The Pennsylvania State University

The Graduate School

College of Communications

DIGITAL TELEVISION ADOPTION TIMING AND FORMAT CHOICES OF BROADCAST STATIONS: EXAMINING THE DYNAMICS OF GOVERNMENT-MANDATED STANDARD TRANSITION

A Thesis in

Mass Communications

by

Pinjia Liao

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Doctor of Philosophy

December 2007

The thesis of Pinjia Liao was reviewed and approved* by the following:

Krishna K. Jayakar
Associate Professor of Communications
Thesis Advisor
Chair of Committee

Richard D. Taylor
Professor of Communications

Jorge R. Schement
Distinguished Professor of Communications

Carleen F. Maitland
Assistant Professor of Information Sciences and Technology

John S. Nichols
Professor of Communications
Associate Dean for Graduate Studies and Research

*Signatures are on file in the Graduate School

ABSTRACT

This study examines the relationship between firm- and market-specific factors with broadcast stations' choice of timing and format while transitioning to the new digital television standard. The case of the American digital television transition is especially intriguing because of its three-fold peculiarity. First, its standard-setting process is a hybrid of both market- and committee-based decision methods. The finally adopted standard is regarded as an atypical standard because it allows multiple formats, which range from high definition to standard definition. Second, while the U.S. digital television transition is government-mandated, it follows a flexible timetable. On one hand, Congress requires all the stations to complete the transition by February 17, 2009, on the other hand, Congress permits transition delays for many stations. Third, in spite of the government mandate, the digital adoption pattern is highly associated with the market performance and firm behavior of broadcast stations. This study focuses on three firm- and market-specific factors—firm size, age and business grouping—to investigate their possible impacts on stations' adoption choice of digital television.

Survival analysis and a competing risks model are employed to examine stations' format choices. The results show that old and established stations tend to adopt high-definition format sooner, but it takes less time for young stations to adopt standard-definition format. The findings suggest that the financial difficulty of digital television transition may have been eased by the flexibility obtained by having multiple formats. The standard choice in digital television transition is also likely to introduce new business models for traditional broadcast stations. Profit-motivated decision making by individual television stations influenced their format selection. Large stations interested in preserving market power chose the high-definition

(HDTV) format, while smaller stations interested in reducing cost and experimenting with new business models chose the standard-definition (SDTV) format. The relaxed transition timetable suggests that the regulator has been industry friendly. However, the regulator failed to boost viewers' awareness of digital television. To ease the difficulty associated with technology adoption, it is recommended for regulators to activate a friendly environment for both firms and consumers.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I am especially appreciative of help from Dr. Krishna Jayakar. He has generously and patiently given me assistance at every stage of my doctoral program at Penn State. It is through his comments and suggestions that help me finally accomplish my thesis. I feel very lucky to be his first doctoral advisee.

I am grateful to my committee, Dr. Richard Taylor, Dr. Jorge Schement, and Dr. Carleen Maitland, for their insightful comments. Their advice and help have enabled me to conduct a thorough investigation on the U.S. digital television transition.

I am also grateful to Dr. Jee-Kwang Park, Dr. Mary Beth Oliver, and Dr. George Farkus. Dr. Park offered me comprehensive instructions on Survival Analysis. I have learned a lot about statistical analysis in general from all of them.

I would like to thank Amal, whose love and encouragement has sustained me through trying moments. Lastly, I would like to thank my parents whose support for me has never waned. I am especially grateful to my mom. She poured all her energy and love to help me fulfill my dream; half of the degree belongs to her.

Thank you all.

Chapter 1

Introduction

This purpose of this study is to understand the decisions employed by television stations during a government mandated transition to a new standard—digital television. Facing the technological change, the U.S. broadcast television industry has been required to abandon analog and switching to digital. Every single American television station has to give up its current analog spectrum and be relocated to a digital channel. As broadcasters are concerned by the financial returns from their DTV adoptions, consumers about the cost of new digital equipment, and advertisers about the possible consequences for viewership and advertising, the case of digital television has become an intriguing subject for scholars in the fields of media economics and public policies.

This study highlights three intriguing aspects of the U.S. digital television transition process. First of all, the American DTV transition process started with a standard setting process. The ATSC DTV standard adopted by the FCC has made an interesting example for standardization because it is neither a de facto standard nor a de jure standard. Rather, the FCC has employed a hybrid approach which employs both market- and committee-based methods in the standard setting process. Consensus between different interests becomes the key for this standardization approach. As a result of the consensus and compromise, the final DTV standard permits a variety of video formats. With stations being able to opt between high definition and standard definition formats, flexibility was embedded right at the beginning of the DTV transition.

Second, the transition timetable adopted by the FCC is another peculiar feature of the DTV case. Regulation of this nature, where firms are expected to achieve conformance over a time period, is common with environmental standards. Depending on the type of regulatory instruments, firms that refuse to conform to the standards may either get fined or have to exit the industry. In the case of digital television too, stations may also choose to exit the industry or keep delaying the transition, although the former behavior is very unlikely. There are indeed many stations that failed to adopt DTV on time. The poor realization of the FCC's DTV timetable is partially caused by regulators' indulgence towards broadcasters. Moreover, the extension of DTV implementation is actually allowed by the Congress if certain conditions are met (BBA, 1997). Thus, the case of digital television is a government mandated transition, with a flexible timetable enforced by indulgent regulators.

Third, the flexibility in the DTV standard and the timetable of implementation, the broadcast stations' behaviors and television market performance become critical to the success of the DTV transition. Thus, the economics behind stations' transition to DTV is the third and very critical focus of this study. As discussed above, regulation and technology have largely shaped the transition process; the remaining uncertainty is associated with firm-specific and market-specific factors that would affect stations' decision on DTV adoption. Previous studies have covered how firm-specific factors affect the general technology adoption decisions of firms. In environmental economics, scholars also discussed environmental technology adoption in the presence of regulation. The case of digital television is similar to environmental technology adoption due the existence of regulation; but the DTV case is also different because the media industry coexists with atypical regulations and holds different market structure.

All these aspects will be fully discussed in this study. Before making the connections between the reality of the transition and the theory for technology adoption, some background with regard to digital television are worth discussing.

1.1 Digital television transition: An international phenomenon

Japan, Europe and the United States have been the leaders in the development of advanced television systems. The term "high definition" was first introduced by Japanese electronic manufacturers (Williams, 2007). Trying to obtain the leadership in the development of ATV systems, both Europe and the U.S. soon joined the race. Regarded as a milestone, the digital television systems were introduced in the U.S. in early 1990s, indicating that the U.S. had taken the lead in ATV development. Before long, pro-active strategies were employed by several European countries to implement the new television technology.

Grimme (2002) provides an in-depth review on the nation-wise deployment and management of digital television in three countries, France, Germany, and United Kingdom. While satellite providers took the lead in transitioning the market to digital television in France and the U.K., cable took the initiative in Germany. Grimme (2002) says that competition between satellite providers was a particularly important factor in France. He credits the regulatory environment in the U.K. for the success of digital television in that country – measures such as setting aside spectrum for digital services and encouraging competition were helpful factors. The lack of regulatory support was notable in Germany accounting for that country's relative lag. Nevertheless, digital television had made some progress in all countries by the turn of the century.

Pressured by the development of advanced television systems (ATV) in Europe and Japan, the U.S. Congress and the FCC participated in the early stage of exploring a potential ATV system. During testing of competing ATV systems, the FCC eliminated analog systems as an option because of the advantages of digital technology. However, it is impossible for digital ATV systems to be compatible with the incumbent analog NTSC system. In 1990, the FCC decided on a simulcast digital television system independent of the existing NTSC standard. That is, another channel will be assigned to stations to enable simultaneous broadcast in both the old and new television standards. With regard to the new television standard, the ATSC reported that a digital HDTV system was achievable by early 1993. Before long, a "Grand Alliance" was formed by seven companies and institutions[1] to develop a final digital ATV system. On November 28, 1995, the ATSC voted to recommend the Commission's adoption of the ATSC DTV Standard (4^{th} R&O, 1996).

1.2 The U.S. policy on digital television transition

Ever since television was born, its signals have been broadcast through certain airwaves. In the United States, television stations have employed both the very high frequency (VHF) band and the ultrahigh frequency (UHF) band to provide television services. Here, the VHF band refers to channel 2 to 13, and the UHF band for broadcast television refers to channel 14 to 69.[2] The fast development of wireless communications has greatly raised the value of UHF spectrum.

---

[1] They are: AT&T, General Instrument Corporation, Massachusetts Institute of Technology, Philips Consumer Electronics, David Sarnoff Research Center, Thomson Consumer Electronics, and Zenith Electronics Corporation.

[2] Channels 2 to 4 are located between 54 to 72 MHz; channels 5 and 6 are assigned for 76 to 88 MHz; channels 7 to 13 are in between 174 to 216 MHz; channels 7 to 13 occupy 470 to 608 MHz; and channels 38 to 69 are located between 614 to 806 MHz.

Since the over-the-air television occupied a considerable amount of UHF spectrum, the changes in the allotment and assignment of DTV channels have raised a lot of concern.

Indeed, a key motivation for Congress to encourage the DTV transition was associated with spectrum auctions. Since the digital technology enables the more efficient utilization of broadcast airwaves, Congress decided in the Balanced Budget Act of 1997 to direct the FCC to reallocate a portion of broadcast television spectrum for public safety and commercial use.[3] This potion of spectrum is generally referred as the 700MHz band. While most current wireless services are delivered at higher frequencies than UHF television stations, the 700MHz band—if applied for mobile communications—has the advantage to transmit the signals more effectively. The fact that wireless services are growing strongly today makes the 700MHz band exceedingly attractive for a variety of broadband service providers. The potentially lucrative deployment of the 700MHz band for wireless services largely depends on the timely clearance of the broadcast airwaves by incumbent television stations; that is, the FCC's active supervision and broadcasters' cooperation in the DTV transition are the basics for realizing success in the 700MHz band auctions.

In addition to Congressional support for the DTV transition, the FCC also adopted several rules with regard to advanced television technology to implement the Telecommunication Act of 1996. These rules are elaborated in the report and order of the FCC entitled "*Advanced Television Systems and Their Impact upon the Existing Television Broadcast Service*".

---

[3] The Act directs the FCC to allocate from radio spectrum between 746 and 806 MHz: (1) 24 MHz for public safety services; and (2) 36 MHz for commercial purposes to be assigned by competitive bidding (Balanced Budget Act of 1997, Sec. 337.a).

According to the Fourth Report and Order on *Advanced Television Systems and Their Impact upon the Existing Television Broadcast Service*, the FCC adopted the ATSC DTV standard on December, 24, 1996. Based on the consensus reached by the ATSC, the DTV standard does not include the video format constraints "with respect to scanning formats, aspect ratios, and lines of resolution" (4th R&O, 1996). The FCC claims the standard setting process of the DTV standard "demonstrates how competing industries, working together, can develop de facto industry selected standards that satisfy the interests of contending parties"(4th R&O, 1996).

The FCC believes that the "decision not to specify video formats will result in greater choice and diversity of equipment" (4th R&O, 1996). The Commission further claims the DTV standard "does not overreaching or overregulation by government", since it is a "voluntary" standard based on agreement between competing industries. Last, the FCC claims its action of adopting of the DTV standard provides "the appropriate level of certainty that the digital television market will need to move forward" (4th R&O, 1996).

The FCC established more detailed rules on the DTV transition in the Fifth Report and Order. On the one hand, the Commission limited its regulation, "to maximize broadcasters' flexibility to provide a digital service to meet the audience's needs and desires" (5th R&O, 1997). On the other hand, the following rules were adopted to foster the DTV transition: first, "an aggressive but reasonable construction schedule"; second, "a requirement that broadcasters continue to provide a free, over-the-air television service"; and third, "a simulcasting requirement phased in at the end of the transition period" (5th R&O, 1997).

The guideline employed by the FCC with regard to the DTV transition is "to promote competition and reduce regulation in order to secure lower prices and higher quality services for telecommunications consumers and encourage the rapid deployment of new telecommunications technologies" (5th R&O, 1997). Thus, the Commission decided to leave the DTV format choice up to broadcasters "so that they may respond to the demands of the marketplace." In other words, the FCC expected stations to "take a variety of paths: some may transmit all or mostly HDTV programming, others a smaller amount of HDTV, and yet others may present no HDTV, only SDTV, or SDTV and other services" (5th R&O, 1997).

Meanwhile, an aggressive construction schedule was adopted by the FCC: "Stations affiliated with ABC, CBS, Fox and NBC must build digital facilities in the ten largest television markets by May 1, 1999. Stations affiliated with ABC, CBS, Fox and NBC in the top 30 television markets, not included above, must construct DTV facilities by November 1, 1999. All other commercial stations must construct DTV facilities by May 1, 2002. All noncommercial stations must construct their DTV facilities by May 1, 2003" (5th R&O, 1997). This "market-staggered approach" was employed by the FCC for two reasons. First, "the most viewed stations in the largest television markets can be expected to lead the transition to DTV and that these stations are better situated to invest the capital necessary to establish the first DTV stations" (ibid); and second, "smaller market stations will find it easier to begin DTV service after learning from the experience gained by the larger market stations" (5th R&O, 1997).

In relation to the transition timetable adopted by the FCC, the Congress offered some rules with regard to the recaptured broadcast television spectrum. While all stations are required to adopt DTV before December 31, 2006, the Balanced Budget Act of 1997 allowed any station to request extension in any television market if: i) one or more of the four largest networks has an affiliate in the market that is not broadcasting a digital signal; ii) "digital-to-analog converter technology is not generally available in such market" (BBA, 1997, sec. 3003); or iii) 15 percent or more of households in the market are capable of receiving digital broadcasts. Supported by the

Congress's rules, stations are given some latitude to decide the timing of DTV adoption.

1.3 Stations' choices in a government mandated standard transition

The digital television system represents a significant technological breakthrough for the broadcast television industry. While the DTV standard improves visual quality and enables multicasting of programs, the advanced technology also raised many concerns. Would the digital technology only favor the incumbent players and drive less established firms out of business? Or would the new technology bring opportunities for new entrants and make the market more competitive? How soon will digital broadcast television be implemented in the industry? What are the factors influencing the transition process? What are lessons we can learn from the DTV case about standard-setting processes in general? This study aims to answer these questions by examining the interactions between technology and economics in the U.S. broadcasting television industry.

As of July 24, 2007, there are 1,596 full power television stations—commercial and noncommercial—that have adopted DTV across the United States (NAB, 2007). While the television industry is facing more than one technical standard with regard to the video format, what are the factors that affect stations' choices on DTV standard and how? As one decade has passed since the ATSC DTV standard was adopted by the FCC, stations have shown different attitudes toward the transition. Some were enthusiastic about the new standard and became the leaders in the transition; some waited until the last minute permitted to them under the FCC schedule; others delayed the transition even beyond the deadline due to financial or other difficulties. The following tables illustrate some patterns with regard to the DTV transition.

Table **1.1**

Table **1.1**: DTV adoption times with regard to ownership

	Local	Small	Medium	Large	Super large
Time	1937	2015	1731	1759	2086
N	89	118	185	167	51

Note: Based on BIA (2006) and Television & Cable Factbook.
Ownership indicates the number of stations owned a by a group owner. This is an ordinal measurement: local (1-2), small (3-9), medium (10-29), large (30-49) and super large (more than 50).

Table **1.2**

Table **1.2**: DTV adoption times with regard to network affiliation

	ABC	CBS	NBC	Fox	Others
Time	1704	1758	1760	1697	2068
N	103	109	107	72	219

Note: Based on BIA (2006) and Television & Cable Factbook.
Time refers to the average number of days since December 26, 1996.

Table **1.3**

Table **1.3**: DTV adoption times with regard to market ranking

	Top 30	31 to 100	101 to 210
Time	1569	2003	2135
N	248	238	124

Note: Based on BIA (2006) and Television & Cable Factbook.
Time refers to the average number of days since December 26, 1996.

Table 1.1 shows that stations that belong to medium size owners tend to lead the DTV transition; an average station in this group adopt DTV on September 20, 2001—1731 days after the FCC adopted the ATSC DTV standard. Accordingly, an average station owned by a large station group would adopt DTV on October 18, 2001; the date is April 14, 2002 for a typical locally owned station; it is July 1, 2002 for an average small-group-owned station to adopt DTV;

and the date is September 10, 2002 for a typical station owned by a super-large-group. The table indicates that stations that are owned by medium and large size groups tend to adopt DTV sooner, while stations that belong to small group owners or super large group owners are likely to lag in the transition. Meanwhile, locally owned stations are neither first movers nor laggards in the transition. Table 1.2 shows that there is no big difference among the top-four-network affiliates in terms of DTV adoption times. However, all top-four-network affiliates seem to adopt DTV much earlier than independent stations or stations that are associated with smaller networks. Table 1.3 reveals that stations in major markets tend to adopt DTV significantly earlier than stations in non-major markets.

The three tables discussed above show that not all stations decided to adopt DTV at the same time. Top four network affiliates in major markets tend to move to digital much sooner than their counterparts. While Table 1.1 indicates that business grouping may be a factor affecting the timing of DTV adoptions, other firm-specific factors like firm size may also influence stations' decisions on DTV adoption times. Obviously, a major factor behind DTV adoption times is the government mandate—the FCC timetable with regard to the transition. But the transition is not absolutely determined by the FCC timetable, as many stations failed to adopt DTV on time. It indicates that stations still have some latitude in deciding the timing of DTV adoption.

More importantly, broadcast stations "have been given some flexibility in determining how to structure their DTV services" (GAO, 2002b, p. 12). A station can adopt the high definition format of DTV standard, or it can air a number of standard definition channels (SDTV). In practice stations have sometimes chosen to air a combination of these two as well—a hybrid format. The following tables provide some details about stations' DTV standard choices.

Table **1.4**

Table **1.4**: DTV format choices with regard to ownership

	Local	Small	Medium	Large	Super large
SDTV	38	37	63	46	33
Hybrid	4	13	17	12	3
HDTV	11	22	43	47	1

Note: Based on BIA (2006) and Television & Cable Factbook.
Ownership indicates the number of stations owned a by a group owner. This is an ordinal measurement: local (1-2), small (3-9), medium (10-29), large (30-49) and super large (more than 50).

Table **1.5**

Table **1.5**: DTV format choices with regard to network affiliation

	ABC	CBS	NBC	Fox	Others
SDTV	24	15	29	36	113
Hybrid	21	9	9	3	7
HDTV	21	48	31	5	19

Note: Based on BIA (2006) and Television & Cable Factbook.

Table **1.6**

Table **1.6**: DTV format choices with regard market ranking

	Top 30	31 to 100	101 to 210
SDTV	93	85	39
Hybrid	21	20	8
HDTV	57	50	17

Note: Based on BIA (2006) and Television & Cable Factbook.

In the sample of 390 stations, more than half (217) have chosen the SDTV format. Stations that belong to super large group owners have shown strong preference of SDTV over HDTV. Locally owned stations are also likely to pick SDTV over HDTV. In contrast, large-group-owned stations have equal preference of HDTV and SDTV. If the choice of hybrid formats is also considered as HDTV adoption, then the data show that more large-group-owned stations have adopted HDTV than SDTV. For stations that belong to small and medium sized groups, there are more stations adopting SDTV than those adopting HDTV. But when the choice of hybrid formats is counted as HDTV adoption, it turns out that HDTV and SDTV adopters are approximately the same in number. Table 1.5 reveals some interesting patterns of DTV standard choices with regard to network affiliation. ABC affiliates seem to have no preference between SDTV, HDTV or the hybrid of the two. But CBS affiliates have shown strong preference of HDTV over SDTV. Almost equal numbers of NBC affiliates have opted for HDTV or SDTV. In contrast to CBS affiliates, Fox affiliates, independent stations and affiliates of smaller networks very much prefer the SDTV format to the HDTV format. Table 1.6 indicates that there is no significant difference between major and minor markets with regard to DTV standard choices.

