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Abstract

This paper examines price data on over 222 LCD televisions to estimate indirect network effects arising from two sources. First, we conjecture that the disconnect between the timing of when broadcasters are required to convert to an only-digital-signal world and when television manufacturers are required to have an ATSC digital tuner install on all new televisions has created an indirect network effect whereby television that are backward compatible with the NTSC analog QAM and VSB-8 systems have short-run value. Over time, however, we argue that the ATSC digital tuner will become more valuable. The second indirect network effect we estimate stems from the number and types of ports available on LCD televisions. In each case, we find statistically significant evidence for the presence of indirect network effects in the market for LCD televisions.

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I. Introduction

The U.S. Census Bureau's Statistical Abstract of the United States reports that the average American is projected to spend an astounding 1,704 hours (71 days) watching television in 2008. While the vast number of hours Americans dedicate to watching TV is, in part, a reflection our society's wealth, it is also a function of the number and variety of shows available. Indeed, the impending February 2009 standards transition from the current National Television System Committee's (NTSC) analog system to the Advance Television System Committee's (ATSC) digital system will allow broadcasters to further increase both the number and variety of shows. This change alone is likely to increase consumers' utility, and provide one source of an indirect network externality.

The 2008 Census Bureau estimate, however, does not capture the fact that today's televisions are used for much more than watching broadcast television. Indeed, today's high-definition televisions (HDTVs) are multi-functional entertainment centers with adapters that enable compatibility with many other devices that (potentially) increase consumers' utility. The additional functionality of today's televisions include compatibility with videogame consoles, household PCs, video input and output devices (including high-definition devices), and input and output audio devices. The vast number of products that are compatible with today's televisions would accordingly influence consumers' value of television beyond a simple device used to watch traditional broadcast television. Hence, the market for HDTVs is likely to exhibit an indirect network externality beyond an increase in program variety.

While several projection technologies exists to deliver HD signals to consumers homes – plasma, LCD and projection – in this paper we focus on the market for LCD televisions to cleanly identify network externalities arising from compatibility with the forthcoming ATSC digital standard and other devices. Accordingly, we collect price, image tuner and quality, and product compatibility characteristics from CNet's Shopper.com to estimate a hedonic pricing model for over 200 LCD televisions on 3 November 2007 and 27 August 2008. In following this methodology for estimating network effects, we build on the approaches of Gandal (1994, 1995) and Chakravarty, Doganand Tomlinson (2006).

II. Literature Review

The explosive growth in network industries has led researchers to address new and interesting empirical and theoretical questions. Many of these industries exhibit direct network externalities whereby each consumers' utility increases as the total number of consumers that buy that (or a similar) brand increases. Early theoretical research on direct network externalities includes Katz and Shapiro (1985, 1986, 1992, 1994) and Farrell and Saloner (1985, 1986).

Theoretical research has progressed beyond understanding direct network externalities to indirect or complementary network externalities, which arise when consumer utility and number of users occurs via variety of complementary products (cf. Matutes and Regibeau (1988); Economides (1989); Chou and Shy (1990); and Church and Gandal (1993)).

The theoretical work on direct and indirect network externalities has also been followed by a number of interesting empirical studies (cf. David (1985); Greenstein (1993); Gandal (1994, 1995); Hartman and Teece (1990); Baseman et al. (1995); Bresnahan and Greenstein (1997, 1999), Brynjolfsson and Kemerer (1996)).

III. Background Methodology, Data and Empirical Model

Our primary objective is to identify network externalities arising from compatibility with the ATSC digital standard and other input/output devices in the market for LCD televisions. Our empirical strategy is to use a hedonic price to estimate the various characteristics of LCD televisions. The LCD television market is currently in a state of transition. While all televisions imported in the U.S. or shipped via interstate commerce before 1 March 2007 are required to have an ATSC digital tuner, few broadcasters where offering a wide array of digital programming at that time. Therefore, many LCD televisions in our sample were shipped with multiples tuners: An ATSC digital tuner and an analog tuner that could carry either cable or terrestrial signals (either a QAM or VSB tuner, respectively). We conjecture that LCD televisions with multiple tuners would be more valuable by permitting backward compatibility with the existing analog broadcasting system. However, sole compatibility with the forthcoming ATSC broadcasting standard, we conjecture, should become more valuable over time.

