a market share of 67%\(^2\), whereas Chandrasekaran and Tellis found the average maximum penetration potential, based on hundreds of products, to be 52%\(^3\). The other possibility is that the CFL market is experiencing natural fluctuations common to product adoption. The premise of the adoption theory is that groups of potential customers would adopt a new product at different rates of time, reaching a maximum saturation point. One of the defining characteristics of the groups of adopters was disposable income. The economic decline of 2009 has not only decreased disposable income, but has potentially altered the adoption groups leading to change in consumers’ purchasing decisions. Lastly, a fundamental shift may have occurred in the market rendering the ‘S’ curve an inappropriate forecasting tool.

This research provides a discussion regarding the adoptive path of CFLs in the Pacific Northwest and whether greater potential exists based on comparisons with the adoption of other products, along with quantitative relationships with other factors such as income, and utility incentives. What would have happened to the CFL forecast using the ‘S’ curve in the absence of EISA? Next, this paper compares the forecasts with a diffusion curve adjusted for a peak saturation point in 2008 with a simple linear regression of CFLs with GPD to see which better predictor was in 2009, 2010, and 2011. Lastly, the discussion concludes with possible outcomes due to EISA.

2 The basis for the 67% was The Energy Independence and Security Act of 2007 which phases in efficiency levels for lighting starting in 2012 and becomes the most stringent by 2014.
3 This comparison would be much more dramatic if Chandrasekaran and Tellis removed entertainment and social networking/communication products which have much higher penetration rates than durable goods.
Introduction – The State of CFLs in the Pacific Northwest

Energy conservation programs aimed at transforming the lighting market via compact fluorescent lamps (CFLs) in the Pacific Northwest began in earnest in 1997.\(^4\) Pacific Northwest utilities began promoting CFLs in 2001, due to the energy crisis in the Pacific Northwest (Marquardt). Utility offerings included CFL coupons, give-aways, and direct installations. The graph below shows historic, total retail CFL sales in the Pacific Northwest, along with the portion that received a utility incentive. The first year of recorded regional CFL sales was 1997 with 204,000 CFL sales\(^5\). Total CFL sales peaked in 2008 at approximately 25.5 MM\(^6\). By outward appearance, it looked as though CFL sales had reached ‘critical mass’ allowing for self-sustaining growth. The Northwest Energy Efficiency Alliance (NEEA), an energy efficiency organization servicing the Pacific Northwest (PNW), had considered the initiative self-sustaining to the point that it eliminated its market transformation efforts to focus on other initiatives by mid-year 2007. Although initial sales plummeted due to the economic crisis in 2009, sales have continued to trend downward and by 2011 only 15.9MM CFLs sold, a post-2008 low. Therefore, the timing of NEEA’s decision may have been premature.

Figure 1. CFL Retail Sales in the Pacific Northwest and Number of Sales with Utility Incentive

Despite the fact that NEEA suspended activity in the CFL market, NW utilities remained active. Given that utility incentives make CFLs more price competitive with incandescent bulbs, it is not surprising to find a high correlation between regional sales and aggregate local incentives. Measured over an 11 year engagement period, PNW utility incentives have a 0.87 correlation coefficient with CFL retail sales\(^7\). This is a good case in point where a strong

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4 Although lighting conservation with CFLs began in the Pacific Northwest with the inception of the Northwest Energy Efficiency Alliance (NEEA) in 1997, NEEA’s the first structured program, LightWise, began in September 1998 (Dethman & Associates)

5 NEEA has received regional sales data from multiple contractors over the past 15 years. Please see NEEA’s website for a full list of evaluation studies which cover the data sources and extrapolation methodologies to arrive at the regional numbers. www.neea.org

6 MM=million.

7 Correlation coefficient shows the linear dependence between two variables. See Wikipedia for a mathematical derivation.
correlation coefficient provides poor predictive power. Recent utility incentive levels show little correlation. Over the last five years, the Correlation Coefficient between utility incentives and retail CFL sales is 0.05. Further detail shows in 2008 PNW utility incentives accounted for 9.7 MM bulbs or 38% of the purchases, while utilities supplied approximately 10.1 MM incented bulbs in 2011 for 63% of total sales.\(^8\) Utility incentive totals have remained somewhat static over the last four years, while overall sales dropped.