These tables provide evidence that stations do have the freedom of choice, when it comes to DTV format. While network affiliation is shown to have significant impact on stations' standard choices; the impact of station ownership on standard choices are also revealed. Stations' latitude to decide how to transition their systems is the most important part of this thesis. How factors such as market size, network affiliation, station ownership, station size, and station age affect the choice of digital standard is the key research question of this study.

The U.S. DTV transition is a perfect illustration of the interactions between economics, technology, and regulations. Keeping in mind that television stations are driven by profit. Facing the new television standard, each station is calculating the cost or benefit of switching earlier or later to digital, or of selecting HDTV versus SDTV or hybrid. In spite of concentrating on how broadcast stations are coping with the powerful technological change, this study also aims to seek the policy lessons we can learn from the digital television case, for it is viewed as an example of government-mandated standard transitions.

1.4 A brief outline

In Chapter 2, the general background of advanced television systems is provided first. Many sources have identified the tremendous economic opportunities created by the digital technology through the reassignment of broadcast spectrum and the boost to the domestic consumer electronics industry. On the other hand, some scholars have raised questions about the viability of television standard transition—especially, with regard to the standard setting, consumer adoption, and consequences for the advertising market and audiovisual production. These two pressures—desire for the economic opportunities of digital broadcasting and profound misgivings on the part of many stakeholders—resulted in a controversial and highly contested process. Dupagne and Seel (1998) noted that the ATSC DTV standard resulted from a great compromise between broadcasters, television manufactures and computer industry leaders. This compromise explains why the final standard allowed 18 different formats to be adopted by stations. The flexibility embedded in this “non-standard standard” has allowed stations to exercise a measure of choice. On top of the standard choices, the CBO report (1999) explains the technical, legal and financial reasons that allow stations to adopt DTV under a more flexible schedule in contrast to the FCC timetable. A few empirical studies have tentatively identified some market- and firm-specific factors that can affect stations’ decisions in the DTV transition with regard to the two kinds of flexibility—DTV adoption times and DTV standard choices.

The theoretical foundation for firm choices is discussed in Chapter 3. The literature shows that firm size is a critical determinant of technology adoption decisions. Besides, business grouping is also identified as a possible factor to influence firms' decisions on technology adoption. However, the peculiarity of the DTV transition—a government mandated standard transition—shifts our attention from an average firm's technology adoption decision to environmental regulation and environmental standard adoptions. The literature indicates that the stringency of regulation assures timely adoption of environmental standards. Some scholars suggest that the combination of regulation and technological change can cause some firms to exit the industry. The literature also shows that firm size and business grouping are two important factors that explain firms' technology adoption decisions under environmental regulations.

In Chapter 4, the hypotheses with regard to DTV adoption times and DTV standard choices are presented. Those hypotheses are established around firm size, business grouping, and firm age—the three most important firm-specific factors. The next part of Chapter 4 highlights the characteristics of the DTV transition data. The key data is the time to DTV adoption. Our focus on DTV adoption times indicates that survival analysis is an appropriate approach. Further support is found in previous studies where researchers have repeatedly employed survival models to study the problem of firm adoption of technology. Thus, survival models are discussed in details in this chapter. The nonparametric method of survival analysis is introduced at first, and its advantage and disadvantage are discussed in contrast to parametric methods. Regarded as a semi-parametric method, the Cox model is highlighted due to its simple assumptions and robust estimation power. With regard to parametric methods, a comparison is drawn between the proportional hazard (PH) model and the accelerated failure time (AFT) model. All those methods are able to reveal different facets of the timing decisions on DTV adoption. The competing risks model is introduced to study stations' standard choices. The model is an advanced method of survival analysis where there are multiple destinations—in the DTV case, the DTV adoption can be specified as HDTV adoption and SDTV adoption. The multinomial logistic model is also discussed as an alternative method to study DTV standard choices.

The data sources are presented in Chapter 5. It is followed by descriptions on the operationalization of the key factors—firm size, business grouping, and firm age. DTV adoption times and standard choices are the explained variables. Through the survival analysis, the AFT-log-logistic model will be highlighted due the special features associated with its distribution assumption. The results from competing risks model and logistic models will be compared. These findings with regard to DTV standard choices deserve more attention, since they confirm stations' freedom in this government mandated standard transition and reveal the impacts of firm-specific factors on this transition.

Chapter 6 returns to the key theoretical questions of this thesis: what do we know about the behavior of firms confronted with government-mandated standards transitions? The major findings—the effects of the three firm-specific factors on DTV adoption—will be summarized. Policy implications will be drawn with regard to the U.S. strategy on the DTV transition. Also discussed are the limitations of this study.

Chapter 2

The history of digital television in its economic, social and policy context

This chapter starts with an introduction to the history of advanced television systems and the policy discussions with regard to the DTV technology. Then, the standard setting process of the DTV technology will be highlighted. More attention will be shifted to the interesting feature of the ATSC DTV standard—a "non-standard" standard, in the words of Huff (2001)—adopted by the FCC. The critical part of this chapter centers on the timetable of the American DTV transition—though mandated by law, indulgent regulators provided considerable flexibility in the transition timetable to television stations. Thus, it will be argued that both the timing of the transition and the peculiar DTV standard adopted were subject to local characteristics. The investigation of these differences in timing of the transition, and in choice of the DTV standard is the subject matter of this dissertation.

The issue of advanced (digital) television technology has been a hot topic for more than a decade. The existing literature has provided a comprehensive review for the evolution of the new technology (Dupagne and Seel, 1998; Huff, 2001). Paralleling the historical perspective, another group of studies have emphasized the analysis of the associated policies involved in today's digital television transition (CBO, 1999; GAO, 2002; Kruger, 2005). Some scholars were concerned about the economic and social aspects of the new television technology (Humphreys and Lang, 1998; Brown, 2003; Adda and Ottaviani, 2005). Other scholars such as Farrell and his associates (1992) highlight the standard-setting processes associated with advanced television technology. In his critiques on the FCC's standardization strategy, Huff (2001) regards the DTV standard as a non-standard standard. The flexibility of the DTV standard adopted by the FCC has set the tone of the digital transition process of American broadcast stations. The stations have indeed exploited their latitude in implementing the ATSC DTV standard.

While the articles listed above provide a general background on the DTV transition, a few studies (Oberg, 2000; GAO, 2002a; GAO, 2002b) have specifically addressed the research questions motivating this dissertation. Acknowledging the importance of the FCC's mandated timetable on the DTV transition, they surveyed American broadcast stations to explore the differences in timing of digital switch and in digital standard choices. These studies suggest that major network affiliates tend to handle the digital switch smoothly. Meanwhile, stations that operate in big markets may face great demand for digital television; thus the digital switch happened earlier for them. Besides, due to the high-facility requirements associated with the HDTV format, high-revenue stations tend to adopt the HDTV format, while independent stations may prefer the SDTV format.

The sections below discuss in greater detail the general background of the digital television transition, as well as the articles more specifically addressing the research questions of this dissertation.

2.1 Pre-digital technology and the run-up to digital television

In the last sixty years, the American television industry had gone through four major technological changes. The first transformation happened during the infant years of American television. It was associated with the discovery and employment of the Ultra-High Frequency (UHF) band. In the early 1940s, the development of television was impeded by interference problem in limited VHF band. After a four-year freeze on new station licenses, the FCC created a master allotment plan that assigned frequencies for 2,053 current and future stations (Walker and Ferguson, 1998, p. 19). Utilization of the frequency between 300 MHz and 3.0 GHz to transmit television signals was the key solution to generate enough spectrum for a number of television channels in different geographic areas.

Compared to the VHF (Very High Frequency), the UHF band faced technical limitations. The signals degraded faster than in VHF transmission, leading to poorer reception for some viewers and requiring UHF stations to spend more for electric power to improve signal quality. The reliance on the UHF band for additional stations created a dichotomy among stations in many markets. Pre-freeze stations located on the VHF band were usually affiliated with NBC or CBS. Many post-freeze stations were forced to use the UHF band and affiliated with the weaker ABC or DuMont networks.

The second major change, color television, also took place in that period. In 1953, RCA succeeded in developing a fully compatible color system which was adopted as the industry standard by the FCC. However, color equipment both for stations and consumers was very costly. In 1955, an average color television cost $500, while a black-and-white one cost only $138. In 1956, when the figures were $356 for color and $106 for black-and-white, only 5.3 percent of the nearly 53 million homes with television in the United States had color sets. Only after all three networks (NBC, CBS and ABC) made a substantial commitment to color programming with the first full-color season in 1966-1967 did the color receiver sales start to surge. By 1976, 75 percent of U.S. households had color receivers (Farrell et al, 1992).

Compared to the utilization of the UHF band, the change from black-and-white to color television is only a technical improvement. Through the latter technological change, the three major networks' market power was strengthened. In contrast, expanding broadcast television to the UHF band made possible the competition from a third network. The established position of today's ABC is directly associated with that particular technological change.

The third technology breakthrough is cable television. Till 1970s, "television" for American audience was free broadcast signals received by household antennas. Programs produced by the Big Three networks were the primary options for television viewers. Cable's expansion in the late 70s and early 80s, however, shook broadcast television's landscape. As an absolute substitute of the over-the-air method, CATV (cable television) signals were transmitted directly to household televisions through fixed coaxial cables. UHF stations were among the first beneficiaries of cable television because their signal inferiority would not be discernable over a cable-distributed system.

While over-the-air broadcasting suffers from spectrum crowding and interference problems, cable systems' enclosed environment enables greater channel capacity and better signal quality. As national systems of microwave and coaxial cable relays were gradually developed, cable-specific program networks emerged one after another. The increased original programming on cable networks became a full-fledged competitor for television viewers. The very technology—CATV—brought a radical change in front of traditional broadcasting players. The 1980s began with three major networks controlling nearly 90 percent of the prime-time audience. The decade ended with these networks struggling to hold on to 60 percent of that audience, facing two well-entrenched competitors, the Fox Network and the cable television industry.

Satellite television can be viewed as the fourth major technological change. If CATV is regarded the most significant technological change that happened to American television industry, direct broadcast satellite (DBS) has all the potential to reshape the industry. Although communication satellites first came into use for international broadcast relays in the 1960s, it is only in the 1990s that DBS became a reality in the States. By delivering programs to consumers without going through an intervening broadcast station or cable system, DBS has rendered any land-based delivery system obsolete. Currently in the United States, DBS is employing the Ku band, the spectrum between 11.7 GHz and12.2 GHz specifically, for the point-to-point transmission of television programs.

A broadcast transmitter reaches only a limited area. Cable systems must hard-wire each subscribing home. A single DBS transmitter, in contrast, can serve the entire country. The technological superiority has made DBS a serious competitor to cable. According to the FCC's 12th Annual Video Competition Report, the number of DBS subscribers was 26,120,000 in 2005 compared to 65,400,000 cable subscribers. While DBS serves only a fraction of homes that cable does, DBS's popularity is increasing and its growth is stable and significant.

Compared to the previous technological changes, the on-going digital revolution has been regarded as the most dramatic change in electronic media technology. It is reforming every aspects of how television functions. Digital technology represents high quality and great capacity in all the three essential fields of television: programs relay, recording, and delivery. The current DTV transition is only a segment of the digital revolution, but it is having a crucial impact on the landscape of traditional broadcast television. That is why so many scholars (Adda and Ottaviani, 2005; Brown, 2003; and Humphreys and Lang, 1998) have been concerned by a range of policy issues associated with the transition.

2.2 General background on advanced television technology: Policy strategy

Dupagne and Seel (1998) provide a survey of advanced television systems (ATV) development in a global context. Their book covers almost every aspect of high-definition television's (HDTV) development: from HDTV's birth in Japan, European multiplexed analog components (MAC) policies, to the U.S. policy making battles around ATV technologies. In particular, the authors discuss television technology's impact on American consumer electronics industry and argue that the push for a national DTV policy in the United States was at least partially motivated by the desire not to lose ground to foreign competitors. While the U.S. companies lost a major share of the color television market, Japanese firms became global technology leaders in consumer electronics market. The authors regard American firms' overemphasis on profit margins and low R&D investments as the main reasons for the loss of their leading position. Comparing to the U.S. belief in free market, Dupagne and Seel (1998) observe that Japanese government views industry growth as a matter of national security, and thus appreciates industrial policy.

The Congressional Budget Office (CBO, 1999) is concerned about the U.S. DTV transition because the federal budget will be affected through the potential radio spectrum auction, which is made possible by digital technology. Recognizing the monetary value of licenses for the radio spectrum, Congress passed the Balanced Budget Act in 1997 that provides a conditional deadline for broadcasters to make the digital switch. The Act allows a station to request an extension of the deadline if less than 85 percent of households in the broadcaster's market are capable of receiving digital broadcasts. The desire to exploit the enormous economic benefits to be realized from the reassigned broadcast spectrum was another driver for the DTV transition.

On the one hand, policymakers, regulators, and industry experts agreed on the merits of the analog-to-digital transition; on the other, there are many factors that could obstruct the DTV transition. The literature is therefore filled with a number of studies with recommendations on how to manage these potential problems. For instance, the CBO (1999) provided a list of recommendations. Firstly, every component of the DTV system has to work as promised. This includes built-in digital tuners and digital-to-analog set-top boxes. Secondly, digital broadcasts are advised to begin early in the transition. CBO (1999) believes the digital switch timetable established by the FCC will effectively expedite station's transition to digital television. Thirdly, the study regards cable carriage of digital broadcasts as an essential factor affecting the DTV diffusion. Lastly, CBO (1999) points out that the falling price of DTV equipment can greatly accelerate the DTV adoption. Responding to broadcasters' concern on cable carriage of digital broadcasts, the FCC (2007a) proposes that cable operators must either: (i) carry the signals of commercial and non-commercial must-carry stations in analog format to all analog cable subscribers, or (ii) carry those signals only in digital format for all-digital systems.

Another potential problem that worried policy planners was the willingness of consumers to adopt digital television. In the light of Everett Roger's theory—*Diffusions of Innovations*—a great guideline to manage technological changes, Rhodes (2004) analyzes the U.S. adoption of digital television under Roger's theoretical framework. The author argues that certain characteristics of digital television affected the consumer's adoption decision. For example, how much better is the new technology than the old one? Though high-definition television offers better video quality than analog service, Rhodes (2004) suggests broadcasters and manufactures should intensify their promotion of DTV's advanced features. Observing that consumers are quite confused about DTV and HDTV products, the author regards it is government responsibility to provide effective education on digital television.

If the receiver can be viewed as the hardware of television system, then programs should be television's software. To expedite the DTV adoption, Rhodes (2004) urges the digital transition of broadcast stations and cable systems while consumers are encouraged to switch to digital television products. Considering government has an important role in deploying digital television, the author also suggests government offering tax incentives for broadcasters, manufacturers, and consumers to motivate early adoption of digital television. Overall, Rhodes (2004) recommends policymakers bearing the diffusion theory in mind to construct helpful rules for the DTV transition.

Kruger (2005) concentrates on policy issues involved in the U.S. digital television transition. He firstly points out that the FCC has an important role in promoting the transition, because the FCC has the authority to license broadcast stations and the duty to oversee their performance. Kruger (2005) further reports a series of rules and modified rules set by the FCC to promote the digitalization of broadcast stations. For example, one rule modified in 2001 permits stations to initially build lower-powered digital facilities, but to upgrade to full power later. As broadcast stations are under close supervision to make the digital switch, Kruger (2005) observes that cable companies are participating more actively, following the FCC's suggestions, in this transition. As a result, viewers in 177 out of 210 DMAs (Designated Market Areas) can receive a package of HDTV services from their cable operators (Kruger, 2005, p. 9).

Acknowledging the efforts made by broadcasters, cable systems, and the FCC, Kruger (2005) believes the digital transition is hindered by a chicken-and-egg dilemma. That is, while the number of viewers with digital television receivers remains small, broadcasters and cable operators expect more DTV-ready viewers before their DTV programs supply reaches a greater quality and quantity. Kruger (2005) discusses a list of issues that have emerged in the transition process. For example, to watch over-the-air television programs, viewers need a receiver that is able to catch digital signals. Thus, the FCC adopted a phase-in plan requiring most new television sets to contain built-in digital tuners by 2007 (p. 15).

As Head and his associates (2001) point out, the universal access is the essence of broadcast television. The free broadcasting service appeals public interest and political support. Will the new technology jeopardize the universal access of broadcast television? While the question raises concerns in the Academia, several scholars conduct research on how will public interest, viewer’s utility, and the media market be influenced or reformed by the digital technology.

By examining television business and viewer welfare, Adda and Ottaviani (2005) explore valuable policy options to foster digital television transition. The authors highlight the necessary role of government in digital television development, by noting the social objective of universal access and plurality for policy that is associated with terrestrial spectrum. Economic policy is also relevant because coordination is essential for all competitive platforms to contribute to digital television diffusion.

Focusing on the demand side of digital television, Adda and Ottaviani (2005) regard viewer preference and switching cost (analog to digital) as the key factors affecting the DTV diffusion. Besides, the authors introduce several possible policies that may foster the DTV diffusion: for example, a mandated analog turn-off in ten years, subsidies to set-top boxes, making free basic satellite service available, and assigning more spectrum of DTV channels.

Based on a simulation model that incorporates all those factors, Adda and Ottaviani (2005) analyze the impact of different policies on consumer surplus. Their estimations show that a rapid analog turn-off can lead to a significant reduction in consumer surplus, since the policy eliminates the consumer choice which is to continue receiving the analogue signal. While the increase in the DTV channels is associated with a moderate increase in consumer surplus, the estimations show that the offering of free basic satellite service would bring a significant increase in consumer surplus. Yet, the provision of set-top-box subsidies is estimated to have a neutral impact on welfare. Noting the possibility that the emergence of new technologies may completely transform the television business, Adda and Ottaviani (2005) conclude their study with doubts on the future of terrestrial television.

Observing the large channel-capacity brought by the new technology, Brown (2003) concentrates on how the finance of broadcast television would be influenced by the digital technology. The key contribution by Brown (2003) is his hypothetical model of broadcast television market which is transformed by the digital technology. First, the author assumes the market is only supported by adverting revenues; the number of viewers and program cost remain constant. Brown's key assumption is that, after the introduction of digital technology, channel numbers will be determined by market forces rather than assigned though licensing. Under those assumptions, Brown (2003) infers that the increase in the number of channels will lead to a decline in the number of viewers per program. Following the decline in viewership, average advertising revenue per channel also drops. In the meanwhile, the increase in channel numbers requires additional programs; thus, the total program spending goes up. The advertising revenue decreases while the spending increases. Average profit per channel decreases as a result (Brown, 2003, p. 44). In summary, the model expects the digital transition to move forward smoothly, but confront stations with declining profitability in the aftermath.

Based on the model, Brown (2003) suggests that the optimal strategy for television stations to deploy digital channels would involve product differentiation and niche markets. Besides, the author also notes the important role of government in assigning the expanding digital channels. Brown (2003) further suggests government to assign the new channels to both incumbent and new broadcasters. Yet, the author points out that the survival of new entrants may be difficult in the already saturated television market, although digital technology brings new opportunities. He doubts that the new technology would significantly change the current structure and ownership of the broadcast television industry.

The digital television transition has been of interest to scholars not just in the United States, but abroad as well. For instance, Humphreys and Lang (1998) discuss the potential impact of digital television in the European context. The authors believe the digital technology can (i) bring more channels over the terrestrial spectrum; and (ii) offer a route on the "information superhighway" (p. 10). Yet, Humphreys and Lang (1998) are concerned by the uncertainties and challenges come along with the digital technology. While the DTV deployment can be hindered by the rising price of programs and the uncertain consumer demand, Humphreys and Lang (1998) worry that monopoly is the only solution to digital television's pricy establishment. Besides, noting the policy trend of allowing cross ownership of telecoms and media, the authors claim such convergence may increase the power of some giant telecom and media companies. Beyond those uncertainties tied to the emerging DTV market, Humphreys and Lang (1998) wonder if the new technology can effectively enhance the pluralism of electronic media.