Similarly, LCD televisions come equipped with different input/output ports that permit connectivity with compatible devices. In general, more ports are preferred to fewer since they facilitate compatibility with more devices. However, the mix of ports offered with LCD televisions is evolving since compatibility with old and new technologies is still required. Therefore, while network effects should be present with the number of ports, over time these ports will be more or less valuable, depending on whether they facilitate connectivity with old or new technology devices.

However, prior to addressing these issues it is important to discuss the evolution of the broadcasting and television markets to understand what is driving the increase in demand for LCD televisions.

i. Background Methodology: Broadcasting Evolution

Until recently it was difficult to think about the market for televisions exhibiting network externalities let alone a method to measure their presences. In 1941, when the NTSC standardized the broadcasting system on a 525-line system, the U.S had no national broadcast programming service. Instead, U.S. television was a decentralized, market-oriented system characterized by local ownership. These local media markets were either affiliated or owned and operated by a TV network. Until the 1970s, there were three major commercial networks in the U.S[3]. Local broadcasting stations (independents) not affiliated with one of the big three networks aired only locally produced and syndicated programming and broadcast on the ultra high frequency (UHF) band. Therefore, between 1941 until the 1970s consumers basically had access to three, localized television broadcasting networks.

The decade associated with the 1970s is characterized by wide spread consumer adoption and national-network contribution to cable broadcasting. Unlike broadcast networks, that vary local programming between local markets, cable networks typically broadcast the same programming nationwide. That is, on cable networks consumers in Los Angeles, CA, generally, have the same programming as consumers in New York City, NY. Widespread consumer adoption of cable television vastly increased programming variety. Cable programming helped to increase consumers' viewing options and utility, and provided a

[3] CBS Broadcasting Inc. was formerly named Columbia Broadcasting System.

starting point to open discussions whether this market exhibited measurable indirect network effects.

Between 1970 and 1990, cable television remained the dominant television broadcasting service.[4] In the 1990s, however, Direct broadcast satellite introduced television services that directly competed with cable television. This method of television broadcasting distributed programming via satellite to local affiliates, which had the benefit of providing increased programming variety.

On February 19, 2009, the U.S. television market dramatically will change, again, when broadcasters will be required to broadcast digital signals. The ATSC signals are designed to utilize the same 6 MHz bandwidth as NTSC signals. However, the primary difference in the digital and analog technologies is the way in which signals are broadcast. Digital television sends and receives moving images and sound via discrete (or digital) signals. This contrasts with analog signals, which broadcasts picture and sound information via a continuous signal. The move to digital television is designed to be more flexible and efficient than analog television, and provide higher-quality images, sound and more programming choices.

While the broadcasting television market has certainly since the 1940s, improvements in the market for televisions primarily has occurred picture quality, dimensions, technology and convenience. Indeed, by 1955 half of all U.S. households had a black-and-white television. Color television consoles did not become popular until after the mid-1960s, when an increasing proportion of programming was broadcast in color and the cost would come down. [5]

[4] Cable operators were required by law to include local over-the-air stations in their cable services.
[5] The transition was no accident. Evolution from black-and-white broadcasting to color required figuring out how color signals could be displayed on televisions with only black-and-white technology.

Today, 99 percent of U.S. households have at least one color television. These televisions vary in size, image and sound quality. However, the impending conversion of to digital television signals renders many of these televisions obsolete, in the sense that they will require a signal converter to view and listen to digital programming.

While televisions in the U.S. are now required to have a digital tuner, manufacturers recognize that consumers utilize televisions for much more than watching programming and install ports that enable compatibility with a multitude of products. For example, television manufacturers install a variety of input/output) ports to enable consumers to connect devices such as Blu-Ray or HD dvd, traditional dvd format, VCR, gaming consoles, personal computers, home audio systems, among others.