Bhandarkar offers two intuitive reasons for declining sales that are frequently echoed in the energy efficiency community. First, declines in disposable income have priced groups of adopters out of the market. Second, consumers are not happy with color and quality issues. The latter reason implies continued will not influence consumers to replace their incandescent bulbs prior to EISA timelines. The first reason implies that segments of the population must have the necessary disposable income to overcome the price discrepancy between the incandescent bulb and a CFL. For instance, Vermont Energy has had relatively unique increased CFL success primarily due to aggressive incentive campaigns, such as their $.99 bulb promotion (Badger and Reed).

The Pacific Northwest suffered the same fate as most of the country with declining 2009 sales, due in large part to the national economic downturn (Bonn, and The Cadmus Group, Inc./Energy Services and Nexus Market Research, Inc.). However, CFLs were expected to rebound relative to incandescent bulb sales with improvements in the economy, assuming economy improvements also increased disposable income. Another phenomena with regard to the overall market trend, is that as CFLs replace incandescent bulbs, the size of the sales market will decline since the life of a CFL is 5 times that of an incandescent bulb. CFL sales should eventually drop and hold steady at the replacement/burn-out rate. Despite the eventual theoretical drop in CFL sales, market share, should increase as they replace incandescent bulb sales. In actuality, market share dropped from 34% market share to 26% market share between 2008 and 2011\(^9\).

The next graph shows changes in CFL sales relative to the economy in the Pacific Northwest. During the 15 year time frame, GDP change is negative only one year. This negative change occurs between the years 2008 and 2009, where year on year change is -.02%. The second most precipitous decline in growth occurs between 2000 and 2001 with growth at 0.009%. Declines in CFL growth occur concurrently or immediately following these economic slowdowns. Although not proven to show causality, the Correlation Coefficient between gross sales in CFLs and gross domestic product (GDP) in the Pacific Northwest is 0.93. As with utility incentives, the last 5 years of data have almost no correlation with sales, -0.23 and may be a poor predictor of future CFL sales.

Alternative to specific income effects, it may be the case that CFLs reached their maximum saturation ‘naturally’. Chandrasekaran and Tellis (henceforth C&T) reviewed dozen of adoption studies of new products and found the average of these products to have a market penetration ceiling of 52%. Whereas, NEEA adopted a ceiling of 67% according to their current interpretation of the EISA standards. An over-estimation of the CFL market saturation would lead to an overly optimistic CFL forecast. Further, C&T identified that Brown Goods, electronics and social media goods, took off much faster than other goods as they promote social status, thus implying higher maximum penetration. There is no reference that this author is aware of, of CFLs being linked to social status, and therefore, it may be safe to assume, given complaints about product quality and cheaper short-run alternatives (incandescent bulbs) that CFLs may fall on the lower end of the spectrum with regard to ceiling penetration of new products.

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\(^8\) The free-ridership is not addressed in this paper.

\(^9\) Market share was determined by assumptions about the market size and CFL sales number that are evaluated annually and approved by NEEA’s Cost-effectiveness Advisory Committee, comprised of utility members and stakeholders. Please, reference NEEA’s website for historic Cost-effectiveness Advisory Committee packets that contain the individual assumptions and sources for assumptions.
Adoption of ‘Energy Efficiency’ Innovation

Historically, NEEA has used a logistic or ‘S’ curve to estimate CFL sales trajectories. The underlying theory behind the ‘S’ curve is based on Roger’s adoption of innovation. This theory says that groups of adopters, with similar categorical traits, adopt innovation at differing rates. Roger’s shows that economic status is highly correlated with the initial adoption of a new technology. The other groups are characterized by similar socio-economic status and education levels. Rogers categorizes adoptive groups according to a normal distribution, which cumulatively shapes the ‘S’ curve. A summary of Roger’s adopter categories is below (Table 1). The adopter illustration was taken from Wikipedia (Figure 3).

**Table 1. Summary of Roger’s 5 Adopter Categories**

<table>
<thead>
<tr>
<th>Adopter Category</th>
<th>Definition</th>
</tr>
</thead>
</table>
| **Innovators** | Innovators are the first individuals to adopt an innovation with the following attributes:  
  - Risk takers, youngest in age, highest social class, highly educated, have great financial lucidity, very social and have closest contact to scientific sources and interaction with other innovators. |
| **Early Adopters** | This is the second fastest category of individuals who adopt an innovation with the following characteristics:  
  - Highest degree of opinion leadership among the other adopter categories, younger in age, have a higher social status, have more financial lucidity, advanced education, and are more socially forward than late adopters. |
| **Early Majority** | The middle group to adopt innovation with the following characteristics:  
  - Above average social status, contact with early adopters, and seldom hold positions of opinion leadership in a system. |
| **Late Majority** | Second to last group to adopt with the following characteristics:  
  - Skeptical of innovation, below average social status, very little financial lucidity and therefore less willing to take on the risk of innovation failure, in contact with others in late majority and early majority |
| **Laggards** | Last to adopt innovation with the following characteristics:  
  - Show little to no opinion leadership, advanced in age, have an aversion to change-agents, focus on “traditions”, likely to have the lowest social status, lowest financial fluidity, in contact with only family and close friends |
Figure 3. Normally distributed adoption classes and cumulative adoption curve.