The authors believe that the “de-massification” of mass media will be seriously challenged if large media conglomerates gain a gate-keeping control over digital services (Humphreys and Lang, 1998, p. 21). By creating their own encryption/decryption systems for digital services, according to the authors, the DTV first movers can establish the entry barrier and further gain monopolistic control over the digital gateway. To answer these hypothetical questions, Humphreys and Lang (1998) compare the DTV deployment in Britain and Germany. Britain has developed a detailed regulatory network with an emphasis on the introduction of digital terrestrial television. By contrast, Germany has barely developed any particular regulation for digital television. In terms of the outcome, while the DTV deployment in Britain is ahead of other European countries, Germany faces a slow diffusion of digital television.

Noting the European trend of associating digital television with pay-TV, Humphreys and Lang (1998) warn regulators to support the operation of freely accessible public television services. In conclusion, the authors think the massive costs and risks will severely limit the competition in digital television market. They expect, through the digital transition, incumbent firms will further consolidate their position in the market. Humphreys and Lang (1998) finally suggest regulators to (i) ensure the fairness of consumer access to the DTV services, and (ii) protect the meaningful presence of public broadcasters.

2.3 Standard-setting processes of the DTV technology

As shown in the previous section, the digital television transition was motivated by enormous economic opportunities, among them a boost to the domestic consumer electronics industry and the benefits from the reassigned broadcast spectrum. At the same time it raised daunting questions about the viability of transition as well, not limited to the willingness of consumers to adopt the costly new devices and the reaction of advertisers. But among all the possible questions, one dominated: the standard setting of the DTV technology. While there has been a rich literature on standard setting issues, this section will only discuss the terms and processes that are helpful for the understanding of the DTV standardization. Also included in the discussion are the standard setting processes of advanced television technologies in Europe and the United States.

Many scholars (Rosen et al, 1988; Farrell and Saloner, 1988; and David and Greenstein, 1990) have tried to define standardization and classify the relevant processes. Rosen and his associates are among the first to provide some insights on the basic elements of a standardization process. They firstly highlight the scenarios where standardization is necessary: (i) when complementary products are required; and (ii) when interconnections are important. Secondly, Rosen and his associates (1988) list the main players that engage in four different standardization approaches; respectively those players are (i) government, (ii) industry coalitions, (iii) free-market, or (iv) an industry leader.

A key contribution by Rosen and his associates (1988) is their discussion on the pros-and-cons of the four standardization approaches. While proposing that government mandated standards can be established with greater objectivity, Rosen and his associates (1988) point out such standards often serve political purposes rather than market demand; besides, such standardization processes often proceed slowly. The authors acknowledge that industry-coalition standardization approach is also subject to slow decision processes, but, they regard this approach is more responsive to market than a government mandate. Rosen and his associates (1988) regard the free-market approach best reflects consumers' preference and encourages new entries. However, its drawbacks are: (i) processes are also slow; (ii) many consumers may end up with obsolete technologies; (iii) winning standards are not necessarily the best. Standards set by industry leaders would diffuse rapidly with few orphaned consumers. Yet, such an approach may not bring the best standard and may increase the entry barrier.

Similar to Rosen and his associates' classification of standardization processes, David and Greenstein (1990) present four types of standards: (i) un-sponsored standards, which have no identified originator holding a proprietary interest, but exist simply because of market competition; (ii) sponsored standards, where one or more sponsoring entities holding a direct or indirect proprietary interest creates inducements for other firms to adopt particular sets of technical specifications; (iii) standards agreements arrived at within, and published by voluntary standards-writing organizations; (iv) mandated standards, which are promulgated by governmental agencies that have some regulatory authority. The first two types emerge from market-mediated processes and are referred to generally as de facto standards. The latter pair is sometimes tagged loosely as de jure, though the force of law only resides in the last case. David and Greenstein (1990) point out the key difference between de jure and de facto standards is whether standardization happens before or after a product is commercialized.

As revealed by Rosen and his associates (1988), none of the four standardization approaches is perfect. Farrell and Saloner (1988) examine the different types of coordination in standardization processes and compared their relative speed, efficacy, and payoffs. The first involves explicit communication and negotiation before irrevocable choices are made: it represents what standardization committees do. The overall game is a war of attrition. The second coordination process is the market or bandwagon process. The overall game is a grab-the-dollar game, and it is a simple version of market leadership. Farrell and Saloner (1988) show that in some cases committees may outperform market forces in coordinating standards by giving firms an opportunity to choose standard by negotiation before they make irreversible investments. They also argue that hybrid policies may be even more effective, in the sense that negotiated standards may be backed up by market investments, so strengthening commitments.

Farrell (1996) studies the process of searching for consensus by standards-developing organizations. He regarded such process mingles technical discussion and political negotiation, and is slightly faster than the emergence of de facto standards. Yet, the war of attrition in the consensus-approaching process can bring in severe delays. Farrell (1996) models the tradeoffs between speed and quality in the process and suggested strategies to reduce delay, such as urge standardization in advance of the market before vested interests grow strong.

The study by Tilson and Lyytinen (2004) also suggests that a hybrid arrangement of committee and market standardization processes may lead to an optimal outcome. In their discussion on technology revolution in the wireless industry, Tilson and Lyytinen (2004) highlight three critical elements--the regulatory system, the innovation system, and the market place—that are involved in a standardization process. The innovation system develops novel technologies based on research and development activity; the marketplace produces services that exploit the potential within a standard; and the regulatory regime influences any activity throughout the technology revolution.

Whether the DTV standard is a de facto or de jure standard; it is largely determined by the national and historical context. The standard setting approaches carried out in Europe are very different from those taken by the United States. Different outcome have also emerged due the different processes. Grimme (2002) examines the standard setting processes of advanced television technologies in Europe. Considering the European HDTV standardization as an outcome of direct regulation, the author claims the European Commission rushed into conclusion on the analog HDTV standard. Subsequently, this standard became obsolete when digital technologies were developed in the United States. Eager to lead in the HDTV competition, the European Commission (EC) had decided to accelerate the HDTV development in later 1980s. This decision is carried out by adopting the already existing Multiplexed Analog Components (MAC) system. Grimme (2002) criticizes such an approach raises a pure focus on the speed of standardization rather than on the pursuit of the best technology. While business interests of the television set manufacturers were considered in the HD-MAC standardization process; program makers, broadcasters, and consumers were left out of the crucial phase of standard setting (Grimme, 2002).

The EC seems to learn a lesson from its failure in the first-round of standardization. The second-round standard setting process started with the establishment of the DVB (Digital Video Broadcasting) group. Aiming to incorporate a variety of interests, the DVB group adopted a family of standards with different specifications for satellite, cable and terrestrial transmission of digital signals. Grimme (2002) considers such a committee standardization approach was efficient and effective; thus, it is preferred to a direct regulatory standardization approach.

Compared to the European approach, the committee approach was employed in the U.S. early on in the standardization process of advanced television systems. Owen and Wildman (1992) have discussed the standard-setting process in the early 1990s, and the strategic problems and opportunities faced by the television industry. They study the relationship between advanced television (ATV) standards, the quality of television services and technology benefits for viewers. In early 1990s, the new ATV standards developed in the U.S. included HDTV, EDTV and IDTV standards. Among them, HDTV possesses the best video quality. Owen and Wildman

(1992) believe that the large installed base of the analog standard--NTSC—is the major obstacle for ATV adoption. Besides, the authors expect the incompatibility between NTSC and ATV systems will bring commercial failure for ATV adoption. To realize ATV's replacement of NTSC, they suggest ATV system has to be at least partially compatible with NTSC. Based on the video quality associated with those standards, Owen and Wildman (1992) regard IDTV and EDTV systems intermediate between NTSC and HDTV. The authors considered the multiple ATV standards as a big issue faced by the FCC. By modeling viewer's benefit from ATV adoption, Owen and Wildman (1992) analyze the possible outcome resulting from the dynamics of IDTV/EDTV and HDTV development. The key point of their model is that when the benefits of being part of a large group using common standard are significant, products based on different standards may find it difficult to compete (Owen and Wildman, 1992, p. 312). In the case of ATV standards, although HDTV system provides higher-quality video, IDTV/EDTV system is less costly and easier to deploy. Thus, the authors argue that if IDTV/EDTV system is firstly introduced and gains big viewer installed base, the development of HDTV system would be likely to be delayed or eliminated.

The U.S eventual adoption of the advanced television technology standard was coordinated through a FCC-initiated standard selection process. This process focuses on terrestrial television standard. Before modeling technology benefits from adopting ATV standards, Owen and Wildman (1992) firstly discuss several issues relevant to the standard setting process. Reviewing the FCC's performance with regard to the ATV technologies in the 1990s, Dupagne and Seel (1998) regard (i) the U.S. policy was initially reactive; (ii) then the FCC took a proactive approach which resulted in the digital high definition television system; (iii) overall, the U.S. policy has evolved with the technology development. In the end, the authors consider the final digital television standard a success built upon very close cooperation between industry and government.

The study by Farrell and his associates (1992) provides a more detailed discussion on standardization in the broadcast television industry. Firstly addressing the issue of the ATV standard selection in a global context, the authors note that there has been little attempt to adopt an international ATV standard. Then Farrell and his associates (1992) closely examine the U.S. development of the ATV technology. The authors make two intriguing observations on the FCC's actions towards the ATV standard setting: first, the U.S. industrial policy was in favor of the existing broadcasters; second, rather than letting the market choose, the FCC decided to pick a standard for the ATV due to the significance of issues like compatibility and network externalities. Exploring the theoretical framework to support the FCC's good performance in the ATV standard setting, the authors employ economic models to address ex post and ex ante concerns in regards to technology choice. Having outlined a variety of technology selection mechanisms, the authors note that the FCC appears to be gauging systems' quality, and tends to set a deadline and pick the best system at that date (Farrell et al 1992, p. 46, 50).

Setting theories for standard selection and adoption aside, Farrell and his associates connected the ATV case to the U.S. adoption of color television. The authors claim the U.S. color television standardization results from competition between CBS and RCA. RCA's electronic color standard was the winner because it was compatible with the black and white signals. Once RCA's standard was adopted, NBC efficiently played the complementary role by providing thousands of hours of color programming.

An interesting pattern about color television adoption, noted by the authors, is that many stations adopted color when little color programming was available, yet they increased advertising rates right after their color adoption. The authors argue broadcasters' immediate investments in color capabilities between 1954 and 1955 were driven by their network affiliation status. In contrast, a significant increase in the amount of color programming did not take place until 1964. In the following decade, hence, it is witnessed a continuously rapid growth in color television ownership by American households (Farrell et al 1992, p. 53-58).

In the end, Farrell and his associates (1992) project that the lag between the ATV standardization and the ATV set penetration is likely to be long, because there is a large and costly installed base of the NTSC sets. They suggest the delay in the U.S. ATV standard selection may lead to the development of significantly better technology, which can be beneficial in the long run.

In the case of digital television, the FCC seems to take an active role in the standard setting process. But Huff (2001) has pointed out that the FCC is indeed an indulgent regulator. The proof identified by the author is the absence of standard in the development of AM stereo technology. While the technology provided significant improvement for AM radio, it was not able to reach the critical mass in the end. Huff (2001) argues that the AM stereo's failure to launch was caused by the FCC's indecision to pick a standard among competing AM stereo systems. The resulting uncertainties inhibited AM stereo's diffusion. After fierce struggles, Motorola's C-QUAM system eventually became the de facto AM stereo standard. It is hardly a success, however, because the rise of digital audio broadcasting has already made AM stereo system obsolete. While the outcome is not always optimal for a government mandated standard, Huff (2001) argues that it is difficult, if not impossible, for the marketplace to select the best technical standard over the short term. The AM stereo case is the perfect example. Some may argue that the market chose the C-QUAM system, but failure was tied to the standard since its installed base was small and refused to grow. Having blamed the FCC for the failed attempt to improve AM radio, Huff (2001) points out that while standardization itself does not guarantee a technology's success, it does serve as an essential element for a technology's growth.

The importance of standardization in the DTV transition is discussed in this section. While the FCC indeed has been engaged in the DTV standardization process, some peculiar features of the DTV standard have emerged under the FCC's special strategy. These features will be discussed in the next section.

2.4 The peculiarity of the ATSC DTV standard

Following the history and standard setting issues of the DTV technology, the focus of this section is the features of the ATSC DTV standard which was adopted by the FCC in 1996. To illustrate the development of the DTV technology, Dupagne and Seel (1998) highlight the following significant episodes in FCC's standard setting process. The first landmark was made by General Instrument, which developed an all-digital high definition television system in 1990 (Dupagne and Seel, p. 23). Soon later, the digital HDTV system was born based on a consortium of seven European and American entities. The authors also highlight that the digital system was developed to be suitable to terrestrial television, because the FCC determined that the new technology is tied to the public interest.

In 1995, with analog systems being eliminated, digital rather than high-definition became the focus of television revolution. And by the end of 1996, the FCC accepted the modified DTV standard—recommended by Advanced Television Systems Committee (ATSC)—which is flexible in the sense that it allows for 18 different video formats. The variations of these formats are based on the number of lines per each picture frame (high definition or standard definition) and the scanning techniques (interlaced or progressive). More specifically, the SDTV format is associated with 480 lines per frame, while the HDTV format has either 720 or 1080 lines per frame.

Huff (2001) is among the first to acknowledge that the ATSC DTV standard is a "non-standard standard". He connects the AM stereo experience to the case of advanced television systems. Arguing that the FCC was too late in setting a standard for AM stereo contributing to the failure of that technology, Huff (2001) regards the FCC has played a more active/proactive role in shaping the ATV development compared to what happened to advanced radio technologies. Notably, two conditions are incorporated into the ATV standardization rationale by the FCC: (i) an ATV standard would bring substantial public benefit; (ii) private industry itself is not likely to achieve a standard (Huff, 2001, p. 106).

Following the ATSC's (advanced television systems committee) endorsement on the digital television systems, the FCC adopted the DTV standard in 1996. Huff (2001) believes the standard is a "non-standard standard", because 18 different formats are simultaneously included in the ATSC DTV standard. Reacting to this "non-standard standard", CBS announced its decision to employ the HDTV format; NBC considered using prime-time HDTV but SDTV at other times; Fox leaned to multichannel SDTV (Huff, 2001, p. 157). With regard to the deployment of digital television, the FCC requires the broadcasters that are most able to bear the risks of introducing digital television to proceed most quickly (p. 150). In the meanwhile, the FCC's DTV policy also protects incumbent broadcasters by limit initial eligibility for DTV licenses to them (Huff, 2001, p. 149). In conclusion, Huff (2001) emphasizes the significant role of the FCC in standard setting the emerging broadcast technologies. While new technologies keep emerging, it is the policymaker's duty to decide the timing of setting a standard to promote technology diffusion.

Focusing on standards transitions in the broadcast television industry, Hall (2002) considers that this flexible DTV standard might be an outcome of the more complex environment in which it originated. According to Hall (2002), the standardization behavior by industries and regulators may result from the uncertainty and complexity that come along with new technologies. The author illustrates the distinction by comparing two technological change cases: color television and digital television. Having gathered the historical evidence related to innovation, regulation, and standardization in the two standard-transitions, Hall (2002) points a notable difference between color TV and the DTV. That is, due to their different historical context, the DTV is a highly substitutable product while no media could replace color TV decades ago. As the ATSC DTV standard results from a greater compromise in a more complex environment, it is not surprising that the final standard allows 18 different formats to be adopted by stations.

However, observing that in both color and DTV cases, established firms tend to dominate and benefit from the standard-transition process, Hall (2002) believes such a pattern has been caused by regulatory environment and the complexity embedded in new technologies. In particular, much of the tension between innovation and regulation seems to be between two conflicting needs: the need for change and the need to prevent change. While supporting the standardization of broadcasting technologies, Hall (2002) points out that "investors of a new technology must be able to rely to some degree upon government assurances against the risk that they will be replaced by a newer technology before they can earn a return on their investment"

(p. 497). Hall (2002) concludes that both color and DTV standards resulted from a series of compromises from the competing interests.

To summarize, there are three choices in implementing the digital television standard: the HDTV format, the SDTV format, and a hybrid format involving the mixture of the two. The atypical feature of the ATSC DTV standard generates great latitude for stations to adopt such a "non-standard standard". Then, the question is what accounts for station-difference in the choice of the DTV standard. Few studies (Oberg, 2000; GAO, 2002a; GAO, 2002b) so far have tried to explore the answer.

2.5 Stations' reactions to the government mandated DTV transition

Very few studies have taken an empirical approach to examine the digital television transition. This makes the following two studies particularly valuable. Both studies employ survey research method and focus on the U.S. digital television transition. Oberg (2000) examines broadcasters' readiness for the new technology. Taking a broader perspective, the GAO reports (2002a, 2002b) surveys broadcasters, policy markers, and television salesperson.

Focusing on the digital transition of terrestrial television, Oberg (2000) examines how the digital technology has been perceived by local broadcasters. While the FCC has set the timetable for broadcast stations to make the switch; the Commission follows the principle of (i) deploying few technical mandates, (ii) leaving the decision on end products to the DTV market. Although most stations are performing well in the analog format, Oberg (2000) notes that the first-mover advantage and to remain competitive in the local market are the motives for stations to adopt the digital technology.

Echoing Huff's claim that the DTV standard is a "non-standard standard", Oberg (2000) highlights the standard's flexibility. In adoption a wide range of standards, including both the HDTV and the SDTV formats, "the FCC gives broadcasters the right to decide how best to pay for the transformation to digital" (Oberg, 2000, p. 7). Besides, the author further argues that ownership will affect the strategies employed by local broadcasters during the transition. Hypothetically, a group-owned station can be an agent to carry out the corporate decision with regard to the digital-switch timing.

Oberg (2000) conducted a mail survey in 1999, targeting broadcast stations that are affiliated with ABC, CBS, NBC and Fox networks. General managers from 188 stations replied to the survey. The survey reveals that while the majority of broadcasters regard broadcasting as their primary business, a few of them expect to provide information services through the digital technology in the near future. In terms of technology decisions, it is found that a number of managers believe they and the group owners equally share the authority to formulate their transition strategies. Oberg (2000) also found that the amount of local programs is positively associated with station's readiness for digital switch. The results reveal that the majority of stations have not planned to produce their local programs in the digital format. In conclusion, Oberg (2000) speculates that local broadcasters are taking a wait-and-see approach for the digital transition. He suggests that the wise management of digital technology is important for terrestrial television's future. Since the study is conducted in the early phase of digital television transition, the technology diffusion pattern is yet to emerge. The scope of the study is consequently limited.

Based on interviews and surveys, the GAO (2002a) report provides valuable first-hand information on the U.S. digital television transition. In fact, the report has covered a variety of aspects in order to offer comprehensive suggestions for the DTV policy makers. To enforce the transition process, the FCC mandated local stations to return analog broadcast spectrum if more than 85 percent of television households in the market can receive DTV. Yet, the GAO (2002a) points out some implementation problems with respect to the 85 percent rule. For example, even if digital signals are available over the air or through cable service, there is lack of information on whether television viewers have the equipment to receive the signals. The overlapping but different coverage by broadcast stations and cable systems largely complicates the procedure for counting the DTV households.

The GAO (2002a) further challenges the 85 percent rule by comparing the FCC rule to the DTV policy in other countries. The U.K. government, for example, has decided on turning off the analog signals when at least 95 percent of households can receive DTV. Based on interviews with one thousand plus American people, the GAO finds only 14 percent of respondents were very familiar with the difference between an analog and a digital television set in 2001 (GAO, 2002a, p. 16). The GAO also interviewed sales staffs from 23 consumer electronic stores. It is found that the staffs tended to overstate the available amount of high definition content; besides, the staffs were not sure if local stations have made the digital switch.