In the remainder of the paper, we will focus on how exampling how these ports contribute to the value of today's televisions and how we identify these ports as exhibiting network externalities.

ii. Data

Our data set of 222 LCD televisions comes from CNet's Shopper.com on two different dates; 3 November 2007 and 27 August 2008[6]. In addition to price information, we collect a number of characteristics that measure image and audio quality as well as information on the mix of input/output ports. Variables measuring image and audio quality are important covariates that contribute to the price of a television and to accurately measure indirect network externalities arising from compatible components.

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[6] It is our objective to collect this data on a weekly basis to continue this valuation technique and determine whether a convergence in the number and types of ports is achieved. As the technology changes and updates, it is likely that the servicing ports will too.

Signal Modulation and Transmission: Types of Tuners

By Federal Communication Commission (FCC) mandate, all new televisions sold in the U.S. must have an ATSC tuner to receive digital television signals. Given the two-year lag between this hardware requirement and when broadcasters are required to only transmit digital signals, some television manufacturers have opted for installing both digital and analog tuners.

Table 1 illustrates the distribution of television tuners in our sample of LCD televisions. While all of the televisions in our sample have an ATSC digital tuner, almost 77 percent of televisions are also equipped with an NTSC analog tuner as well. The primary purpose for multiple tuners is backward compatibility with current NTSC standards during gap between the hardware requirement and when broadcasters are required to broadcast only digital signals. We conjecture that LCD televisions equipped with only an ATSC digital tuner will be less valuable than those equipped with both ATSC and NTSC tuners. However, we also conjecture that over time, the televisions equipped with only an ATSC tuner will be more valuable. If our empirical model produces evidence consistent with these conjectures, we will take this as evidence supporting the claim that the market for LCD televisions exhibits positive, indirect network effects.

Image Quality Variables

Given our primary research interest of examining network externalities arising from compatibility with ATSC standards and complementary products all the LCD televisions in our data set have an image aspect ratio of 16:9; the aspect ratio that is consistent with the ATSC standard. The image aspect ratio measures image width divided by its height. While many consumers measure the quality of a picture by its image aspect ratio, it is only one component. Indeed, consumers often discuss the quality of a television's picture by its horizontal and vertical resolution. According to the Image Science Foundation, the quality of a television's image is largely determined by the image contrast ratio, which measures a display system's capability to produce the brightest color (white) to the darkest color (black).

Table 2 illustrates the primary image quality measures for 222 LCD televisions for each date in the sample, summarized by make and model. There are 55 televisions that appear on both dates. These measures include the width (in inches); vertical resolution; image contrast ratio; and whether the television uses progressive scan technology[7]. The mean width of the LCD television in the entire sample is 36.3 inches. The mean vertical resolution, which measures the number of distinct vertical pixels in a picture's display, is 889. Over the entire sample, the vertical resolution took on three distinct values; 480, 768 or 1080 lines of vertical resolution.

Somewhat related to the lines of vertical resolution is the method by which moving images are displayed, stored or transmitted. Two technologies exist for LCD televisions: Progressive scan or interlaced. Progressive scan updates moving images sequentially drawn in all lines of each frame. In contrast, interlacing technology, used in traditional television systems, alternatively draw odd and even lines to capture moving images. The proportion of LCD televisions utilizing progressive scan technology is about 90 percent in our sample, as illustrated in Table 2.

[7] We omit horizontal resolution and height (in inches) for econometric reasons discussed in the Empirical Model sub-section.

The image contrast ratio is, arguably, the most important measure of image quality for an LCD television. It measures the ratio of the luminous of the brightest whites to the darkest black that the television is capable of producing. In our sample of 222 LCD televisions, the image contrast ratio ranged from 400:1 to 8,000:1, with the average image contrast ratio being 1,450:1. While this suggests significant variability in the image contrast ratio for our sample, manufacturers employ different measurement methods, operation and other variables render the image contrast ratios potentially incomparable across manufacturers. In the *Empirical Model* section of this paper, we will discuss a method for dealing with this issue.

