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The dynamics of incremental costs of efficient television display technologies

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ABSTRACT

We study the evolution of the incremental cost and price of efficiency for televisions in the U.S. market. We focus on televisions due to their rapid technological evolution and large number of annual shipments, such that costs and prices evolve on short timescales as compared to other consumer durable goods. Using the experience curve approach, we compare manufacturing costs and selling prices of two liquid crystal display (LCD) technologies. We find a mean experience rate of 27% for less efficient cold cathode fluorescent lamp LCD televisions and 14% for more efficient light emitting diode LCD televisions, using price data. This corresponds to an annual decline of approximately 17% per year in price for both television types. Our results also suggest that the incremental cost or price of efficiency, holding other major features constant, declines much more rapidly than the baseline cost or price. We find that the incremental cost or price declines at roughly 50% per year. The fitted parameters do depend on the specific technology modeled, as well as on whether cost or price data are used. Our results for LCD televisions are qualitatively similar to other display technologies, even very mature ones, suggesting that the cost and price decline extends many years after a technology is considered mature. We also analyze the selling prices of ENERGY STAR® and non-ENERGY STAR televisions, which support our main findings. These results highlight the consumer benefits of efficient display technologies, and how the dynamics of incremental costs differ from baseline costs.

1. Introduction

Improvements in the energy efficiency of consumer products are generally considered to increase the manufacturing cost and purchase price of such products. When assessing the impact of any potential energy efficiency technology, it is often necessary to make engineering-based *ex ante* estimates of this incremental cost for any future deployment. This is true regardless of the program mechanism (*e.g.*, minimum efficiency standards, labeling programs, utility rebate programs). Retrospective evaluations have demonstrated, however, that *ex ante* estimates of incremental costs and prices tend to overestimate the actual costs and prices seen in the market [10,6], because such estimates do not address future dynamics that may influence incremental costs. In order to properly assess energy efficiency technologies, it is important to consider the effects of technological learning and innovation.

Televisions are well suited in studying these dynamics. Like most other consumer electronic products, televisions have a relatively short lifetime, and consumers are increasingly purchasing several televisions for their homes. As a result, annual production is high. In the U.S. alone, television shipments totaled more than 35 million units in 2011. By contrast, refrigerator shipments in the U.S. hovered just above 10 million, and light vehicle shipments were approximately 13 million. Innovation in the consumer electronics space is also very rapid, making it easier to observe changes in the market on short time scales. Televisions are therefore a good case study for how the cost and price of efficiency evolve over a relatively short period of time, reducing the length of time series data needed to perform an analysis. For

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other consumer durable goods, one would typically need many more years of data to perform a similar analysis.

Televisions are available with a variety of display technologies. These include the cathode ray tube (CRT), an emissive technology that was dominant until the last decade. CRT televisions are a mature technology and inexpensive to manufacture today, but are generally limited to smaller screen sizes. Liquid crystal displays (LCDs) were first popularized as computer and laptop monitors. They enable larger screen sizes that take up significantly less space, and have now become the dominant television technology worldwide. LCDs are a transmissive technology, and require a backlight to generate an image on the screen. Until recently, this backlight technology was dominated by cold cathode fluorescent lamps (CCFLs). In the last few years, LCDs with light emitting diodes (LEDs) as a backlight have begun to gain significant market share. The LEDs can be arranged either along the edges of the LCD television for a slim profile (LED-Edgelit), or arranged in an array behind the LCD layer for optimum light level control (LED-Backlit). Of these two configurations, the LED–Edgelit–LCD television is by far the more popular model in the global market. Another television technology, albeit with a small global market share, is the plasma television. Plasma Display Panel (PDP) televisions are emissive in nature, similar to CRT televisions, but do not suffer the same physical constraints as CRT televisions. Finally, organic light emitting diode (OLED) televisions are only just starting to enter the market. A few, limited-run OLED televisions have already been sold in the past, and many prototypes have been demonstrated. OLED televisions are emissive, and can be manufactured with incredibly slim profiles. There are, however, challenges with current OLED technology that must be overcome before OLED televisions become widespread. In particular, OLEDs suffer from color instability over time, and have low yield at larger sizes resulting in very high production costs.