Since the majority of Americans receive television service via cable, the GAO (2002a) also interviewed representatives of cable systems. According the interviewees, a key incentive for cable systems to provide digital signals is competition with direct broadcast satellite. Besides, cable companies expressed their preference of high definition content to standard definition multicasting signals. After reviewing the FCC documents, the GAO (2002a) pointed out that great improvement is required for many cable systems to be capable of digital carriage. In terms of another distribution channel—DBS— the GAO observes that local digital content has not been carried by DBS providers. Yet, enhanced service is available for subscribers to receive local signals (GAO, 2002a, p. 23). To foster the transition comprehensively, the GAO suggests the FCC requiring cable systems to be digital ready by a certain date.

While the digital upgrading of distribution channels is important, the essential part of the transition is the digitally-produced content. The GAO (2002a) observes that many broadcast stations have chosen standard definition format over high definition. On the digital channels, many stations were found simply duplicating their analog content into the SD format. With regard to networks' race on digital programming, CBS and ABC are the leaders with NBC and Fox lagging behind (GAO, 2002a, p. 29). While the cost of producing HD programming for big networks is relatively low, the GAO reveals that broadcast networks were not making great efforts to get advertisers excited about DTV. In conclusion, the report highlights the importance of raising public awareness about the DTV transition.

Another study was conducted by the GAO (2002b), which is based on a survey of 1,182 full-power commercial television stations by the end of September 2001. In this survey, the stations are divided into two groups. First, the DTV stations: this group represents stations that were broadcasting a digital signal at the end of September 2001. There are 168 stations in this group. Second, the remaining stations are categorized as transitioning stations. 1,014 stations belong to this group. The survey shows almost three-quarter of the DTV stations are providing some amount of HDTV content (GAO, 2002b, p. 12). It is found that CBS affiliates are one of the biggest supporters of HDTV; while smaller network affiliates are broadcasting no HDTV. In addition to offering high definition content, 22 percent of the DTV stations are multicasting (p. 13).

According the survey (GAO, 2002b), the majority of the DTV stations perceive little consumer interest in their digital broadcasts. Moreover, it was found that relevant promotion activities by the DTV stations were very limited. With regard to digital transition cost, the survey showed an average cost of $3.1 million for a DTV station and an average of $2.3 million for a transitioning station (p. 16). Yet, such expenditures account for a much smaller amount of annual revenues for the DTV stations than for transitioning stations. The GAO (2002b) finds that the most commonly source of funding for both the DTV stations and transitioning stations comes from the stations owner or parent company. It is notable that six percent of transitioning stations were considering sale of the station as a way to fund the digital transition (p. 21).

The report (GAO, 2002b) shows many transitioning stations are having problems to meet the May 1, 2002, deadline. Such difficulty is prominent especially for stations with less than $2 million annual revenues, and for stations outside of the largest 100 television markets. Yet, the GAO (2002b) finds that the difficulty of on-time transition is not affected by station network affiliation or size of the station owner (based on how many broadcast stations the owner held). Without a government mandate on digital transition, about 3 percent of the stations reported they would never switch to digital while most transitioning stations report they would switch to digital much later (GAO, 2002b).

The empirical studies discussed so far (Oberg, 2000; Huff, 2001; GAO, 2002a; GAO, 2002b) have provided valuable guidelines for this study. Together they reveal two important flexibilities allowed for stations when following the DTV transition mandate: first, the standard choices tied with the “non-standard standard”; and second, the variability in the timing due to the FCC’s tolerance of delayed transitions. Facing these flexibilities, station’s decision making process on the DTV adoption is affected by firm- and market-specific factors. The correlated relationship is the very focus of this study.

2.6 Conclusions

This chapter has covered four major aspects with regard to advanced television technology and the digital television transition: (i) the general background of advanced television systems; (ii) the standard-setting processes in broadcasting industry; (iii) the peculiarity of the ATSC DTV standard; and (iv) the factors affecting station's adoption of the DTV standard.

Firstly, despite the supposedly strict transition timetable set out by the Congress and the FCC, stations have been able to obtain a more flexible transition schedule, aided by indulgent regulators. The Balanced Budget Act in 1997 has entitled some stations to an extension for digital transition due to technical, legal and financial reasons (CBO, 1999). As of April 12, 2002, the GAO (2002b) reported that 298 out of 1,240 commercial television stations had completed the DTV construction and were broadcasting a digital signal (p. 11). Among those 298 stations, 179 stations had elected to switch to digital before they were required to do so (GAO, 2002b). In the presence of regulators' tolerance and broadcasters' voluntary cooperation, evidently, stations enjoy a certain amount of flexibility to decide on the timing of their digital adoption.

Secondly, the ATSC DTV standard is considered as a "non-standard standard" (Huff, 2001); it allows stations to pick from 18 different formats. Due to the "non-standard standard", stations are free to adopt the HDTV format, the SDTV format, or the combination of the two formats. This flexibility had allowed stations to exercise a measure of choice with regard to the specific standard to adopt. According to the GAO report (2002b), 100 stations were providing some amount of HDTV content by the end of September, 2001, while 35 stations had picked the SDTV format (p. 12).

The literature also tentatively identifies some of the factors that would influence the stations' decision with regard to transition timing and standards choice. First, with regard to the timing flexibility of the DTV adoption, the GAO report (2002b) reveals that richer stations make the transition sooner; and major market stations switch to digital more smoothly. Besides, Hall (2002) suggests that the big stations would be the early movers in standard transitions. Farrell and his associates (1992) suggest that network affiliation would foster station's adoption of technological standard. Second, with regard to the DTV format choice, the GAO reports (2002a, 2002b) find that network affiliation had some influence on standards choice. CBS affiliates are the strongest supporter of the HDTV format; ABC and NBC affiliates are catching up in providing HD programs; while Fox affiliates and other stations prefer the SDTV to the HDTV format. Huff (2001) has also suggested similar patterns regarding the DTV standard choice. Oberg (2000) suggests that independent station's standard choice is more explainable by local factors.

In chapter 5, all the aforementioned factors will be incorporated into statistical models. The 2006 data on American broadcast stations will be analyzed to test the significance of those factors in affecting the DTV standard adoption.

Chapter 3

Theorizing firm Choice

The previous chapter discussed the general background of the digital television conversion, and introduced the concept of flexible standards. Some of the factors that influence when a broadcast television station would make the mandated switch-over to digital transmission, and the choice of standard were also discussed. In this chapter, the topic of firm choice in response to government mandated standards is explored. Of specific interest will be the relationship between technological change and firm growth, the impact of firm-specific factors on technology adoption, and regulation's impact on firm behavior and technology adoption. The keywords in this chapter are technology, regulation and economics. The dynamics around the three forces are the framework for my examination on the DTV transition, while the focus is station's choice in the presence of a government mandate.

The U.S. DTV transition is a government mandated standard transition. Though there are indisputable system-wide benefits through the more efficient utilization of the spectrum, American broadcast television stations have almost uniformly regarded the adoption of the new technology as a challenge. However, the digital transition has been mandated by the Congress and the FCC. Since broadcasters are using public spectrum, they are subject to government supervision and regulation. The FCC has been deeply involved in the DTV transition since the early stage of standard setting process. To ensure all stations are moving forward in this transition, the FCC has adopted a timetable that pushes stations to realize the transition in a timely manner. In spite of the inevitability of technological change and regulators' enforcement, individual stations are still the ultimate agent to accomplish the DTV transition. Essentially, the successful transition of a station is determined by the firm's internal mechanism, which can be indicated by features like firm size, age and degree of integration. In a word, finance is the key for a station's sustainable growth; as well as to its digital transition.

In the context of the dynamics of technology, regulation and economics behind the digital television transition, this chapter seeks to inquire why firms innovate, how firms handle technological changes and how technology adoption is shaped by firm-specific factors.

3.1 The relationship between technology innovation and firm/industry growth

Many studies have covered the dynamics between technology innovation and firm or industry growth—the positive relationship widely expected between these two variables goes a long way to explain the willingness of firms to adopt new technologies. However, a more complex and nuanced picture emerges from the literature. For instance, Nelson and Winter (2002) regard innovation and technology adoption as continuous, cumulative and evolutionary. Tushman and Anderson (1986) argue that technological change can be disruptive and discontinuous: they highlight two types of technological change, competence enhancing versus competence destroying. With regard to the interactions between technology and economics, some scholars examine the relationship between firm specific factors and technology investment; others analyze the impact of technological changes on firm survival. This section therefore examines the literature on technology change and firm/industry growth, to better understand why firms innovate.

Considering industry as organism, Nelson and Winter (2002) apply the theory of evolution to examine firm performance and industry growth. The authors highlight the evolutionary approach's advantages to analyze firm specific issues like strategies to maximize profit and to stay competitive. According to Nelson and Winter (2002), a central question regarding Schumpeterian competition (technology-induced competition) is whether competition has a tendency to self-destruct and give way to monopoly. The authors consider the answer under two scenarios. First, when the technology comes from outside the industry, an incumbent firm does not necessarily maintain its competitive advantage. Second, when technological change is cumulative in the industry, a dominant firm tends to remain as a leader (Nelson and Winter, 2002).

Reviewing several studies that have taken the evolutionary approach, Nelson and Winter (2002) highlight the industry lifecycle theory. The theory posits that there are a lot of entries when a new technology is introduced. Then, a dominant design gradually emerges; it brings some firms sustainable survival but leads others to exit. Thirdly, the remaining firms prosper with the technology, while entry decreases. Lastly, a small number of large firms come to dominate the market.

With regard to the relationship between technology innovation and firm growth, Nelson and Winter (2002) believe that the organized research and development efforts of firms are the source of innovation; as the function of R&D is to identify new opportunities and to adapt and to commercialize them. Further, the authors claim that technological change is cumulative at the firm level in the sense that efforts to advance technology today build from what the firm achieved yesterday. Successful innovation tend to enhance the profitability of a firm, and thus to lead that firm growing larger and spending more on R&D. In contrast, firms that are technologically behind have little chance to leapfrog the leader.

Believing technology to be one of the central forces shaping competition dynamics between firms, Tushman and Anderson (1986) provide a contrasting perspective that stresses technological discontinuities. They conceptualize two types of technological changes: competence-destroying and competence-enhancing. They claim competence-destroying technological discontinuity requires a fundamental change on technology-associated skills and knowledge base. Consequently, there will be major changes in the distribution of power within the industry. New firms founded to exploit the new technology will gain market share. Industry structure can be disrupted by such technological changes. Competence-enhancing discontinuity, in contrast, is simply the improvement of existing technology (Tushman and Anderson, 1986). Since it happens within a product class, such discontinuity does not render obsolete the skills tied to existing technology. Incumbent firms have the advantages to introduce and exploit competence-enhancing technological changes. Such discontinuities, according to the authors, tend to consolidate industry leadership.

Tushman and Anderson (1986) select three industries to test their two-types-of-technological-change hypothesis. The industries are cement manufacturing, air transportation, and computer manufacturing. Over a period of more than a century, the authors observe that competence-destroying discontinuities happened twice; while competence-enhancing discontinuities happened six times in the three industries together. Detailed investigation of those technological changes reveals that incumbent firms are more likely to introduce competence-enhancing discontinuities. Competence-destroying discontinuities are rare; they are introduced by new firms in both the observed cases. The evidence of these patterns can be easily identified in the computer manufacturing industry. For both types of technological change, early adoption is found to bring greater firm growth rate. The authors also note that competence-destroying discontinuities occur early during industry lifecycle; while the competence-enhancing discontinuities happen later and result in consolidated market structure.

The property of technological changes—highlighted by Tushman and Anderson (1986)—and the consequent choices by market leaders and followers have meaningful application in the case of the DTV transition. If digital television is a competence enhancing technological change, established players will take the lead in deploying the standard. But if it is competence destroying, it will be market laggards or new firms that will take the lead. However, due to the peculiar nature of the broadcast licensing system, it is the incumbents who are allocated the new frequencies for digital broadcasting: the established distribution channels and models are still the primary means employed by the current DTV technology. The behaviors of television viewers remain unchanged in the presence of the new television technology. Thus, the DTV technology is regarded as competence enhancing.

Referring to the discussion with regard to competence enhancing technological changes by Tushman and Anderson (1986), it is established stations that would have the advantages to initiate and exploit new possibilities opened up by the DTV standard which builds upon the competence they already possess. Thus, the projection is that the DTV transition tends to consolidate the leadership of major stations; the rich stations are likely to get richer due to the digital technology. The DTV standard may also increase barriers to entry and minimum scale requirements. In this regard, relatively fewer entries relative to exits are expected through the DTV transition.

Many scholars have taken an empirical approach to examine the driving forces for technology innovation, with contrasting specifications of the associated relationship. For example, Chandy and Tellis (2000) investigate the myth behind the so-called “incumbent’s curse”; Armour and Teece (1980) believe vertical integration is helpful for technology innovation.

Chandy and Tellis (2000) firstly discuss the advantages and disadvantages for incumbent firms to introduce product innovation. On the one side, the authors argue that incumbent firms may be reluctant to introduce innovations, because the significant rents from existing products and the firm mechanism would become much less effective for a new technology. Such an argument is consistent with the association made by Tushman and Anderson (1986) between competence destroying technology and new firms. On the other side, Chandy and Tellis (2000) recognize the financial, technical and market capabilities that enable established firms introduce and develop innovations. Similarly, Tushman and Anderson (1986) discuss such connection between competence enhancing technology and established firms.

To clarify the relationship between incumbent firm and innovation, Chandy and Tellis (2000) collect information on innovation from hundreds of previous studies. Setting the time frame from 1850 to 1994, the authors select 64 significant innovations for their analysis. Among the independent variables, firm size is measured by number of employees. Moreover, firms are coded as innovators, incumbents, and new entrants according to their association with an innovation.

The findings show little evidence for incumbent’s curse. That is, incumbent-introduced innovations are found just as many times as those by less established firms. Yet, the findings show that most innovations were introduced by less established firms before 1940s, while the majority of recent innovations were introduced by incumbent firms. Chandy and Tellis (2000) thus conclude that incumbent's curse can only apply to the old economic period, since large, established firms have learned the lessons and are engaging in more innovative activities. The nonexistence of incumbent's curse may also apply to the DTV technology. If we regard the DTV technology as a continuation of a prevailing business model (and not as a disruptive "competence-destroying" innovation), it is expected that stations that have strong financial and market capabilities to initiate and exploit the DTV standard, while less established stations may be left behind through the transition.

The primary question for Acs and Audretsch (1987) is how innovative activities are affected by firm size. Unsatisfied with previous measures of innovative activities, R&D investment or number of patented inventions, the authors adopt and settle on the innovation rate. This is defined as a ratio between the number of innovations and number of employees. With firms being categorized as large and small based upon number of employees, Acs and Audretsch (1987) compare the innovation rate in large and small firms to test their hypothesis. Furthermore, market structure factors like entry barriers and concentration ratio are incorporated into the analysis of a 247-industry sample.

The findings indicate that large firms have innovative advantages in capital-intensive and highly concentrated industries. It is also found that small firms are likely to develop their innovative advantages when skilled labor is a key for the industry. Acs and Audretsch (1987) suggest that large firms are more likely to engage in innovative activities in general. They also note that most small-firm innovations tend to happen in the early stage of industry lifecycle.

In the case of digital television, there are significant government expenditures on technology development. So individual firms (or station groups) are not high on R&D because they prefer to ‘free ride’ on technologies developed elsewhere – for instance in the consumer electronics industry or in government labs. Since R&D on new television technologies are not conducted on the station level, the industry cannot be viewed as capital intensive in the typology of Acs and Audretsch (1987). However, television production does require skilled labor. Major stations in top markets tend to have a number of talents for program production and promotion. Besides, every station requires skilled technicians to maintain station facilities. Thus, the television industry can be viewed as a labor-intensive industry. According to Acs and Andretsch (1987), small firms are tied to innovative activities in labor-intensive industries. In digital television transition, the new technology is likely to favor small upstarts rather than large and established stations.

Research has also focused on innovation in vertically integrated firms, an aspect particularly relevant to the television industry with its network structure and group ownership. A valuable hypothesis raised by Armour and Teece (1980) is that a firm can promote innovation activities by setting common ownership of R&D across vertical stages of product-processing. The authors contrast the efficiency of vertical integration with the significant transaction cost of technological know-how exchange. Due to the economic efficiency of sharing technological information vertically, the authors claim that vertical integrated firms can foster the implementation of new technology.

The authors employ the data on the U.S. petroleum industry to test their hypothesis. Armour and Teece (1980) choose firm’s R&D expenditure to measure innovation activity, their dependent variable. Firm size, measured by firm’s assets, is one control variable. Vertical integration, the key independent variable, is measured by the number of product-processing stages that a firm engages in. The findings indicate that a higher degree of vertical integration is associated with greater R&D expenditure, supporting their theory. One problem with the analysis: while the measurements for innovation activity and vertical integration are quite straight-forward, they are only proxy measures that approximate the complexity of the modern firm. Nevertheless, Armour and Teece's work raises questions about the relative capacity and/or willingness of vertically integrated [network-affiliated] and vertically non-integrated [independent] firms to adopt innovation.

3.2 The factors that affect firm's technology adoption decision

Previous studies are not limited to technology innovation within firms; the diffusion and adoption of new technologies developed outside the firms have also attracted many scholars' attention. Both theoretical and empirical studies have been conducted to identify firm specific factors and diffusion effects that are tied to firm's technology adoption decision. When facing technological changes, first and for most firms will calculate the cost or benefit of adopting a new technology. When more than one technology is available, firms will consider which technology is most profitable to be adopted. Considering the profit motive as the context, several scholars have paid special attention to the effect of firm size on technology diffusion pattern. One often-cited example is the study conducted by Rose and Joskow (1990). Since the statistical methods used to empirically test models of technology adoption by firms is of particular interest to this dissertation, the following paragraphs discuss these as well.

Studying the diffusion of coal-fired steam-electric generating technology, Rose and Joskow (1990) examine whether firm size has a positive or negative impact on technology diffusion. While many studies have examined the possible Schumpeterian effects of firm size and market structure on technology adoption decisions, Rose and Joskow (1990) distinguish their study by decomposing the firm effect into two components: one part is associated with the possibility of technology adoption, the other is about technology innovation.

The analysis mainly focuses on firm's adoption of one electric generating technology, conventional units. The authors expect factors like fuel cost, time, utility size and ownership, will affect the firm's adoption decision. They also note some possible connections between firm size and innovativeness: large firms have more resources, are capable to absorb technology risks, and possess economies of scale; thus they are more likely to introduce new technologies (Rose and Joskow, 1990).

The sample covers 144 electric utilities from 1950 to 1980. Rose and Joskow (1990) apply three different models to the data: Tobit, Weibull proportional hazard, and log-logistic hazard. The findings show that firm size has a significant and positive effect on adoption decision across all the models. The log-logistic model suggests the hazard rate of utilities adopting conventional units declines over time. As investor-owned utilities are larger than municipal and cooperative utilities, they are found more likely to adopt the technology. Overall, Rose and Joskow's study provides solid evidence that firm size and ownership have positive impact on technology diffusion.

Their focus on technology adoption (Rose and Joskow, 1990) perfectly matches the research interest in this dissertation: broadcast stations' adoption of the DTV standard. Their findings may also have valuable application to the case of the DTV transition. If the electric generating industry and the broadcast television industry are comparable, then established stations are likely to adopt the DTV standard faster than other stations. Besides, group-owned stations may also switch to digital earlier than independent stations.