Component Compatibility Variables

The functionality of today's televisions is extremely broad and provides compatibility with many external devices. At this point in the evolution of the LCD television market, there is no *de facto* standard number or types of ports. Yet, the mix of ports available determines the array of products that can be connected to the LCD television and determines the magnitude of the indirect network effects. Over time, we conjecture that the type and number of ports will become more standard as clear as analog-port-compatible devices go to the wayside and adoption of digital ports devices become more widespread.

Compatible devices are connected to LCD televisions in a variety of ways. Analog connection types include component audio/video and S-video. Component audio/video is a connection type that splits analog audio/video signals into three components. Devices that utilize component audio/video ports include traditional VCR, DVD players, and game consoles. Similarly, S-video carries analog video data over two separate signals. S-video is commonly found on consumer televisions, traditional DVD players, Digital TV receivers, DVRs, and game consoles.

There are a number of ways to connect personal computers (PC) and other related peripherals to LCD televisions. The three primary PC connections methods are Video Graphic Array high density 15 pin (VGA HD15), Digital Visual Interface (DVI), and High-Definition Multimedia Interface (HDMI). The VGA HD15 port permits analog video signals to be transmitted from a compatible device to an LCD television. VGA HD15 ports are a common way from a computer to transmit video signals to a monitor. However, analog signals are being replaced by their digital counterparts (DVI and HDMI) for higher quality transmissions.

DVI and HDMI are standards that permit transmission of digital video signals. They are designed to carry uncompressed digital video data to a display, such as an LCD television. While HDMI is becoming the *de facto* standard, DVI-D (digital) is electrically compatible with the HDMI video signal. Therefore, HDMI is backward compatible with DVI-D used on LCD televisions.

Table 3 shows the various combinations of connection interfaces on the LCD televisions in our sample. Given HDMI is becoming the *de facto* digital standard and VGA HD15 is the current analog standard, any combination of these interfaces will be more highly valued than an LCD having solely a DVI digital interface.

The final set of ports that permit connectivity with compatible devices are two standards of serial bus interfaces: Universal Serial Bus (USB) and IEEE 1394. The IEEE interface is used for high-speed communication and isochronous real-time data transfers. It has been adopted as the standard connection for audio/visual component communication. The USB interface is designed to allow many peripherals to be connected to the LCD television and provides a standardized interface socket with plug-and-play capabilities. We conjecture that the addition of the interfaces to any LCD television will increase its value and will be increasing over time.

iii. Empirical Model

We use a hedonic pricing model to estimate demand for LCD televisions to value its different characteristics. We categorize characteristics into three categories: installed digital television tuners, image-quality variables and input/output ports for compatible devices.

While estimating a hedonic pricing model is relatively straight forward, the image contrast ratio is highly dependent upon how the manufacturer measures and reports this variable as well as the width of the television in inches. To control for this potential multicollinearity, we estimate a preliminary regression to "purge" manufacturer and television width factors from the image contrast ratio. We use the resultant predicted image contrast ratios conditioning on manufacturer effects and television width. The estimated natural logarithm of the predicted image contrast ratio is used in the hedonic pricing model.

Specifically, we estimate the following OLS regression model.