Several examples illustrating ‘S’ curve adoption paths and characteristics of new products exist in the literature. Meade, N. and Chandrasekaran, D. and G. J. Tellis provide comprehensive reviews with several supporting authors on the subject of the adoption of new products. The literature shows the wide expanse of adoption curve applications and outcomes. New products achieve varying degrees of success. For example, a new product may reach maximum saturation, such as a refrigerator in every household. Or a product may reach full or near saturation, then become ‘extinct’ with the development of a newer technology. A good case in point is the VHS extinction with the advent of DVDs, nicely illustrated in Coplans paper. Extinction occurs during the ‘Decline’ stage, the fourth of four stages, in the adoption process. The tables below list the 4 stages and 4 turning points of new product adoption. The fourth turning point, called the Saddle Point, is a more recently studied phenomenon that Goldenberg, Libai, and Muller (2002) found in 50% of the 32 product categories they examined. The Saddle Point is illustrated in Figure 4. It is possible that CFLs are experiencing a Saddle Point. A temporary downturn in market share may have been created as some adopters may have been pushed into latter adopter categories due to a sustained decrease in disposable income.

Table 2. Characteristics of Adoption Curves: Turning Points and Stages

<table>
<thead>
<tr>
<th>Turning Points</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercialization</td>
<td>The date a new product is first sold to a mass market</td>
</tr>
<tr>
<td>Takeoff</td>
<td>First dramatic and sustained increase in a new product's sales</td>
</tr>
<tr>
<td>Slowdown</td>
<td>Beginning of a period of temporarily decreasing product sales after takeoff</td>
</tr>
<tr>
<td>Saddle Point</td>
<td>First trough in new product sales following post takeoff peak</td>
</tr>
</tbody>
</table>

Instead of a Saddle Point, CFLs may be in the ‘Decline’ stage (Table 2). C&T cite some drivers of Slowdown: every 1% increase in price leads to a 5% increase in the probability of a Slowdown; and every 1% decrease in GNP...
is associated with a 17% increase in the probability of Slowdown. Higher upfront costs, despite sometime significant long term savings, are a common obstacle to the adoption of energy efficient technologies (Heinzle; and Gallagher and Randell). Meade and Islam state that diffusion of innovation will cease if critical mass is not achieved, “as may occur if there is a discontinuity in the distribution of adoption thresholds.” It is unknown whether the recent turn in economic events was substantial enough to cause such a discontinuity.

**Table 3. Characteristics of Adoption Curves: Turning Points and Stages**

<table>
<thead>
<tr>
<th>Stages</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>Period from a new product’s commercialization until its takeoff</td>
</tr>
<tr>
<td>Growth</td>
<td>Period from a new product's takeoff until its slowdown</td>
</tr>
<tr>
<td>Maturity</td>
<td>Period from a product's slowdown until sales steadily decline</td>
</tr>
<tr>
<td>Decline</td>
<td>Sales steadily decline until a product’s demise</td>
</tr>
</tbody>
</table>

Figure 4 illustrates the temporal relationship between the adoptive turning points and stages.

**Figure 4. Illustration of Adoption Characteristics**

The driving factors behind the CFL forecast in any year are the assumptions around the terminus of the ‘S’ curves the history of prior years’ sales. The lower portion of the ‘S’ curve is shaped to fit through historic CFL sales data. The terminus is an estimation based on anticipated socket saturation. Below, the figure shows NEEA estimation of CFL forecasts as of March 2009. In this figure, 2008 was the last year of point-of-sales data for retail CFLs in the region. Market Share is defined as percentage of CFLs to all medium screw-based bulbs sales. According to this estimation, a 41% market share was projected for 2009 which equated to approximately 29 million gross CFL sales. This is 4 million more than the prior year. It is important to note that the market size is dynamic as shorter life incandescent bulbs are replaced with longer-life CFLs.