The dominant technology worldwide is the CCFL–LCD television, though LED–Edgelit–LCD televisions are quickly catching up. In terms of efficiency, LED-based LCD televisions are the superior technology, both because the generation of light is more efficient and because LEDs enable a finer control of light levels across the screen [17]. If the displayed image is dark, fewer individual LEDs need to activate to generate the image (this is known as global and local dimming). CCFL–LCDs generally only have a few individual tubes coarsely arranged behind the LCD, limiting the dimming strategies available. As a result, the CCFLs tend to be fully powered even if the image is dark, and the LCD layer must block most of the backlight. Park et al. [18] analyzed power consumption data for a number of 32″ and 40″ CCFL–LCD and LED–LCD television models that were available in 2011. They found that on average LED–LCD televisions consumed 56 W at 32″ (24 models) and 79 W at 40″ (35 models), compared to 71 W at 32″ (44 models) and 118 W at 40″ (33 models) for CCFL–LCD televisions. All power consumption values are with automatic brightness control disabled. This represents approximately 20% and 35% in power consumption reductions for 32″ and 40″ LED–LCD televisions, respectively. Both television types had a similar spread in power consumption among all the models, with a difference of over 40 W from minimum to maximum at 32″, and nearly 60 W from minimum to maximum at 40″.

Other than the backlight, however, CCFL–LCD televisions and LED–Edgelit–LCD televisions share many of the same attributes that consumers consider in their purchase decision, including screen size, resolution, and framerate. As a result, a direct comparison between CCFL–LCD and LED–Edgelit–LCD televisions is also mostly a comparison of efficiency, and is the main focus of this paper. OLED televisions offer the potential of even greater efficiency, given observed trends in mobile devices. Current production is very limited, however, and efficiency gains will likely need to wait for subsequent generations of OLED televisions.

In order to model the price and cost dynamics of televisions, we utilize the experience curve formulation, which models real production cost and price declines as a function of cumulative production [20,1,4,5]. There is extensive historical evidence supporting this phenomenon, and experience curves have been applied to a wide variety of products, industries, and sectors. For a comprehensive review, see Fusfeld [11], Yelle [20], Day & Montgomery [7], Dutton & Thomas [9], Argote & Epple [2], Newell [16], IEA [12], McDonald & Schrattenholzer [14], and Weiss et al. [18](and references therein). The main causal factors responsible for this phenomenon at an industry-wide level include improving labor efficiency, process improvements, capital investments (*e.g.*, upgraded machinery), increased automation, product design improvements, and improved distribution. Although economies of scale are occasionally cited as a casual factor of experience, strictly speaking the concept is distinct and separate. Practically, however, a scale up in production coincides with an increased repetitive action of producing a good, leading to experience in producing that good. Therefore experience and economies of scale are generally coincidental and difficult to disentangle, and mutually reinforce each other, leading to increased production efficiency. For further information, see Lindman & Söderholm [13] who discuss this issue in greater detail and attempt to control for scale in their analysis of wind power learning rates. Ultimately, the concept of the experience curve is an empirical one, where cumulative production is a proxy measure for accumulated knowledge, and encompasses many casual factors.

Note that the literature often interchanges the concepts of "learning" and "experience". Learning is a microeconomic concept and is generally more narrowly focused on production of a single product at a single facility (or within a single firm), whereas experience is a macroeconomic concept and extends more broadly to entire industries and encompasses several underlying casual factors. In competitive markets, improvements in production of one product at one firm can quickly diffuse to other similar products and competitors, which is how "learning" at one firm becomes "experience" for an entire industry. The mathematical formulations, however, are similar, and are empirical relationships. In this paper, we consider the global television market and average over all television manufacturers, therefore the appropriate term is the experience curve.

This paper explores the dynamics of baseline and incremental costs of improved efficiency using high-quality market research data. We consider a baseline product to be the least efficient on the market, and we assume that more efficient units carry additional incremental costs at a given point in time. In particular, we seek to determine the

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