$$\ln p_{ikt} = \beta_0 + \boldsymbol{\beta}_1^{'}\mathbf{X}_k + \boldsymbol{\mu}_k + \boldsymbol{\tau}_t + \boldsymbol{\mu}_k \times \boldsymbol{\tau}_t + \boldsymbol{\gamma}_k + \varepsilon_{ikt} ,$$

where the dependent variable $ln\ p_{ikt}$ is the natural logarithm of firm i's price for LCD television model k on date t. $\boldsymbol{X_k}$ is a vector of image quality variables consisting of the 1) natural logarithm of the television width in inches; 2) natural logarithm of the vertical resolution; 3) natural logarithm of the predicted image contrast ratio (interacted with date); and 4) a dummy variable indicating whether the LCD television use interlaced or progressive scan technologies to update the image. Vector $\boldsymbol{\mu_k}$ consists of dummy variables estimating the presences of various indirect network effects. Specifically, $\boldsymbol{\mu_k}$ consists of a dummy variable for whether the LCD television has only an ATSC digital tuner (= 0) or NTSC and ATSC tuners (= 1); a dummy variable for the presence of at least one USB port; a dummy variable indicating the presence of at least one IEEE1394 port; and a dummy variable indicating the presence of at least one S-video port.[8] The vector $\boldsymbol{\tau_k}$ consists of date dummy variables for 3 November 2007 and 27 August 2008. Finally, $\boldsymbol{\gamma}_k$ is a vector describing the mix of PC interfaces installed on LCD model k.

IV. Empirical Results

The results of our OLS estimation of the hedonic pricing model are contained in Table 4. Our results indicate that image quality variables play a statistically significant role in determining the price of an LCD television. A 10 percent increase in the predicted image contrast ratio increases price by 1.6 percent. However, over time the predicted image contrast ratio declines. Similarly, 10 percent increases in the vertical resolution and widths increase an LCD televisions price by 10.309 percent and 15.771 percent, respectively. Take together this suggests that image quality is an important determinant in an LCD television's price.

Image quality is not, however, the only determinant that statistically impacts an LCD television's price. Indeed, LCD televisions equipped with only an ATSC tuner reduces the price by 0.0555 percent. Somewhat differently, between our two sample dates of 3 November 2007 and 27 August 2008 LCD televisions with an ATSC digital tuner and at least one NTSC analog tuner commanded a higher price than televisions with only an ATSC tuner. We take this as empirical evidence of an indirect network effect resulting from a disconnect between when LCD

[8] In some instances, multiple ports of a single variety existed. Since it is our intention to estimate the presence of an indirect network effect, we constructed a variable looking at the presence versus non-presence of the port.

television manufacturers were required to comply with having all new televisions equipped with an ATSC digital tuner and when television broadcaster are required to fully convert to digital programming. As the date broadcasters are required to provide only digital programming approaches, however, LCD televisions with only an ATSC positively impact price in a statistically significant manner.

Indirect network effects are not relegated to the presence of an ATSC digital tuner. The presences of an IEEE 1394 interface and S-video port have a positive, statistically significant impact on the price on an LCD television. Over time, S-video negatively impacts price since it is an analogy technology meant to provide backward compatibility with existing devices like DVD players and video game consoles. In contrast, the IEEE 1394 interface increases the value of an LCD television since it was adopted as the High Definition Audio-Video Network Alliance (HANA) standard connection interface for audio/video component communication.

Interesting, the presence of a USB port reduces an LCD television's price by 0.04 percent. Over time, the negative impact of the presence of a USB port has a positive and statistically significant impact on the price of an LCD television.

These various port connections suggest another source of an indirect network externality. Over time, the S-video technology is reducing the price of an LCD television by about 0.24 percent while USB ports are increasing the value by approximately 0.119 percent.

The mix and variety of connectivity interfaces to PC provides another source of network externalities. Relative to the LCD televisions with solely a VGA HD15 interface, televisions with all three interfaces – DVI, HDMI and VGA HD15 – statistically increase price by 0.88 percent. Relatively to only the VGA HD15 interface connection, all other combinations of ports, except only DVI, statistically contributes to a positive influence to an LCD television's price. We take this as further evidence of network externalities in the market for LCD televisions.

V. Conclusion

The evolution of the television and broadcasting markets has brought the market to a point where multiple sources of indirect network externalities. Forthcoming changes in the standards broadcasters will have to adhere to are coming in February 2009. These changes will impact both the quality and programming variety available to consumers. Indeed, the ATSC system uses digital signals to carry video and audio data, which is of higher quality than the existing NTSC analog standard. The disconnect between when broadcasters convert to a digital-only signal and when television manufacturers were required to comply with the new standard has created a market whereby both digital and analog tuners add to an LCD television's price relative to televisions with only an ATSC tuner.