Also focusing on the relationship between firm size and technology adoption, Hall and Khan (2002) provide a detailed review on previous studies. Based on their observations on firm's adoption of new technology, the authors present a list of factors that can affect the technology diffusion process. Firstly, Hall and Khan (2002) point out that technology's smooth diffusion requires skilled labor. Secondly, the successful diffusion of a new technology asks for a stable user base. While they acknowledge that the technology adoption pattern is affected by firm size, Hall and Khan argue that such effect can be either negative or positive. On the positive side, the authors list three qualifications of large firms: (i) available funds for research and development, (ii) financial resources to purchase and install a new technology, (iii) capability to take technology-related risk. On the negative side, the authors consider (i) large firm's bureaucracy and (ii) resources sunk in the old technology can obstruct the switch to new technology. Next, Hall and Khan (2002) consider regulation as a positive factor in promoting technology diffusion, at least in most cases. Lastly, the authors discuss additional factors that can influence technology diffusion when the process takes place in a global context.

While firm size turns to be the focus of the aforementioned studies, many economists have identified and tested some sophisticated effects through the technology diffusion process. Their arguments are based on economical modeling and empirical testing. The methods include survival analysis and general regression.

Assuming the profit-maximizing behavior of firms, Gotz (1999) examine how technology adoption decision is affected by firm-specific factors. The author highlights two types of force driving firms to adopt a new technology. First, differences in firm size, R&D expenditures, market shares, or prior beliefs of a new technology affect the firms' adoption timing. Second, the benefit to the marginal adopter depends on the cumulative number of previous adopters.

Highlighting both factors, Gotz (1999) construct a profit maximization model that includes the cost and payoff of technology adoption. The model predicts that a firm's profit decreases as more and more firms adopt the technology. It also indicates a positive relation between firm size and the speed of adoption. Besides, increased competition is shown to often promote diffusion. Since his model focuses on adoption cost and demand side, Gotz (1999) suggests that future research should incorporate the treatment of supply and cover the interactions between demand and supply that may arise in technology diffusion.

Similar to the findings by Rose and Joskow (1990), Gotz (1999) also found a positive impact of firm size of technology diffusion. Findings from both studies suggest that stations with higher ratings and in top markets would be more likely to speedily adopt the DTV standard.

Seeking a better model for technology diffusion, Karshenas and Stoneman (1993) highlight the spreading nature of information. The authors illustrate such epidemic force with three types of effects. First, the rank effect depicts the relevance of adopter's characteristics (such as firm size) to technology adoption timing. Second, the stock effect captures the relationship between number of adopters and adoption benefit. Third, the order effect portrays the interaction between rank and stock effects (Karshenas and Stoneman, 1993). Those effects together involve four factors that the authors consider to be important in technology diffusion modeling: adopter's characteristics, number of adopters, adoption benefit, and time. Furthermore, the authors incorporate those factors into hazard models to capture the process of technology diffusion.

A U.K. case is employed by Karshenas and Stoneman (1993) to empirically test their model: the diffusion of the CNC, computer numerically controlled machine tools, in nine engineering industries from 1968 to 1980. Generated from hazard model estimation, the findings show large firms are more likely to adopt CNC. It is also found that industry growth rate has a positive impact on firm's CNC adoption. While strong evidence for rank effects is found in the CNC diffusion, the signs for stock and order effects are not obvious. Karshenas and Stoneman (1993) regard the CNC diffusion process not drastic enough to exhibit the latter two effects. One general problem noted by the authors with regard to research on technology diffusion is the lack of data.

Although Karshenas and Stoneman (1993) discuss the stock and order effects in the presence of positive network externalities, their findings only provide strong evidence for the rank effect. That is, it is found firm size is positively associated with technology adoption. The finding is consistent with findings by Rose and Joskow (1990) and Gotz (1999). With regard to broadcast television, indirect network effects exist between programming and distribution. Yet, the order and stock effects may not apply to the DTV transition since direct network externality is absent. But the rank effect can be singled out and still apply to the DTV standard adoption.

The study by Majumdar and Venkataraman (1998) investigates the factors that induce a firm to adopt a new technology in the presence of network effects. The authors highlight a special context of technology adoption, where there is interdependence between different components in an industry. Under such condition, the authors highlight two forces that can affect firm adoption of a new technology (Majumdar and Venkataraman, 1998). First is conversion effect, a large installed base will impede new technology adoption. Second is called consumption effect: high density and variety of a network's user population can foster technology adoption.

To capture the two effects, Majumdar and Venkataraman (1998) conduct an empirical analysis on local telephone company's adoption of electronic switches in the 1970s and 1980s. The sample includes 40 firms that are the largest in the industry. The authors set the dependent variable as the percentage of electronic switches by operated by each firm. Majumdar and Venkataraman (1998) associate the conversion effect with a firm's physical network size (i.e. wire mileage). For consumption effect, market variety is measure by the percentage of business lines by firm.

Through regression analysis, the findings suggest firm size is positively associated with technology adoption (Majumdar and Venkataraman, 1998). It is found that firms with more business lines are more likely to adopt electronic switches. The authors find little support for the conversion effect; one possible explanation can be that the measure of a firm's installed base should be the number of subscribers rather than its wire mileage. Yet, Majumdar and Venkataraman (1998) do find some support for the consumption effect.

From Rose and Joskow (1990) to Majumdar and Venkataraman (1998), there is a common assumption shared by all these studies: the technology diffusion pattern is determined by firm specific factors, that is, the firm decides whether or not to adopt a technology based on factors specific to itself. By contrast, scholars such as Lieberman and Montgomery (1988) and Hall and Densten (2002) take a different perspective—they regard technology adoption as eventually unavoidable; what they are really concerned with is the firm's timing of technology adoption and the outcome associated with the decision.

Assuming that early adoption of new technology is due to firm-specific factors like resources, foresight and luck, Lieberman and Montgomery (1988) examine the benefits associated with the timing of technology adoption. The authors generalize three kinds of first-mover advantages with regard to new technology. First, having successfully innovated a new technology, a firm can charge its competitors for technology patent. Second, early adoption of technology provides a firm enough time for strategic behaviors against its competitors. Third, early adoption of technology can bring a firm a considerable market share, for consumers may be reluctant to switch to other firms with late adoptions (Lieberman and Montgomery, 1988).

In the case of the DTV transition, the DTV technology is a common standard and is equally accessible to all broadcast stations. The advantage associated with patent does not apply to the DTV case. But first-mover advantages in terms of market share gains or greater visibility still stand in the DTV case. It is believed that these competitive advantages more meaningful than the advantage associated with patents. Compared to the patent advantage, competitive advantage reflects the idea of an open market; it encourages competition and may eventually benefit consumers. The introduction of technology patents will only increase the entry barrier and cause the market to be manipulated by a few players.

Lieberman and Montgomery (1988) also point out several disadvantages related to early adoption of new technology. First, first-mover may have made huge investment for innovation, while followers imitate the process at a low cost. Second, early adoption is always associated with uncertainty, but the adoption decision can be guaranteed profitable after a dominant design emerges. Third, because technology continues growing, incumbent lock-in may happen to the first-mover, while late adopters may choose to adapt to new changes (Lieberman and Montgomery, 1988). These disadvantages are applicable to the DTV transition. Early adopters of the DTV standard face expensive investments for facilities and programming. They have to deal with the risk of no gain in advertising revenue due the transition.

Exploring evidence for first-mover advantages/disadvantages, Lieberman and Montgomery (1988) point out several problems on empirical analysis. For example, early adoption may make a firm more likely to survive, but it is difficult to ascertain whether this stems from pioneering or from some more basic characteristic of the firm. For future empirical studies, Lieberman and Montgomery (1988) suggest that first-mover opportunities should be treated endogenously, for such opportunities are gained through some combination of proficiency and luck.

Interested in successful absorption, Hall and Densten (2002) examine the factors that enable firms to perform well after their adoption of a new technology. The authors firstly highlight the association between the entry order and success potential with regard to technology adoption. According to Hall and Densten (2002), the benefits of being technology pioneers include pre-emption of scarce assets, preferential access to distribution channels, and dictating competition by setting the industry standard. In contrast, technology followers can take advantage of the learning effect of a new technology. It becomes easier for them to manage the new technology; besides, they face less uncertainty in the market.

Believing that technology pioneers and followers have equal chance of success, Hall and Densten (2002) analyze the relationship between the return of technology adoption and the adoption decision with an emphasis on technology followers. The authors argue that, by keeping an active strategy to pursue market and technological opportunities, early followers can earn above-average long-run returns from technology adoption. Yet, technology followers can produce below-average returns by adopting a wait-and-see strategy or splitting the resources on both old and new technologies. Overall, Hall and Densten (2002) highlight that a firm’s existing resource is an important factor shaping technology adoption outcome. They believe that the success of technology adoption is determined by a firm’s capability to match their resources to market opportunity.

Though the above discussion of a firm’s innovation activity and technology adoption decision have provided a number of insights into the digital television transition, these precedents are not completely applicable to DTV due to some crucial differences. These differences are (i) that the shift to a new technology or innovation in many prior instances was not mandatory—firms had the discretion to stay with the established "legacy" technology or go to the new innovation; (ii) there was no mandated timeframe for the shift, as in the case of digital television; and (iii) there was flexibility in the final standard (the "non-standard standard") in the case of DTV compared to a clear cut standard discussed in studies by Rose and Joskow (1990), Karshenas and Stoneman (1993), and Majumdar and Venkataraman (1998).

Due to the presence of government mandate, the DTV transition is different from an average standard transition; however, the area of environmental regulation possesses lots of similarities to the case of digital television on all three counts listed above. To reduce environmental pollution, the U.S. government has employed both command-and-control and market-based (such as tax and permit) approaches in environmental regulation. Many of these approaches have involved transitions over a timeframe. Finally, there has been some flexibility in the implementation of standards as well. To avoid the expenditure increase on pollution abatement, firms have innovated varied technologies that meet the EPA's (Environmental Protection Agency) standard. Because of these similarities, the rest of this chapter is devoted to a detailed study of environmental standards and their implementation in diverse industries.

3.3 Environmental regulation

In the United States, a key legislation dealing with environmental standards is the Clean Air Act of 1963 and its Amendments. This law has impact a number of industries such as electrical power generation, copper smelting, and automobiles. The Act was introduced by the

Congress in 1963 to control smog in major urban centers and in general protect the nation's air quality. While stimulating greater environmental activity in various pollution-related industries, the Clean Air Act also had the potential to inhibit potential innovators. To solve the difficult and expensive procedural problems of the Act, the Environmental Protection Agency (EPA) introduced additional rules to the 1963 Act. Subsequent amendments were passed in 1977 and 1990, with the latest update passed in 2005.

Compared to the 1963 Act, the 1977 Amendments are more flexible by specifying state-by-state air quality control. First, the Amendments employ different environmental technology requirements based on the location of new establishments. "New sources locating in an area with air cleaner than national standards must use the best available control technology, while new sources locating in an area with air dirtier than national standards must comply with the lowest achievable emission rate" (Anonymous, 1979, p. 1717). Second, the 1977 Amendments forbid new establishments to cause any additional degradation according to their locations' air criteria. Third, the Amendments add several penalties to the Act's sanctions to strengthen EPA's enforcement powers. Fourth, the Amendments require the EPA to update the environmental standards every four years, thereby ensuring firms to keep pace with control-technology improvement. Combining the Clean Air Act and its Amendments, the environmental regulation can actually induce and implement emission-control innovation (Anonymous, 1979).

A study published in the 1979 Yale Law Journal evaluates industries' responses, technical and financial, to the Clean Air Act and its 1977 amendments. Using evidence from two regulated industries, copper smelting and electric power, the study finds that the 1963 Act inhibited emission control innovation. Required by the Act, the copper smelting industry made great investments on developing new technologies, while little effort was spent on improving existing technologies. The poor outcome indicates the misallocation of innovative efforts in response to the 1963 Act (Anonymous, 1979). The study regards the 1977 Amendment were more effective because it allowed the requirements to be defined on a case-by-case basis to incorporate the latest technological improvements. Besides, the Amendments strengthened the EPA's enforcement power (Anonymous, 1979). From the perspective of the DTV case, both these innovations of the 1977 Clean Air Act amendments—flexible means to achieve mandated standards and clear enforcement authority—are relevant.

Focusing on the aftermath of the Clear Air Act, Pashigian (1984) examined the relationship between firm size, market share, and regulation. Observing the uneven impact of environmental regulation on different industries, the author separated his sample industries into two groups, high and low cost groups, based on their per unit compliance costs. In the sample, the high-cost group has fewer but larger plants. These industries tend to be capital and energy intensive. The author also notes that the number of plants in the high-cost group decreased between 1972 and 1977. Since plants are the executive sector to comply environmental regulations, Pashigian (1984) employed them as unit of analysis. The findings show that the high-cost industries have greater increases in value added per plant; while they experienced an absolute decline in the number of plants. By dividing plants into three subgroups (small, medium and large) among the high-cost industries, the author finds the distribution of market shares strongly favors large plants during the regulatory period. Overall, the findings suggest small plants suffered more than large plants because of the high costs imposed by regulation.

The study by Pashigian (1984) suggests that stringent environmental regulation has the tendency to favor large firms. In the case of digital television, the conditions for the DTV standard adoption are not quite the same. First, there is great expense associated with not adopting advanced technologies in high-cost industries (Pashigian, 1984); while a considerable amount of investment is required for adopting the DTV standard and the payoffs are uncertain. Second, while stringent environmental regulation is enforced in the environmental industries, the government mandate is executed by indulgent regulators in the DTV transition. Thus, the DTV mandate's impact is less clear compared to environmental regulations.

Jaffe and his associates (1995) study the effects of environmental regulation on manufacturing firms' productivity. Realizing the difficulty of measuring competitiveness, the authors have identified three potential indicators that represent the link between regulation and competitiveness: first, net exports of goods (pollution-intensive manufactures); second, production location (pollution-intensive goods); third, oversea investment (pollution-intensive industries). In terms of the key explanatory factor, regulation, both direct and indirect costs of environmental regulation are covered in their analysis. Firm's productivity can be negatively affected because regulation will influence firm's decision on input, management and investment, and the choice of source and technology. Yet, the authors claim the impact can be good under market-based regulation. That being said, they also note firm's reduced investment due to the cost of environmental regulation (Jaffe et al, 1995). While many studies have assumed that regulations increase production costs, Jaffe and his associates (1995) suggest that regulations may actually stimulate firm growth. The reasons are: first, regulation can induce technological innovation; second, regulation foster firms to be more efficient and productive. These arguments may also work for the DTV transition. The government mandate may indeed push stations to move forward and to make good use of the new technology.

Focusing on environmental technology policy, Kollman and Prakash (2001) illustrate how different regulatory frameworks can lead to varied technology adoption outcomes. Intrigued by the phenomena of supranational standards, Kollman and Prakash (2001) analyze the different standard-adoption patterns influenced by domestic and supranational contexts. One of their key points is: multinational enterprises rather than governmental institutions may play an important role in implementing supranational standard. Regarding EMS (environmental management system) standards as a perfect example of supranational standards, Kollman and Prakash (2001) examine varying responses from British, German and American firms. The main hypothesis of the study is that firms in countries with adversarial economies—where regulators and business are on less than friendly terms—are less likely to adopt EMS-based policies (Kollman and Prakash, 2001, p. 406). The EMS standards require documentation and certification. Facing those adoption costs, British and German firms react positively and enthusiastically, while the responses of American firms are mild and neutral.

Based on their qualitative analysis, the authors find British firms' smooth adoption benefited from a successful pilot EMS program and the British government's cooperative stance towards industry (Kollman and Prakash, 2001, p. 422). German firms' quick responses to EMS standards are caused by a series of detailed laws, imposed by the government, to implement the standard. Influenced by adversarial legalism, American environmental regulation's contesting and uncertain nature caused firms reluctant to adopt EMS standards (p. 425).

Explaining the rapid adoption of EMS standards in the U.K. and Germany, Kollman and Prakash (2001) give credit to the governments for molding the supranational standard regimes to their own policy styles and institutional imperatives. While the difference between the U.K. and the U.S in terms of EMS adoption patterns support the authors' hypothesis, the difference between Germany and the U.S. is against the hypothesis. Inspecting both adversarial economies, American and German, the authors find American regulation has rendered EMS adoption incentives less clear compared to the strict regulation in Germany.

In the case of digital television, the FCC began its cooperation with broadcast stations from the very beginning of the standardization process. By remaining in an interactive relationship, the FCC expected timely adoptions of the DTV standard by broadcast stations. The FCC's strategy seems to be supported by Kollman and Prakash's (2001) arguments—but the criticism has been voiced that the FCC's leniency was responsible for the repeated delays in the implementation schedule. The key difference may be that the British and German governments insisted on specific benchmarks being achieved on a timeframe while showing flexibility on the modes of implementation, whereas the FCC, all too aware of the confrontational litigious culture in the United States, relaxed the implementation timetable as well.

To illustrate how environmental innovations get established and what factors stimulate their international diffusions, Beisea and Rennings (2005) examine two innovations: wind energy technology and fuel efficiency standard. Firstly, observing winder energy's diffusion across European countries, Beisea and Rennings (2005) highlight the positive effects of environment policy. Comparing diffusion patterns and policy strategies of different countries, the authors find the tariff system is associated with a more rapid diffusion than the bidding system. Secondly, Beisea and Rennings (2005) regard that the U.S.' pioneer position in fuel efficiency technology is due to two environmental rules: the corporate average economy rule (CAFE) and the Clean Air Act. However, automobile manufacturers could get away with CAFE by simply paying fines. Yet, the catalytic converter technology associated with the Clean Air Act was more effective. Partly due to the weight of the U.S. market, the innovation was adopted internationally. Based on the two cases, Beisea and Rennings (2005) note the importance of two factors that result in effective diffusions of environmental innovations: demand preferences of major markets and strict environmental regulations.

3.4 Quantitative analyses of firm decisions

Many economists have studied regulation's impact on firm's technology decision; the following studies are the perfect examples which closely parallel the DTV situation in multiple ways – mandated de jure standards; a transition timetable; and flexible standards, the "non-standard standard". While every study relates to environmental regulations, a variety of technological changes are covered here. The scope ranges from chlorine manufacturing, electricity generating, petroleum refining, to paper manufacturing. Half of the following studies (Snyder, et al. 2003; Kerr and Newell, 2003; Popp, 2006) have employed survival analysis as the primary method; while the rest use certain regression methods for the firm level data analysis. In this section, papers dealing with firm decision-making are reviewed, given special attention to the methodologies used in them.

Targeting the U.S. environmental regulations, Jaffe and his associates (2002) review a number of studies on changes in environmental technology. According to the authors, there are usually three stages in the process of technological change: invention, innovation, and diffusion (Jaffe et al, 2002). A variety of perspectives support the idea that environmental requirements can stimulate invention and innovation. One example is the viewpoint that a firm's R&D (research and development) activity is a means for the harmonization of technology with environmental policy (Jaffe et al. 2002). Once certain technology is proven be efficient and economical, its widespread diffusion would lead to great environmental gains. Yet, the diffusion speed will be affected by two factors: the environmental policy instruments and the possibility of market failure (Jaffe et al. 2002). The authors claim environmental policies, particularly those with large economic impacts, have a significant role in promoting technological developments.

Based on the link between policy instruments and technological change, Jaffe and his associates (2002) perceive two types of environmental policies: command-and-control or market-based approaches. The two kinds of instruments are assessed based on the resulting rate and direction of technological change, and the relevant environmental protection outcome. However, previous studies found it impossible to prove that market-based policy is absolutely better than command and control in promoting innovation (Jaffe et al. 2002). Yet, many studies did find that market-based policy is better than direct regulation in promoting technology adoption. In the case of digital television, the DTV transition mandate is a mixture of command-and-control and market-based approaches. On the one hand, all stations are mandated to adopt the ATSC DTV standard established by the FCC; there is a timetable and a final deadline for stations to follow and to accomplish the transition. On the other hand, i) the timetable is close to a case-by-case criterion which is based on firm- and market-specific factors; ii) the DTV standard is a "non-standard standard"—stations have the flexibility to choose the specific DTV format they prefer.