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10 Total lighting market sales estimation is based on of national shipments, the Pacific Northwest’s percentage of national households. A burn-out model of both incandescent bulbs and CFL’s is applied.
Figure 3. NEEA’s Logistic Curve CFL Forecast as of March 2009

NEEA’s assumptions are updated annually\(^\text{11}\). Figure 4 shows the adjusted forecast given 2009 retail sales data. 2009 gross sales were approximately 18.3 million. Additionally, NEEA updated there terminus assumption to be consistent with the Regional Technical Forum’s 67%. Basically, the Regional Technical Forum’s analysis of the legislation concluded that approximately 33% of the sockets in the PNW households would not be EISA compliant. This assertion alone may over exaggerate CFL potential because consumers with a strong aversion to CFL and the economic means can purchase alternatives, such as LEDs. It should also be noted that the lower end of the curve was no longer fit through the historic data and a bit of art was applied in an attempt to be more conservative with forecasts.

Figure 4. NEEA’s Logistic Curve CFL Forecast as of March 2010

\(^\text{11}\) All major market assumptions receive annual review. If assumption updates, such as retirement rates or hours of operation change, then retroactive changes may be applied to the market size. Further, new data sources may have been uncovered that would have updated historic CFL sales.
2010 was estimated to have a 37% market share. Although not shown, the 2010 sales and market share of 29%, were far below predicted. Recognizing a fundamental shift in sales trend, NEEA abandoned the ‘S’ curve for the 2011 forecast. With no budget for market intelligence during the forecast year and a strong desire to be conservative with its forecast to its funders, NEEA simply applied a linear trend downward from 2009 and 2010. The downward linear trend provided a better estimate than would have occurred otherwise. Given that 2011 sales continued to decline, and any ‘S’ curve market share would have been upward sloping, the ‘S’ curve abandonment was a good decision.

In light of the CFLs departure from the ‘S’ curve and economic anomalies, NEEA wanted to investigate forecast alternatives to glean possible insights into future forecast activities. The alternative forecasts are provided in the following section.

**Growth Curves and Forecasting Methodologies**

As mentioned earlier, NEEA’s forecast of CFLs was largely driven by adoption of innovation theory and the ‘S’ curve. This next section sets up an alternative scenario where the pre-EISA forecast is treated independently. Additionally, a simple linear forecast using cumulative sales and cumulative regional GDP was estimated. Forecasts for Oregon, Washington, Idaho, and Montana, from state budgetary offices, were used to forecast CFLs.

**‘S’ Curve**

The terminus was reset to equal the average saturation rate for researched durable goods of 52%. The ‘S’ curve used for the forecast follows an excel adaption (Garcia) of a logistic function which allows for diffusion dynamics

\[ X_t = a + \frac{b}{1 + c^{(f + \frac{20 - t}{e})}} \]

where \( a \) represents the initial market share, \( b \) is the upper bound or saturation point, \( c \) is the steepness of the curve, \( f \) is the year in which ‘take-off’ occurs, and \( e \) is the number of years it takes for market transformation. The choice of the terminus or saturation point was somewhat arbitrary, but not unlike a choice that would have been made in the absence of EISA. A 20% decrement from the average saturation rate for new products was chosen given the relative unpopularity of CFLs to other durable goods (Green). This equates to a maximum penetration rate of 42%. 20 years is the market transformation period. It is also assumed that energy crisis of 2001 caused outlier effects not indicative of average market forces in 2001, 2002, and 2003. The data was smoothed between years 2000 and 2004. Mean square errors were minimized between 1997 and 2008.

Figure 5 below shows the re-estimation of the ‘S’ curve and resulting ‘S’ forecast. What was formerly a 41% market share forecast, dropped to 35%. The result would have been 25.2 MM bulbs, given a total market size of approximately 70 MM medium screw-based bulbs with the models current retirement/replacement assumptions.

The ‘S’ was re-estimated two more times to minimize mean square errors with the updated sales data in 2009 and 2010. The estimated 2010 and 2011 market shares with the curve updates were 36% and the 38%. The updated 2011 curve is shown in Figure 6.

Lastly, the 2011 base case forecast using the original, EISA driven saturation point of 67%, applied the same methodology as used for 2009 and 2010.
GDP

Since income is a primary driver of the ‘S’ curve theory, GDP is the other forecast avenue examined. Population weighted regional average GDP was developed from year prior forecasts from the state offices of Oregon, Washington, Idaho and Montana. Simple linear extrapolation was used to forecast CFL sales.
Results

Table 4 shows the forecast results from the base case ‘S’ curve against the ‘S’ curve with the non-EISA driven terminus and the GDP forecasts.