Given that today's televisions are designed to be multimedia entertainment centers, connectivity to other compatible devices is another source of indirect network externalities. While some of the ports permit backward compatibility with analog devices, their value over time tends to decrease. In contrast, ports enabling digital interfaces tend to increase the value of a television through time. In terms of interface connectivity with PCs, relatively to only analog VGA HD15, LCD televisions permitting connection via DVI, HDMI and VGA HD15 interfaces are statistically higher. This is true for all combination of PC interfaces, with the exception of only DVI. We take this as further evidence of network externalities.

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Table 1: Type and Distribution of Television Tuners

Television Tuners	*Frequency*	*Percentage*
ATSC	52	23.42%
ATSC, QAM, 8-VSB[1]	170	76.58%
Total	222	100.00%

[1] Note: All televisions have an ATSC tuner. The ATSC is paired with either QAM or 8-VSB (or both)

Table 2: Summary Statistics for Image Quality Measures by LCD Model

	Total Sample				
Variable	*Observations*	*Mean*	*Standard Deviation*	*Minimum*	*Maximum*
TV width (in inches)	222	36.3	8.851	12.2	72.4
Vertical resolution	222	889.0	154.916	480	1080
Image contrast ratio	222	1496.6	956.332	400	8000
Progressive scan	222	0.9	0.352	0	1

	3 November 2007 Sample				
Variable	*Observations*	*Mean*	*Standard Deviation*	*Minimum*	*Maximum*
TV width (in inches)	128	37.8	0.000	17473	17473
Vertical resolution	128	894.8	9.059	18.1	72.4
Image contrast ratio	128	1378.9	153.835	768	1080
Progressive scan	128	0.8	873.192	500	8000

	27 August 2008 Sample				
Variable	*Observations*	*Mean*	*Standard Deviation*	*Minimum*	*Maximum*
TV width (in inches)	149	35.7	0.000	17771	17771
Vertical resolution	149	889.6	9.585	12.2	72.4
Image contrast ratio	149	1593.6	156.469	480	1080
Progressive scan	149	0.9	1045.668	400	8000

Table 3: Types and Distributions of PC Interfaces

PC Interface	*Frequency*	*Percentage*
DVI	4	1.80%
DVI and HDMI	10	4.50%
DVI, HDMI and VGA HD15	1	0.45%
DVI and VGA HD15	5	2.25%
HDMI	32	14.41%
HDMI and VGA HD15	83	37.39%
VGA HD15	87	39.19%
Total	222	100.00%

Table 4: Hedonic Pricing Model Estimates

	Coefficient Estimates	*p-Values*
Dummy Variables for		
Digital Tuner	-0.0555	0.007
Digital Tuner x Date	0.0792	0.017
IEEE 1394	0.4468	0.000
IEEE 1394 x Date	0.2567	0.016
USB	-0.0410	0.014
USB x Date	0.1190	0.001
S-video	0.0957	0.010
S-video x Date	-0.2471	0.037
Date	1.6285	0.000
DVI	-0.0656	0.195
DVI and HDMI	0.4260	0.001
DVI, HDMI and VGA HD15	0.8896	0.000
DVI and VGA HD15	0.4024	0.000
HDMI	0.3915	0.002
HDMI and VGA HD15	0.5041	0.000
Image Quality Variables		
ln(Predicted Image Contrast Ratio)	0.1668	0.000
ln(Predicted Image Contrast Ratio) x Date	-0.1540	0.000
ln(Vertical Resolution)	1.0309	0.000
ln(Width)	1.5771	0.000
Dummy Variable for Progressive Scan	0.0862	0.000
Constant	-7.3504	0.000

N = 1697

R^2 = 0.8669