Reviewing previous empirical analyses on environmental regulation, Jaffe and his associates (2002) note the frequent appearance of variables like expenditures on pollution abatement and characteristics of environmental regulations. On the issue of technology diffusion, some studies found neither command-and-control nor market-based approaches have much effect, while other studies indicate market-based instruments are more effective to foster the adoption of environmental technologies. Overall, the authors (Jaffe et al. 2002) present a detailed review, covering both theoretical and empirical aspects, on the relationship between technological change and environmental policy.

The study conducted by Snyder and her associates (2003) concentrates on the membrane technology's diffusion pattern in the chlorine manufacturing industry. The membrane cell is regarded to be superior to two other cells—mercury and diaphragm—in the electrolytic process, while diaphragm cell is more environmentally benign than mercury cell. From 1976 to 2001, both proportions of mercury plants and diaphragm plants dropped while the proportion of membrane plants increased. The authors attribute those changes to a series of environmental regulations enforced in 1970s and early 1980s. As a result, a number of mercury and diaphragm plants closed, while several plants chose to switch to membrane technology.

Snyder and her associates (2003) firstly analyze plants' membrane switch decisions. Ten out of 74 plants made the switch over the period from 1976 to 2001. Yet, the hazard models show no significant effects of the regulatory dummy variables on the switch decisions. In terms of exit decisions, 37 of 74 plants ceased operations during the same period. It is found that plants affected by two regulations, the pulp and paper cluster rule and the Montreal Protocol, were more likely to shut down than others. In both analyses, regulatory regimes are measured by several binary variables: whether or not plants are affected certain regulations.

Notably, the authors (Snyder et al, 2003) apply three versions of parametric hazard models--exponential regression, Weibull regression, and Gompertz regression--to both analyses. No significant difference is found between the three hazard models, while all models are consistent on one result: the baseline hazard is increasing over time in both switch and exit decision analyses. In conclusion, the authors suggest that environmental regulation did not particularly stimulate the switch to membrane technology, but it did drive plants with inferior technologies to exit the industry.

That technological changes may cause some firms to exit the industry is an interesting point raised by Snyder and her associates (2003). Similar outcome may happen in the DTV case. As it is true that the costs of compliance with environmental standards can be too high relative to the potential profits downstream; in the case of digital television transition, the transition cost can be overwhelming for a few stations. According to the GAO (2002b) report, the average cost to comply with the initial requirements for digital transmission is $2.3 million. Stations with revenues less than this amount may face a financial crisis due to the transition. In fact, the report (GAO, 2002b) shows that there were 40 plus stations considering sale of the station as a way to fund the DTV transition. In contrast, the remaining hundreds of stations would invest in digital technology and continue operation even though there is financial difficulty.

To provide empirical evidence for the argument that economic incentive based instruments (that is, pollution permits) can encourage technology adoption, Kerr and Newell (2001) examine petroleum refineries' isomerization adoption pattern. The United States's two-decade phase-down of gasoline lead is viewed as a valuable case since it experienced major success in implementing a market-based environmental policy, where a tradable permit market controlling the lead in leaded gasoline from 1983 to 1987 (Kerr and Newell, 2001, p. 2). Isomerization technology is one solution to reduce lead in gasoline; its adoption increased from zero percent to more than 60 percent across the period from 1971 to 1995. To examine regulations' impact on isomerization's diffusion, the authors compile a panel data of 378 refineries over the period 1971-1995, where information include lead regulations, technology costs, refineries' lead-trading behavior, and so on.

The analysis includes two regulatory variables (Kerr and Newell, 2001). First, regulatory stringency is measured by a function of another two variables: the average amount of lead allowed per gallon and the share of leaded gasoline in total gasoline. Second, the form of regulation is a dummy variable, which indicates whether the refinery is subject to economic instrument (with tradable lead permits) or mandatory lead limits. Kerr and Newell (2001) employ several hazard models to estimate isomerization's diffusion pattern: Cox, exponential, Weibull, and Gompertz models. The outcomes are very similar between these models.

The results show a positive influence of increased regulatory stringency on isomerization adoption (Kerr and Newell, 2001). The authors find that the diffusion rate was much greater during the period when trading permits were allowed, compared to the period when refineries were subject to mandatory lead limits. The results also show that an increased concentration of refineries had a negative effect on isomerization adoption, which suggests that refineries in close proximity to other refineries have greater access to substitute technologies. While the results suggest that larger refineries are more likely to adopt, it is also found that refineries that are part of larger companies are less likely to adopt. This is likely due to the multicollinearity problem of the two variables. Since both effects are not economically significant, the two variables seem to have little explanatory power. The findings by Kerr and Newell (2001) suggest that horizontal integration has a negative effect on technology adoption. If the settings of the DTV transition are similar to the case of isomerization adoption, it may be true that stations that are part of larger multi-station ownership groups are resistant to the DTV standard compared to independent stations.

Popp (2006) examines the impact of environmental regulations on the diffusion of nitrogen dioxide emission control technologies. He firstly compares two groups of technologies that are available to handle nitrogen dioxide emission. The first is post-combustion treatment (PCT) which involves chemical reaction of nitrogen dioxide. They are relatively new techniques and are quite efficient. The second are combustion modification techniques (CMT) which involve changing the combustion process to reduce nitrogen dioxide byproduct. They are much less costly compared PCT and are well established in America. Popp (2006) observes that the CMT adoption has increased greatly in the 1990s and they are used by 76 percent of power plants in 2002, compared to less than 10 percent of plants using PMT (p. 17). The author then employs a secondary data set on power plants' fuel usage, electricity production, nitrogen dioxide emissions, and pollution control techniques over the period from 1990 to 2002 (Popp, 2006). Among the 11 nitrogen dioxide reduction techniques facilitated by those plants, nine are categorized as CMT and two as PCT. A series of variables are employed to measure regulations: two binary variables indicating whether plants were regulated by the Ozone Transport Commission (OTC) or whether they are subject to the "State Implementation Plan" (SIP); another binary variable indicating whether plants are subject to maximum level of nitrogen dioxide emissions and a numerical variable presenting the emission standards for individual plants.

Employing parametric hazard models to analyze the CMT adoption pattern, Popp (2006) finds large plants and those subject to OTC or SIP regulations are twice as likely to make the adoption. Besides, the CMT adoption is more likely when fewer emissions are permitted. Yet, due to environmental inefficiency of CMT, plants opt out for the techniques when emission standard is very stringent. In the similar analysis for PMT adoption, Popp (2006) finds both the OTC and the SIP regulations are associated with greater likelihood of adoption, while the effect of the former variable is much bigger than the latter. Besides, newer plants, established in late

1990s, are found to be significantly more likely to adopt PMT. In conclusion, Popp (2006) emphasizes the need for regulations to encourage the adoptions of environmentally friendly technologies. According to Popp's findings, regulations can indeed foster technology adoptions. In the case of digital television transition, while all stations have been pushed to move forward; younger station may be more willing to adopt the DTV standard, implied by Popp's (2006) study.

To discover a significant connection between regulation and productivity, Gray and Shadbegian (1998) have tested for an impact of environmental regulation on a firm's investment decisions. The authors specifically examined "two aspects of the investment decisions for paper mills: the specific production technology installed in a new mill, and annual investment spending at existing mills" (Gray and Shadbegian, 1998, p. 254). The paper industry was chosen for investigation because, as a major polluter, it has to cope with environmental regulation. Besides, the production technologies are essential for the industry. The focus of the study is about the aftermath of the EPA establishment, which stimulates the enforcement of a series of environmental regulations. Thus, Gray and Shadbegian (1998) collect the investment data of 116 paper plants over the 1972-1990 period. The regulatory stringency is measured at the state-level; it incorporates two measurements: first, the pro-environmental voting score for the state's Congressional delegation; second, the fifty-state environmental success index. Comparing the promotion of pulping technology to the DTV transition, the FCC's strategy is more flexible than the EPA's enforcement. While the EPA adopted a rigid state-by-state index, the FCC considered a variety of factors such as network affiliation and market ranking when mandating the transition. Besides, the DTV standard adopted by the FCC is a "non-standard standard".

Subsequently, the adoption was possibly faster in the case of digital television comparing to the advanced pulping technologies.

In their analysis on plants' technology choices, Gray and Shadbegian (1998) separate plants into five groups according to their different pulping processes. Multinomial logistic regression is applied to the dataset. It is found that plants in stringent states are less likely to adopt the dirtier production technologies. Their second analysis focuses on state regulatory stringency's impact on a plant's investment spending. Plants' annual investment is the dependent variable, while technology choice becomes one explanatory variable. It is found that plants with relatively high pollution abatement capital expenditures invest less in productive capital, while the reduction in productive investment is greater than the increase in abatement investment.

Welch and his associates (2000) examined factors influencing electric utilities' voluntary participation in an emission reduction program. Voluntary programs can be an interesting case because it implicates both government regulations and business actions/reactions. This study tended to investigate why utilities participate in voluntary programs, and to explore the extent to which voluntarism contributes to pollution reduction. Correspondingly, two models were developed and applied to a sample of 35 top American electric utilities and their changes in carbon dioxide emissions between 1995 and 1997. In their first model (Welch et al, 2000), the participation decision—opt in or out--is the dependent variable. Direct regulatory action is one explanatory factor. It is measured by the utility's total payment on federal and state environmental regulatory expenses. Due to the binary feature of the dependent variable, the authors employ logistic regression to estimate the model. It is found that the effect of regulatory action is not significant. In the second model, emission change is the dependent variable. Use of technology is one explanatory factor. The ratio between the depreciation of environmental capital in 1995 and total 1995 depreciation served as the proxy, since it provides a comparable measure of the capital use for environmental objectives (Welch, et al. 2000, p. 417). Linear regression is applied to the data. It is found that emission reduction is positively associated utilities' use of environmentally sound technology.

Overall, Welch and his associates (2000) find that firms tend to volunteer for the program if they were subject to higher level of direct federal and state regulation. Their findings show that larger firms with high-polluting utilities are more likely to volunteer for the program. However, the findings indicates that participation in the program have no effect on pollution reduction levels. The authors' interpretation for such outcome is that the ineffectiveness of the voluntary program is due to the general weakness of the regulatory regime. The findings by Welch and his associates (2000) reveal the necessary role of regulation to foster firm's adoption of environmental standard. In the case of digital television, similarly, regulations from both the Congress and the FCC are necessary to push broadcast stations to adopt the DTV standard and to use public spectrum more efficiently. Supported by Welch and his associates (2002), the government mandate is constructive for broadcast stations' growth in the digital age.

Ishii (2004) differentiates his study from other environmental policy research by focusing on economic regulation, which enforces the level of competitive entry and influences firms' pricing/capacity decision, contrasted with many environmental regulations that mandate adoptions of particular types of technologies. Thus, the author examines the indirect effect of economic regulation on firms' technology choice. Ishii (2004) chooses to investigate the electricity generation industry that experiences significant changes in both technology and regulatory regime over the 1980 to 2001 period. The distribution of gas turbine sales is employed as the proxy of firms' technology adoption pattern. The major attributes of gas turbines—

capacity, heat rate, and age—are incorporated as the prime factors in the analysis. The author compares the turbine sales associated with two types of firms: the electric utilities under price regulation and the independent power producers operating without regulation. It is found that utilities under price regulation are more likely to adopt newer gas turbines than independent power producers. The author thus concludes that economic regulation tends to promote the development of advanced technologies in the electricity generation industry.

The studies discussed above are all set in American context. Their focus is mainly about the responses from industries and firms toward the Clean Air Act and its Amendments. The following study is conducted in Japan. While no specific regulation is involved in the study, the main issue here is still about how industries and firms behave under environmental conservations.

Exploring the relationship between regulation and innovation, Arimura and his associates (2005) focus on environmental regulation's impact on firm-level investments for R&D (research and development) activities. Their sample covers 19 Japanese manufacturing industries from 1996 to 2000. The independent variables include firm size—measured by the number of employees—and firm profit. The findings show that both firm size and firm profit have positive effect on firm's environmental R&D activities. Besides, a positive relationship is found between firm size and firm's environmental R&D investment. That firm size has a positive impact on innovative activities is also supported by Rose and Joskow (1990), Karshenas and Stoneman (1993) and Gotz (1999). With or without regulation, industry practice shows larger firms are more likely to introduce competence enhancing technological changes.

On top of their industry and firm-level time series analysis, Arimura and his associates (2005) also examine stakeholders' response towards environmental regulation. They particularly focus on four policy instruments: technology standard, performance standard, energy tax, and pollution tax. The survey shows stakeholders from large firms prefer performance standard to technology standard, while most stakeholders are against the economic-incentive instrument—tax. Arimura and his associates (2005) have also studied the R&D investments of 75 Japanese automobile firms over 1989 to 2002. Since different vehicles are subject to different emission standards, the authors directly link regulatory stringency to a firm's automobile production inventory. The results show a significant effect of regulation on firms' environmental R&D investments; that is, firms under stringent environmental regulation tend to invest more on relevant R&D activities (Arimura et al, 2005).

While it is true that environmental regulation encourages relevant R&D efforts, such an impact may be less crucial in broadcasting industry where the regulator has the ability to close down the business by denying license renewal. In the DTV transition, on top of accelerating the DTV standard adoption, the presence of regulation may encourage stations to experiment with creative usages of digitalized channels.

3.5 Conclusions

While all three forces—technology, economics, and regulation—have the power to shape the development of the broadcast television industry; the regulatory factor has become the key element in the U.S. digital television deployment. The Federal Communications Commission was deeply involved in the standardization process before the ATSC DTV standard was born. After the digital terrestrial television standard was set, the FCC continued to enforce the DTV transition time table over last ten years. The U.S. digital television evolution is indeed a government mandated standard transition.

As discussed earlier in this chapter, firm behavior and market performance in regulated industries has gathered research interest from a variety of scholars. Similarly, firm's technology adoption decision in the presence of regulation has also been repeatedly studied in environmental economics. Many scholars (Rose and Joskow, 1990; Karshenas and Stoneman, 1993; and Gotz, 1999) have suggested that firm size has a positive impact on technology adoption. The findings by Kerr and Newell (2001) indicate that affiliation with larger business groupings may reduce the likelihood of technology adoption. Jaffe and his associates (2002) suggest that market-based instruments have better outcome with regard to technology adoption than command-and-control policies. The findings by Gray and Shadbegian (1998) imply that stringent standards may have negative impact on technology adoption. Some factors may not be crucial to the DTV transition. For example, Arimura and his associates (2005) suggest that regulation encourages firm's R&D efforts; such impact is just indirectly associated with stations' adoption of the DTV standard.

In addition to the theoretical framework, the studies discussed above also provide excellent methodological guidelines for my research on the U.S. digital television transition. Many scholars (Rose and Joskow, 1990; Karshenas and Stoneman, 1993; Kerr and Newell, 2001; and Snyder et al, 2003) have employed survival analysis approach to examine technology diffusion processes. The latter two studies are very helpful for my research on the DTV transition because: first, both studies examine technology adoption in the presence of regulation; second, a number of survival models are employed and compared in both studies. Snyder and her associates (2003) employ three versions of parametric survival models—exponential regression, Weibull regression, and Gompertz regression—to fit their data; while Kerr and Newell (2001) also use Cox model in addition to the aforementioned three survival models. Both studies show that all those models have shown consistent results with regard to technology adoption rate. In the next chapter, survival analysis and its associated different models will be discussed in details.

The current DTV transition is a perfect illustration of the interactions between economics, technology, and regulation; as the history of the television industry vividly displays shakeout and residue caused by the three forces. Guided by the three-force framework, this study focuses on how broadcast stations are coping with the powerful technological change. The goal is to identify the firm-specific and market-specific factors that induce firms to adopt digital technology. In the meanwhile, the digital television transition is viewed as an example of a government mandated standards transition process. The ultimate question is what policy lessons we can learn from the digital transition process.

Chapter 4

Methodology: Survival models and logistic models

Based on the literature reviews in previous chapters, it is believed that firm size, business grouping, and firm age are the key firm-specific factors that would affect the DTV standard adoption pattern. With regard to the impact of firm size, scholars like Rose and Joskow (1990) believe it increases the tendency to adopt the new technology. Yet, Tushman and Anderson (1986) argue that the impact of firm size depends on the nature of technological change. The impact on openness to innovation can be negative if it is a competence-destroying innovation. In terms of business grouping, Kerr and Newell (2001) indicate that affiliation with larger business groupings may reduce the likelihood of technology adoption. In contrast, Armour and Teece (1980) suggest that vertical integration would increase the tendency to innovate. With respect to firm age, Chandy and Tellis (2000) suggest that old and established firm may not be reluctant to innovate, while incumbency is found to have negative impact on innovative activities in history. On the one hand, older firms are equipped with older technology, which may imply greater expenditures to adopt new technology. On the other hand, older firms can be the more established ones; they may have more name recognition and are more likely to be the market leaders. Thus, they may also be the first movers of new technology. Referring to these competing theories, the hypotheses of this dissertation with regard to DTV adoption times are as follows.

H1. Firm size will foster swift DTV adoptions.

H2. Affiliation with large grouping will have a positive impact on DTV adoption times.

H3. Firm age will foster swift DTV adoptions.

As discussed in chapter 3, digital television may be regarded as a competence-enhancing technological change. Based on the fact that the DTV transition can be very expensive for individual stations, the first hypothesis is that firm size will speed up the pace of transition. Since large grouping is associated with great financial resources, affiliation with large grouping means accessibility to those resources when a station is deciding to adopt DTV. Thus, such affiliation is expected to have a positive impact on DTV adoption times. Thirdly, older firms are usually the more established firms; they are more likely to be the leaders in the DTV transition. While those three hypotheses focus on the timing of DTV adoption, the following three hypotheses concentrates on stations' decisions on DTV standard choices.

H4. Firm size will increase the tendency to adopt HDTV.

H5. Affiliation with large grouping will have a positive impact on HDTV adoption.

H6. Firm age will have a positive impact on SDTV adoption.

According to GAO's report (2002a), the cost of converting the standard definition programming to high definition is about $8,000 to $10,000 for a one-hour show (p. 30). It is noted that these costs are not insignificant, given the small market share for HD. "In addition, the cost and complexity of providing live programming, such as sporting events, in HD can be substantial because of the need for separate cameras and production facilities" (GAOa, 2002, p. 30). Since the HDTV format is more expensive, it is expected that large firms are likely to adopt HDTV. Moreover, the SDTV format—by introducing multiple broadcast feeds—would tend to dilute the brand image of what was formerly a single channel. Market leaders with an established brand presence, would therefore be more reluctant to adopt SDTV, whereas less prominent stations with less to lose, would be more willing to experiment with SDTV.

Meanwhile, because the DTV transition is costly, the interdependence between firms is expected to increase the tendency of HDTV adoption: horizontally integrated (e.g. group owned) or vertically integrated (e.g. owned and operated) stations may be expected to have greater financial resources at their command, and would thus be in a better position to transition their systems than individually owned stations. Since older stations tend to be well established stations and market leaders, they are not expected to delay the transition. Due to the difference between the analog NTSC standard, the HDTV and the SDTV formats—visually, the HDTV format has a greater improvement from the analogy NTSC standard while the SDTV format is only slightly better than the NTSC standard—older stations may be more comfortable with the SDTV format; but younger stations may be more attracted by the HDTV format. In other words, it may be easier for older stations to adjust to the SDTV format than to the HDTV format; while such an effort is not that serious for those younger stations which have already decided to switch to digital.