Table 4. Comparison of Forecasts with Saturation Ceilings with and Without EISA Standards

<table>
<thead>
<tr>
<th>Year</th>
<th>Estimated Bulb Sales using 'S' Curve with 67% Saturation Ceiling</th>
<th>Estimated Bulb Sales using 'S' Curve with 46% Saturation Ceiling</th>
<th>Actual Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>28.9 MM</td>
<td>24.8 MM</td>
<td>18.2 MM</td>
</tr>
<tr>
<td>2010</td>
<td>23.9 MM</td>
<td>22.9 MM</td>
<td>18.8 MM</td>
</tr>
<tr>
<td>2011</td>
<td>27.2 MM</td>
<td>23.0 MM</td>
<td>15.9 MM</td>
</tr>
</tbody>
</table>

Although the forecasts are significantly improved they are still substantially off of the mark. The results using regional GDP are an improvement.

Table 5. Comparison of Original Forecast Using 67% Saturation Ceiling with Regional GDP forecast

<table>
<thead>
<tr>
<th>Year</th>
<th>Estimated Bulb Sales using 'S' Curve with 67% Saturation Ceiling</th>
<th>Using Linear Estimation with regional Gross Domestic Product</th>
<th>Actual Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>28.9 MM</td>
<td>19.7 MM</td>
<td>18.2 MM</td>
</tr>
<tr>
<td>2010</td>
<td>23.9 MM</td>
<td>20.6 MM</td>
<td>18.8 MM</td>
</tr>
<tr>
<td>2011</td>
<td>27.2 MM</td>
<td>21.6 MM</td>
<td>15.9 MM</td>
</tr>
</tbody>
</table>

The forecast using GDP projections provided a much better forecast compared to the updated ‘S’ curve.

Observations and Notes on Lighting Standards

The first observation is that the ‘S’ curve was not robust enough to continue modeling CFL sales in the Pacific Northwest after the economic downturn of 2008. Even if the adoption process was exhibiting a saddle point in recent years, a readjustment of the terminus could not provide remotely reasonable forecast sales estimates. If one were to force the ‘S’ curve to predict the last three years, would require an extremely low terminus that would make all of the prior years’ estimates nonsensical. Instead it appears as though a structure break, due to the 2008 economic collapse, has resulted. Given consumers heightened sensitivity to disposable income, first cost has become a priority over long-run energy savings.

Whether CFL will rebound is a moot point due to the passage of The Energy Independence and Security Act (EISA) 2007. The table below shows the manufacturing and shipping standards imposed by the bill. EISA does not make it illegal for customers to use older vintages of light bulbs, effectively incandescent light bulbs, consumers will eventually no longer be able to purchase them.
Table 6. Timeframe of EISA Manufacturing and Shipping Standards

<table>
<thead>
<tr>
<th>Effective Date</th>
<th>Lumens</th>
<th>Min. Lamp Life (hrs)</th>
<th>Current Wattage</th>
<th>Maximum Allowable Watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan 1, 2012</td>
<td>1490-2600</td>
<td>1000</td>
<td>100</td>
<td>72</td>
</tr>
<tr>
<td>Jan 1, 2013</td>
<td>1050-1489</td>
<td>1000</td>
<td>75</td>
<td>53</td>
</tr>
<tr>
<td>Jan 1, 2014</td>
<td>750-1049</td>
<td>1000</td>
<td>60</td>
<td>43</td>
</tr>
<tr>
<td>Jan 1, 2015</td>
<td>310-749</td>
<td>1000</td>
<td>40</td>
<td>29</td>
</tr>
</tbody>
</table>

As long as EISA is not repealed, the PNW can expect to see saturation close to 70%. The RBSA estimates that 29% of household sockets are currently filled with CFLs and another 42% are covered by EISA or approximately 107 million CFLs (Storm, Baylon, and Geraghty).

There are two directions that consumers may take. First, consumers may suddenly fully embrace CFLs and fill their remaining household sockets with these bulbs. Or, consumers may rebel against the legislation and purchase halogen and LED alternatives. However, one could extrapolate from the GDP experiment above. The results may provide some evidence that consumers are very concerned with disposable income. If that continues to be the case, then the original 67% maximum saturation point may not be that far off the mark, as the current competing technologies are not expected to be price competitive in the near future (Blacker).

References

Badger, C. and Reed, G. “Breaking the Habit…Life beyond the CFL for Efficiency Programs” ACEEE Summer Study 2010.