4.1 Survival models in previous studies

As discussed in chapter 3, many scholars have employed survival models to study the problem of firm adoption of technology. While examining firm's adoption of electric generating technology, Rose and Joskow (1990) employed two survival models—Weibull proportional hazard model and log-logistic accelerated failure time model—and one Tobit model. The findings from the three models turned out to be consistent in this study. Karshenas and Stoneman (1993) employed two proportional hazard (PH) survival models to study the diffusion of computer numerically controlled technology. Both exponential and Weibull models indicated that large firms are more likely to adopt the technology. To examine the diffusion pattern of the membrane technology, Snyder and her associates (2003) employed three PH survival models to the data. While recognizing no significant difference between the three models—exponential, Weibull and Gompertz, the authors find regulation did not have a positive impact on firm adoption of technology. Kerr and Newell (2001) examine policy’s impact on petroleum refineries’ adoption of isomerization technology. Four survival models were employed in their analysis: Cox, Weibull, Gompertz, and gamma. The former three are PH models while gamma is an accelerated failure time (AFT) model. Consistent results are generated from the four models, which indicate firm size has a positive impact on isomerization adoption. Popp (2006) employs exponential PH survival model to examine the diffusion pattern of combustion modification techniques. His findings suggest environmental regulation has a positive impact on technology adoption.

All these studies have suggested that survival models are the right approach to analyze the pattern of firm adoption of technology. It is also worth to note that more than one survival models have been employed in any typical study discussed above. On the one hand, it seems redundant for some scholars (Karshenas and Stoneman, 1993; Snyder et al, 2003) to use two or three PH parametric models at the same time, since those models are not significantly different from one another. However, other scholars (Rose and Joskow, 1990; Kerr and Newell, 2001) intend to include both PH and AFT survival models in their analysis. It is meaningful because the two types of models have different features and may produce more interesting findings with regard to technology diffusion patterns. Overall, the empirical practice by the previous scholars provides excellent guide for this study on station adoption of the DTV technology.

There are two research questions in this dissertation: first, the timing of the DTV transition; and second, the DTV standard choice. With regard to the first research question, a variety of survival models can be applied. But for the second research question, competing risks model—an advanced survival analysis approach can solve the problem. Besides, multinomial logistic model can be the alternative approach. All these methods will be discussed in detail in the rest of the chapter.

4.2 Basic concepts for survival analysis

The essence of survival analysis is to analyze time—the time to the occurrence of an event. Therefore, survival data must have a scale for measuring time; it could be days, months, or years. Second, the data have to record the time of the event. Meanwhile, a starting point of time is required to specify the time duration before the occurrence of the event. In the DTV transition, a key issue is the time of the DTV standard adoption by broadcast stations. The critical event is when a station switched to digital—this transition date is available from the database consulted for this study. The starting point is set at December 24, 1996 when the FCC adopted the ATSC DTV standard. Thus, the DTV transition data serves as an ideal example of survival data; and survival analysis methods are chosen to be applied to the data

Survival analysis is also called event history analysis; the occurrence of an event is also referred to as failure. Despite the everyday connotations of this term, failure in event history analysis means transition from one dichotomous condition to another, with the variable value remaining in the original state for all prior periods up to the instance of failure and in the 'failed' or transitioned state for all subsequent time periods. So, if a station remains in analog broadcasting up until t = T, and then switches to digital broadcasting for all subsequent t > T, then we can model the experience as a survival model with failure equivalent to the adoption of digital broadcasting.

Box-Steffensmeier and Jones (1997) have identified three key concepts of survival analysis: the survival function, the occurrence of an event, and the hazard rate. First, the occurrence of an event refers to the probability of an event occurring within some short time period.

$$f(t) = \lim_{\Delta t \to 0} \frac{\Pr(t \leq T < t + \Delta t)}{\Delta t}$$

where T denotes the time to event.

Note $f(t)$ is a probability density function and can be interpreted as "the instantaneous probability of the occurrence of an event at time t" (Box-Steffensmeier and Jones, 1997, p. 1418).

The second key concept is the survival function, which is derived from the cumulative distribution function with regard to the probability of an event to occur.

$$S(t) = 1 - F(t) = \Pr(T > t)$$

$$F(t) = \int_0^t f(u)du$$

The survival function reports the probability of surviving beyond time t. In other words, the function represents the probability that the original state is unchanged prior to t. The survival function is equal to one at t = 0, and decreases toward zero as time passes. The survival function is a monotonically non-increasing function of time (Box-Steffensmeier and Jones, 1997).

The third key concept is the hazard function. It reports the rate of failure, or transition from one state to another, where rate represents the probability within a short period of time. Thus, the hazard rate has unit 1/*t*.

$$h(t) = \lim_{\Delta t \to 0} \frac{\Pr(t \le T < t + \Delta t \mid T > t)}{\Delta t} = \frac{f(t)}{S(t)}$$

The hazard rate is always non-negative. Over time, the hazard rate can increase, decrease, or remain constant. Instead of reporting the time duration prior to an event, the hazard function produces detailed information on the risk that an event occurs at any given time.

Putting these three concepts together: h(t) is the proportion of ***surviving*** units that fail at each instance, whereas f(t) is the proportion of ***all*** units that fail at each instance, S(t) is the proportion of all units that survive at a given instance, and F(t) is the proportion of all units that have failed up to and including that instance.

An additional concept associated with the hazard function is the cumulative/integrated hazard function is:

$$H(t) = \int_0^t h(u)du$$

The relationship between h(t) and H(t) is the same as that between f(t) and F(t). The cumulative hazard function measures the total amount of risk that has been accumulated up to time t. It is worth to note the following equation

$$H(t) = \int_0^t \frac{f(u)}{S(u)} du = -\int_0^t \frac{1}{S(u)} \{\frac{d}{du} S(u)\} du = -\ln\{S(t)\}$$

The transformation above shows the relationship between the cumulative hazard function and the survival function. In fact, the functions discussed above are all related.

$$S(t) = \exp\{-H(t)\}$$

$$F(t) = 1 - \exp\{-H(t)\}$$

$$f(t) = h(t)\exp\{-H(t)\}$$

For example, consider the Weibull hazard function— $h(t) = pt^{p-1}$ —where p is a shape parameter estimated from the data. The specified survival, cumulative distribution, and probability density functions would be

$$H(t) = \int_0^t h(u)du = H(t) = \int_0^t pu^{p-1}du = t^p$$

$$S(t) = \exp(-t^p)$$

$$F(t) = 1 - \exp(-t^p)$$

$$f(t) = pt^{p-1}\exp(-t^p)$$

4.3 Nonparametric and parametric survival analysis

Parametric methods are built upon certain assumptions about the underlying distributions, for example normality or equal variance. Based on those assumptions, parametric methods calculate the values of the parameters on which the relationships between variables are based. That is why parametric survival analysis is commonly used in social science and political science because of its ability to specify the impacts of covariates[4] on failure time.

The ordinary least squares method is a well-known parametric method, which is commonly used to estimate the causal relationship between independent and dependent variables. When applying the OLS method to survival data, however, there is a critical problem

---

[4] In survival analysis, "covariate" has a more specific meaning as the independent variables that can affect the time to the event.

about the assumed distribution of the residuals ε_j. In linear regression, the residuals are assumed to be distributed normally, which is to say, time conditional on x_j is assumed to follow a normal distribution:

$$time_j \sim \mathrm{N}\,(\beta_0 + \beta_1 x_j, \sigma^2), \qquad j = 1,\ldots,n$$

But the OLS assumed normal distribution of time is not reasonable for many events (Cleves et al, 2002). An obvious issue is that the distributions for time to an event can be far from the normal for they are very likely to be non-symmetric. In other words, though there may be a few cases possessing normal distributions of time, the normal distribution assumption cannot work in general cases. While the OLS fails to work without the normal distribution assumption, a number of techniques have been introduced in survival analysis to provide an appropriate solution for the time distribution issue. For example, some survival analyses employ Weibull distributional assumption of residuals, which turns to be more reasonable than the normal distribution.[5]

A parametric survival analysis uses probabilities to depict what occurs over a time interval $(t_{0j}, t_j]$, given what is known about the subject during this time (x_j). While the OLS method could model the time as

---

[5] The normal distribution is one type of continuous probability distribution. It has two parameters: mean and standard deviation. The curve of normal distribution is a bell-shaped curve symmetrical about the mean. Weibull distribution is another type of continuous probability distribution. Generally, Weibull distribution has three—location, shape and scale—parameters. The shape parameter enables Weibull distribution to be a versatile distribution that can take on the characteristics of other types of distributions. Under certain value of the shape parameter, Weibull distribution can approximate normal distribution.

In survival analysis, the two-parameter (shape and scale) Weibull distribution is employed. The scale parameter will capture the effects of covariates; while the shape parameter will enable the distribution to resemble the survival data. In contrast, normal distribution's bell-shaped curve cannot be changed by the two parameters of the distribution. Thus, normal distribution is too restrained to fit the survival data.

$$t_j = x_j\beta_x + \varepsilon_j \qquad \varepsilon_j \sim N(0,\sigma^2);$$

A common practice in survival analysis is to parameterize the time as:

$$\ln(t_j) = x_j\beta_x + \varepsilon_j$$

Another way is to parameterize the hazard as

$$h_j(t \mid x_j) = h_0(t)\exp(x_j\beta_x) \quad h_0(t) > 0$$

Details about the two approaches will be discussed in the next section.

To obtain the specified estimation, parametric methods may require rigorous assumptions. However, there is no guarantee that the outcome will perfectly match the real data. Compared to parametric methods, nonparametric methods have no assumptions about distribution. The nonparametric models are absolutely determined from the data. Therefore, nonparametric models always have a better fit to the data than parametric methods.

The Kaplan-Meier estimation is a good example of nonparametric survival models. Similar to other nonparametric methods, the Kaplan-Meier estimation makes assumptions about neither (i) the distribution of the failure times nor (ii) how covariates serve to change or shift the survival experience (Cleves et al, 2002).

Suppose there is a dataset with observed failure times $t_1 \ldots t_k$, the Kaplan-Meier estimate of survival function at any time t_j is given by

$$\hat{S}(t) = \prod_{t_j \le t} \frac{r(t_j) - d(t_j)}{r(t_j)}$$

where $r(t_j)$ is the number of individuals at risk at time t_j and $d(t_j)$ is the number of transitions at time t_j.

In this approach, the value of the survival function between successive distinct observations is taken as constant. In the Kaplan-Meier graph the (survival) curve shows, for each time plotted on the X axis, the proportion of all individuals surviving as of that time. One useful option offered by any nonparametric method is the stratified test. That is, the analysis is able to test equality of survival functions for different subgroups and to combine the results into a single, overall statistic (Cleves et al, 2002).

While the straightforward graphic output and the absence of restrictions on survival patterns are the advantages of the Kaplan-Meier estimator, it is impossible for any nonparametric approach to estimate the effects of independent variables on survival patterns. It is parametric models that proceed with specific evaluations to interpret survival patterns. The key difference between nonparametric and parametric approaches is whether the survival analysis involves an assumption about the distribution of failure times.

Many scholars (Cleves et al, 2002; Hougaard, 2000) regard nonparametric analysis as a useful starting point. With the presence of covariates, the nonparametric approach is usually employed as a data description technique. There are three major differences between parametric and nonparametric models with regard to the estimation. First, the results of parametric models are always numbers, while the results from nonparametric approaches are either tables or figures. Thus, precise estimations can be provided by parametric models while it is almost impossible for nonparametric approaches to generate precise estimation at a random point. Second, parametric models can provide estimation on hazard rate or time duration for any individual, but nonparametric approaches can only offer general trend for the whole sample rather than any individual. Consequently, the detailed estimation provided by parametric models allows interpretation and inference, while nonparametric approaches do not have those features. And third, since parametric models are all based on assumptions about distribution of failure times, their estimation is inherently determined and restricted by those assumed distributions. Thus, there is always the risk in parametric models of failing to identify the right distribution, which may lead to a poor fit for the data. In contrast, estimation in nonparametric approaches comes directly from the data; the process involves no assumption about distribution of failure times. Thus, the estimation automatically fits well with the data.

It is clear that the real advantage of the nonparametric models is the fit; they can handle any kind of distribution. In contrast, parametric models take account of covariates by assuming a distribution pattern for failure times. While there is risk that the distribution and the data do not match, parametric models have the potential to use the data more efficiently. Due to the need to generate precise estimates and predict hazard rate or time duration at station level with regard to the DTV transition, parametric models are favored over nonparametric approaches in this study.

4.4 The proportional hazard and accelerated failure time survival models

Before discussing any parametric models, I want to firstly discuss a semi-parametric model—the Cox proportional hazard model. The model asserts that the hazard function is

$$h(t \mid x_j) = h_0(t)\exp(x_j \beta_x)$$

where $h_0(t)$ is the baseline hazard. The outstanding feature of the Cox model is that it has no particular parameterization of the baseline hazard. In other words, rather than making assumptions about the shape of the hazard over time, the Cox model assumes the hazard function is the same for every subject no matter what the real shape of the hazard is. That is, the ratio of two subjects' hazard rates is constant, c.

$$\frac{h(t \mid x_j)}{h(t \mid x_m)} = \frac{\exp(x_j\beta_x)}{\exp(x_m\beta_x)} = c$$

Since the Cox model has no assumption about the baseline hazard, there is no estimation on the intercept β_0. This is why the Cox model is not considered as a full parametric model (rather, it is called semi-parametric). In fact, the absence of the estimation of β_0 is the only difference between the Cox model and any proportional hazard parametric models. The Cox model can be viewed as a simplified version of the latter. Besides, without specifying the baseline hazard, the Cox model avoids the misleading coefficients results caused by incorrect distribution assumptions.

While the Cox model is a simple and popular approach, it also has certain disadvantages. Although some interpretations can be provided by the Cox model based on its estimation of the β s, the overall survival function is incomplete without β_0. Thus, the survival pattern cannot be fully understood due to the missing baseline hazard assumption. In contrast, the parametric models discussed below are able to provide complete information on the survival function.

As mentioned in the previous section, there are two approaches of parametric survival analysis: one is to parameterize the hazard rate, the other is to parameterize the time itself. Corresponding to the two approaches, there are two groups of parametric survival models. The first is proportional hazard model which employs the equation $h_j(t; x_j) = h_0(t)\exp(x_j\beta_x)$; the second is accelerated failure time model which employs the equation $\ln(t_j) = x_j\beta_x + \varepsilon_j$.

In a proportional hazard (PH) model where hazard rate is modeled,

$h_j(t \mid x_j) = h_0(t)\exp(x_j\beta_x)$ can also be written as

$\ln[h_j(t \mid x_j)] = x_j\beta_x + \ln h_0(t)$

First, $h_0(t)$ is called the baseline hazard; it is the same to every individual in the population. The baseline hazard rate only depends on t, not on covariates. It summarizes the pattern of duration dependence.

Second, $\exp(x_j \beta_x)$ affects the individual specific hazard rate. Equation $\ln[h_j(t \mid x_j)] = x_j \beta_x + \ln h_0(t)$ indicates that individual hazard rate differs proportionally based on observed covariates.

The hazard rate is proportional in that the hazard a subject j faces is proportional to the baseline hazard. The exponential function is chosen simply to guarantee the hazard is always nonnegative (Cleves et al, 2002). The proportional hazard approach simplifies survival analysis in two steps: (i) it employs a functional form for $h_0(t)$; and (ii) it incorporates covariates into the exp() part to parameterize the shift caused by the variations of covariates.

A key assumption of the proportional hazard model is that the explanatory variables do not affect the baseline hazard. If there is an interaction between time and one or more covariates, however, the assumption that the hazards are proportional would no longer hold. Such an assumption necessitates alternative approaches; the accelerated failure time (AFT) model can be a solution. The AFT model enables explanatory variables to act via a scale factor directly on failure times. As mentioned before, time itself is modeled in the AFT models

$$\ln(t_j) = x_j \beta_x + \varepsilon_j$$

where ε_j is a random disturbance term. The log transformation of time here is to ensure that predicted values of time are positive.

While the PH model assumes a distribution for the baseline hazard, the AFT model assumes a distribution for τ_j, where $\tau_j = \exp(\varepsilon_j) = t_i \exp(-x_j \beta_x)$. $\exp(-x_i \beta_x)$ is called the acceleration parameter. The covariates act to expand or contract time through the acceleration parameter. If $\exp(-x_j \beta_x) > 1$, then the model has accelerated failure time with an increase in covariates. If $\exp(x_j \beta_x) < 1$, then the model has decelerated failure time as the covariates increase. Since τ_j is defined equal to $\exp(\varepsilon_j)$, the AFT model can also be written as

$$\ln(t_j) = x_j \beta_x + \ln(\tau_j)$$

The difference between the PH and the AFT models is based on how each method characterizes the cumulative hazards rate. Suppose there are two groups. The PH model says that $H_2(t) = cH_1(t)$ for some c, whereas the AFT model says that $H_2(t) = H_1(t/c)$ for some c. So the question is whether the integrated hazards are proportional on the time scale or the hazard scale. The AFT approach leads to a decreased mean, with a constant relative variability and thus decreased absolute variability. The PH approach also leads to a decreased mean, but with a constant variability (Hougaard, 2000).

Note that the PH model parameterizes the hazard rate while the AFT model parameterizes failure time. The difference is reflected in the statistical results of the two types of models. In a PH model, a positive coefficient implies that the hazard rate increases due to changes in the covariates. In an AFT model, a positive coefficient indicates that the failure time (duration before failure) increases with the covariates.

4.5 Distribution assumptions in survival analysis

While the PH model requires a certain distribution for the baseline hazard; the AFT model requires a distribution picked for time to failure, $\tau_j = t_i \exp(-x_j \beta_x)$. Needless to say, this distribution assumption is the key to parametric survival analysis. Weibull and log-logistic are the two commonly used distributions in survival analysis.

When a PH model employs the Weibull distribution, it assumes the baseline hazard is $h_0(t) = pt^{t-1}\exp(\beta_0)$, where

(i) p is some ancillary shape parameter estimated from the data,

(ii) the scale parameter is parameterized as exp(β_0),

(iii) β_0 is the intercept coefficient.

Thus,

$$h(t \mid x_j) = h_0(t)\exp(x_j\beta_x) = pt^{p-1}\exp(\beta_0 + x_j\beta_x)$$

$$S(t \mid x_j) = \exp\{-\exp(\beta_0 + x_j\beta_x)\cdot t^p\}$$

When the Weibull distribution is assumed, the baseline hazard can be either monotone increasing or monotone decreasing. The exact shape of the hazard is determined by the parameter p. When p = 1, the hazard is constant. If p < 1, the hazard is monotonically decreasing; if p > 1, the hazard is monotonically increasing.

Compared to the Weibull distribution for the PH models, the log-logistic distribution intrinsically suits the AFT framework. Whereas the Weibull distribution implies a monotonic increase or decrease of hazard rate, log-logistic distribution allows for non-monotonic hazard rate. When survival analysis employs log-logistic distribution, it is assumed that τ_j is distributed as log-logistic with parameters (β_0, γ). In other words, $\ln(\tau_i)$ follows a logistic distribution with parameters (β_0, γ).

The cumulative distribution function is

$$F(\tau_j) = 1 - \left[1 + \{\tau_j \exp(-\beta_0)\}^{\frac{1}{\gamma}} \right]^{-1}$$

Based on $\tau_j = t_i \exp(-x_j \beta_x)$, the cumulative distribution function can be written as

$$F(t_j \mid x_j) = 1 - \left[1 + \{t_j \exp(-\beta_0 - x_j \beta_x)\}^{\frac{1}{\gamma}} \right]^{-1}$$

Thus, the survival function with the log-logistic distribution is

$$S(t_j \mid x_j) = \left[1 + \{t_j \exp(-\beta_0 - x_j \beta_x)\}^{\frac{1}{\gamma}} \right]^{-1}$$

where γ is the shape parameter. If $\gamma < 1$, it indicates that the hazard increases at first and then decreases. If $\gamma \geq 1$, the hazard is monotonically decreasing. In this dissertation, alternative models will be developed using both the Weibull and log-logistic distribution assumptions.

So far, a variety of statistical methods have been discussed. Table 4.1 summarizes the differences between those methods and highlights the merits of parametric survival models. Except for the OLS method, all the survival models will be employed in my analysis. The nonparametric method is useful to directly capture the trend and general survival patterns embedded in the DTV transition data. The associated Kaplan-Meier estimation will describe the data exactly and provide useful information for the detailed parametric models. The Cox model can be viewed as a simplified proportional hazard model. The estimation by the Cox model shows the effect size and direction of the covariates, which should be referred to in full parametric models. Yet, without specifying the baseline hazard, the complete understanding of the survival function cannot be achieved through the Cox model.

Table **4.1**

Table **4.1**: Statistical methods and models comparison

Method	Model	Comment
OLS	$T = x_j \beta_x + \varepsilon$	Normal distribution assumed, may not be fulfilled in survival data
Nonparametric	Kaplan-Meier estimator	Simply counting individuals with different status, no estimation at the individual level
Semi-parametric	Cox model	Assuming the hazard ratio for two subjects is constant over time, no estimation on the baseline hazard
Parametric	PH model—Weibull distribution	Weibull distribution is assumed for the baseline hazard. The baseline hazard is not affected by the covariates with monotonic variation.
Parametric	AFT model—log-logistic distribution	Log-logistic distribution is assumed for the time to event. The hazard rate is affected by the covariates with non-monotonic variation.

The parametric models serve as the core for my analysis. A proportional hazard parametric model assumes that the baseline hazard is not affected by the covariates. When Weibull distribution is assumed for the PH model, it means the baseline hazard follows the Weibull distribution and varies monotonically along the time. When it is suspected that the covariates interact with failure times, the accelerated failure time model should be employed. An AFT model with log-logistic distribution means $\tau_j -- \tau_j = t_i \exp(-x_j \beta_x)$ —follows the log-logistic distribution. Compared to the proportional hazard Weibull model, the AFT log-logistic model allows the interaction between covariates and time. Moreover, while the Weibull distribution constrains the hazard rate to either increase monotonically or decrease monotonically; the log-

logistic distribution allows the hazard rate to increase at first and then decrease (if the shape parameter is smaller than 1).

From nonparametric model to the AFT model, each of the four models adds more specifications to a general survival analysis. To the basic Kaplan-Meier estimation, the Cox model adds an estimation of the effects of the covariates. To the Cox model, the PH Weibull model adds a full survival function, with both intercept and covariates. To the PH model that does not permit an interaction between covariates and time, the AFT model, adds that interaction. As indicated by Table 4.1, each of these methods adds some special value to the analysis. The four models are sequentially employed to analyze the DTV transition data.

4.6 Competing risks model

One issue is taken for granted in the previous discussions: that is, only two states are concerned in survival analysis—survival or failure. This is obviously a simplified version of real world cases. What if there are more than two states to be incorporated into survival analysis. What if the destination is not simply failure, but can be multiple options? In this dissertation, we are interested in modeling alternative choices of standards by stations. That is, due to the flexibility in the digital TV standard, stations have the choice of adopting one of several digital TV standards when they make the switch to digital broadcasting. The competing risks model is one approach to handling multiple-destination survival problems.

Assume there are r, k = 1, 2 …r possible destinations that is possible for a subject to experience. A destination-specific hazard rate is modeled as

$$h_k(t \mid x) = \lim_{\Delta t \to 0} \frac{\Pr(t \le T < t + \Delta t \mid T > t, x)}{\Delta t}$$

Note that the hazard function is not conditioned on the state occupied (or destination experienced) prior to the occurrence of the *k*th event. Thus, each event type of destination has its own hazard function. It can be shown that the overall hazard function h(t), which is the hazard for the occurrence of any of the r events, is just the sum of all the destination-specific hazard functions.

For each of these destination-specific hazard functions, one can develop a model for dependence on time and on the explanatory variables. These models may be very much alike, or they can be completely different for each kind of event.

Formally the competing risk model can be specified in terms of a latent variable approach. Let T_k be a (latent) random variable corresponding to the duration until termination due to risk *k (k* = 1...r). Note that of these latent random variables only the smallest can be observed, that is $T_k = \min\{T_1,...T_r\}$ (Diermeier and Stevenson, 1999). In other words, we are only able to observe the earliest transition to one of the possible destinations, since the other transitions are not realized.

In a simple scenario, there are two possible destinations for exit. $h_A(t)$ and $h_B(t)$ are the latent hazard rates of exit to destination A and B respectively; $h(t)$ is the hazard rate for exit to any destination. The key assumption for competing risks model is that the multiple destinations (A and B) are conditionally independent. Thus,

$$h(t) = h_A(t) + h_B(t)$$

The survival function of the competing risks model is

$$S(t) = S_A(t) \cdot S_B(t)$$

The overall likelihood value is the product of each destination-specific likelihood value.

$$\ln L = \{I_A \ln h_A(t) + \ln S_A(t)\} + \{I_B \ln h_B(t) + \ln S_B(t)\}$$

where I_A and I_B are destination indicators: $I_A = 1$ if state A occurs; $I_B = 1$ if state B occurs. The log-likelihood function can also be written as

$$\ln L = I_A \ln h_A(t) + I_B \ln h_B(t) + \ln S_A(t) + \ln S_B(t)$$

when $I_A = 1$, $\ln L = \ln h_A(t) + \ln S_A(t) + \ln S_B(t)$;

when $I_B = 1$, $\ln L = \ln h_B(t) + \ln S_A(t) + \ln S_B(t)$.

By treating multiple destinations as conditional independent, the competing risks model allows more detailed illumination of destination-specific features with regard to failure times. While this approach adds some variations to the general survival analysis; there is a totally alternative method to handle multiple-state problems where survival analysis is no more involved. That is multinomial logistic regression.

4.6.1 Logistic regression

A multinomial logistic (MNL) model is essentially a series of linked binomial logistic models. If there are r possible destinations/states, the MNL model estimates r-1 binomial logistic models to obtain the estimates on the state-specific probability.

Binomial logistic regression is a form of regression which is used when the dependent variable is dichotomous and the independents are of any type. Logistic regression applies maximum likelihood estimation after transforming the dependent into a *logit* variable (the natural log of the odds of the dependent variable occurring or not). In this way, logistic regression estimates the probability of a certain event occurring. While logistic regression is similar to OLS regression, it in general has less stringent requirements than the latter.

The logistic model takes the form

$$\text{logit}(p_i) = \ln\left(\frac{p_i}{1-p_i}\right) = \beta_0 + x_i\beta_x$$

or equivalently

$$p_i = \frac{\exp(\beta_0 + x_i\beta_x)}{1+\exp(\beta_0 + x_i\beta_x)}$$

Multinomial logistic regression exists to handle the case of dependents with more classes than two. When multiple classes of the dependent variable can be ranked, then ordinal logistic regression is preferred to multinomial logistic regression. The ordinal logistic model can simultaneously estimate multiple equations. If there are r categories in the dependent variable, the number of equations estimated by the ordinal logistic model will be r-1. Ordinal logistic regression provides only one set of coefficients for each independent variable. Thus, there is an assumption of parallel regression. That is, the estimates across the equations would not vary significantly if they were estimated separately. The intercepts would be different, but the slopes would be essentially the same.

The ordinal logistic model depends upon the idea of the cumulative logit. This in turn relies on the idea of the cumulative probability. The cumulative probability is defined as the probability that the *i*th individual is in the *j*th or higher category.

$$C_{ij} = \Pr(y_i \leq j) = \sum_{k=1}^{j} \Pr(y_i = k)$$

Turning C_{ij} into the cumulative logit:

$$\log it(C_{ij}) = \log\left(\frac{C_{ij}}{1-C_{ij}}\right)$$

The ordinal logit regression simply models the cumulative logit as a linear function of independent variables:

$$\text{logit}(C_{ij}) = \alpha_j - \beta \cdot x_i$$

Note that there is a different intercept for each level of the cumulative logit, but β does not vary by the level of the cumulative logit. Also note that β is subtracted rather than added. This means (i) each α_j indicates the logit of the odds of being equal to or less than category j for the baseline group (when all independent variables are zero). Thus, these intercepts (sometimes referred to as cut-points) will increase over j. (ii) The β shows how a one-unit increase in the independent variable increases the log-odds of being higher than category j (due to the negative sign). Note the β is not indexed by j because of the proportional odds assumption that a unit increase affects the log-odds the same regardless of which cut-point we are considering.

In summary, logistic regression is the appropriate approach for analyses that involve categorical dependent variables. The (binomial) logistic model is preferred with binary dependent variables. The multinomial logistic model is the solution for data with categorical dependent variable when there are more than two categories. The ordinal logistic model is a special case of multinomial logistic models. It is the proper solution when the categories in the dependent variable can be ranked.

4.6.2 Model fit

Maximum likelihood estimation (MLE) is the method used to calculate the logistic coefficients. MLE seeks to maximize the log likelihood which reflects how likely it is (the odds) that the observed values of the dependent may be predicted from the observed values of the independents. The likelihood varies from 0 to 1. The log likelihood (LL) is its log and varies from 0 to minus infinity. Log likelihood is the basis for tests of a logistic model.

Parameter estimates for survival models are also obtained by maximum likelihood. The basic idea here is that given a set of observations ($t_1, t_2 \ldots t_n$), the best estimate of β is the one that maximizes the probability, or likelihood, of observing those particular data.

$$L(\beta \mid t_1, t_2, \ldots) = f(t_1 \mid \beta, x_1) * f(t_2 \mid \beta, x_2) \ldots$$

Among nested models, Akaike (1974) proposed penalizing each model's log-likelihood to reflect the number of parameters being estimated and then comparing them. Although the best-fitting model is the one with the largest log-likelihood, the preferred model is the one with the lowest value of the Akaike's Information Criterion (AIC). For parametric survival models, the AIC is defined as

$$AIC = -2 \ln L + 2(k + c),$$

where k is the number of model covariates; c the number of model-specific distributional parameters. For both Weibull and log-logistic distributions, c = 2.

4.7 Summary

As discussed in the beginning of this chapter, the timing of the DTV transition and the DTV standard choice are the two principal issues to be examined in this dissertation. A number of previous studies have suggested that survival models are preferred to solve problems involving firm decision on technology adoption. Thus, the methods provided by survival analysis seem to match well with my research questions. Moreover, the DTV transition data itself determine that survival analysis is the appropriate method, because the key information recorded in the data is the time when the DTV adoption happens. There is a starting point when the FCC adopted the standard; there is the date when a station adopts the standard; thus, the time to transition can be calculated from those dates. These three pieces of information make the DTV transition data a perfect example of survival data.

While normal distribution can hardly fit any distribution associated with time, survival analysis employs versatile distributions like Weibull and log-logistic to match the distribution of time to event. While parametric methods have been preferred by many scholars, nonparametric methods of survival analysis are also widely used. Kaplan-Meier estimation is one example of nonparametric survival models. Like other nonparametric methods, Kaplan-Meier estimation is determined from the data; thus, the model fits perfectly with the data. However, the drawback of Kaplan-Meier estimation is that the estimation is not at the individual level, but rather shows the pattern of the whole data. It is parametric methods that can provide precise estimations.

The Cox model is a famous survival model. It provides precise estimation of covariates' effects on time to event. But the Cox model is not a parametric model because it does not specify the baseline hazard. This feature enables the Cox model to work in the absence of any rigorous assumption on distribution; but it also hinders the full understanding of the survival model. The full parametric methods with their assumption on distributions enable the full survival model to be estimated and its interpretation possible.

Weibull distribution and log-logistic distribution are often used in parametric survival analyses. Whether non-monotonic variation is allowed for the hazard rate is the difference between the two distributions. Besides, while Weibull distribution is usually associated with the proportional hazard model, log-logistic distribution is tied to the accelerated failure time model.

The choice between PH and AFT models is determined by whether there is interaction between covariates and time to event. Each of these survival models has its specialty; all of them will be employed in the next chapter.

In the DTV transition, broadcast stations can choose between the HDTV and the SDTV formats. Thus, when a station has switched to digital, there are at least two destinations—HDTV or SDTV. With the possibility of two competing destinations A and B, the model's output changes from "time to event" to "time to event A" and "time to event B". Since stations that adopt the HDTV will not be able to adopt the SDTV and vice versa, the two events here are independent. Under this condition, the competing risks model is the right approach to analyze the transition pattern with two destinations. The model turns to be an advanced model based on general survival analysis. A simple alternative for competing risks model is the multinomial logistic model, as the analysis involves a categorical dependent variable—the DTV format choice. In the latter model, time is no long involved in the analysis. Only format choice is retained as the sole focus.

The next chapter will illustrate the analysis of the DTV transition data. The four survival models—Kaplan-Meier estimation, the Cox model, the Weibull-PH model and the log-logistic-AFT model—will be employed to examine the effects of firm size, business grouping, and firm age on the timing of the DTV transition. Next, the competing risks model and multinomial logistic model will be employed to estimate the effects of the aforementioned firm-specific factors on the DTV standard choice.

Chapter 5

DTV adoption decisions—Data analysis

5.1 Data description

To answer my research questions, data are mainly collected from sources such as Television & Cable Factbook, Investing in Television—Market Report, and the FCC Reports on DTV Applications. The sample includes all the commercial full power television stations (N = 1,313) in the United States. Information on stations' revenue, network affiliation status, ownership, channel assignment, age, circulation, coverage, digital signal on-air date, the DTV format, and the designated market areas (DMA) are assembled together from various sources.[6]

The focus of the study is stations' digital upgrading pattern, which includes two decisions made by individual stations: the digital signal on-air date and the standard choice.

Dependent variables I: The digital signal on-air date

The Television & Cable Factbook—provided by Warren Communications News, Inc—is the primary source for the date information with regard to the DTV adoption. The Factbook has tracked the digital signal on-air date for 610 commercial full power stations. Unfortunately, the rest of the sample—703 stations—are coded with missing values for the time of the DTV adoption.[7] Among the 610 stations, KOMO—an ABC affiliate located in Seattle, Washington—

---

[6] More data sources include Demographics USA-County Edition, DMA Market Rank and Demographic Rank Report, and SQAD's Media Market Guide-Local.

[7] Those 703 stations are missing in the dataset because the Television & Cable Factbook did not record the time when those stations adopted the DTV standard. Variable means are compared across the two groups—group 1 represents stations with the transition date while group 2 represents stations with missing transition date. Significant

is the first recorded station to broadcast a digital signal, on January 1, 1997 (only eight days after the digital television standard was set by the FCC).

According to the FCC document, the Commission adopted the ATSC DTV standard on December 24, 1996. This date becomes the starting point of my observation. In the data, a time variable is established to measure the number of days between the FCC's DTV standard announcement date and a station's DTV adoption date. In the following data analysis, the time variable rather than the date information will become the key variable to be explained by a series of survival models.

The FCC has labeled ABC, CBS, NBC and Fox as the top four networks across the country. As stated in the Commission's DTV transition timetable, (i) a top-four network affiliate in a top-10 market is required to adopt the DTV before May 1, 1999; (ii) top-four network affiliate in markets 11 through 30 are required to adopt the DTV before November 1, 1999; and (iii) all the remaining commercial full power stations have to switch to digital before May 1, 2002. Comparing the FCC deadlines and stations' DTV adoption dates, it was found that 287 out of 610 stations have switched to digital ahead of schedule or right on the date of deadline. For example, the station KHVO--an ABC affiliate located in Hilo, Hawaii—started digital broadcasting more than four and half years before it is supposed to as a commercial station

---

difference is found between the two groups with respect to firm size, business grouping and firm age. The revenue of an average station is group 1 is $19,651,566 higher than an average group 2 station ($t = 10.40$, $p < .001$). The average station age of group 1 is seven years older than that of group 2 ($t = 7.61$, $p < .001$). Stations in group 1 averagely belong to larger group owner compared to group 2 stations ($t = 13.34$, $p < .001$). The difference between the two groups of stations indicates that there is systematic bias in the data collection. The data is skewed toward rich stations that belong to large group owners. This is a limitation of the study, but unavoidable because the Television & Cable Factbook is the only comprehensive and publicly available database on television stations' digital transition.

located in a non-top 30 market. By contrast, the station WINK—a CBS affiliate from Fort Myers, Florida—delayed its digital adoption by four years after the FCC scheduled deadline.

Table **5.1**

Table **5.1**: DTV adoption times with regard to the FCC timetable

	ABC	CBS	NBC	Fox	Others	Total
On time	52	64	53	37	81	287
Delayed	51	45	54	35	138	323
Total	103	109	107	72	219	610

The top-four network affiliates have shown similar patterns with regard to prompt digital switch. About half of these affiliates adopted the DTV on time. Judged by the number of stations, the CBS affiliates have done a better job than affiliates of the other three networks. Overall, the top-four network affiliates are more likely to adopt the DTV on time than independent stations or stations affiliated with smaller networks. This pattern is connected to the FCC timetable, because the major network affiliates were under more pressure for the DTV transition than their independent counterparts. Another notable pattern is that many stations waited until the last minute to adopt the DTV. This is supported by the fact that 77 stations—more than twelve percent out of 610—switched to digital right on the scheduled deadline.

Dependent variable II: Standard choice

It can be argued that stations' timing decisions on digital adoption are predictable because they are subject to the FCC's mandatory timetable. But when it comes to picking which specific DTV format, stations do have a few choices. The ATSC DTV standard set by the FCC in 1996 is not a simple uniform standard, but allows for eighteen different video formats – the result of the compromise between broadcast television industry, motion picture industry and computer industry. Those formats vary on three main aspects: (i) the number of lines and pixels per each picture frame, (ii) frame rate, and (iii) scanning format.

One common categorization of these formats is based on the number of lines per frame. If there are 1080 or 720 active lines per frame, the format is labeled as HDTV (high definition television). If there are only 480 active lines per frame, the format is regarded as SDTV (standard definition television). Other than the differences in picture/video quality that exists between the two types of formats, broadcasters were more interested in the different modes of utilization of the radio spectrum between HDTV and SDTV formats. Within its assigned 6 MHz spectrum, a station can transmit one or two channels with HDTV formatted programs. In contrast, if a station adopts SDTV, it may be able to carry three to five channels within the same radio space. Besides, the facility investments for SDTV broadcasting are relatively lower than that for the HDTV format. Depending on their financial capabilities and targeted market, stations have sought to make a deliberate and well-considered choice in deciding which type of formats to adopt.

The Television & Cable Factbook is again the primary source for stations' choices on the DTV format. The Factbook records the format decisions for 390 commercial full power stations. Among these stations, 217 of them adopted SDTV format; 124 stations chose HDTV format; while 49 stations adopted a hybrid of HDTV and SDTV formats. It is notable that among the 124 HDTV adoptions, 105 of them—nearly 85 percent—are conducted by stations that are affiliated with top-four networks. When it comes to SDTV adoption, less than half of the adoptions are by top-four network affiliates. It seems that the major network affiliates have shown a preference of HDTV format to SDTV format.

Table **5.2**

Table 5.2: DTV format choices overview

	Top 4 network	Others	Total
SDTV	104	113	217
Hybrid	42	7	49
HDTV	105	19	124
Total	251	139	390

Control Variables

The first control variable is network affiliation status. Originally, there are two categories under affiliation status: network affiliates and independents. The U.S. commercial broadcast networks include ABC, NBC, CBS, Fox, CW, i, My Network TV, Univision and so on. Among them, ABC, NBC, CBS, and Fox are the top networks which have an affiliated station in almost every market throughout the country. According to the Television & Cable Factbook (2006), the top-4 network affiliates account for nearly 63 percent of all commercial full power stations in the States. The remaining stations are either independents or associated with other networks such as CW, i, My Network TV and Univision. Secondly, stations that are not affiliated with any network are the independent stations. If an independent station shows no special interest with regard to programming, it usually would rely on a basic counter programming philosophy to compete with the network affiliates.

Rather than incorporating the natural categorization, this study chooses to employ an indicator with regard to top-4 network affiliation. Such operationalization is based on the network-affiliation distribution pattern and, more importantly, is in conformity to the FCC's categorization with regard to the DTV transition timetable. In the sample, there are 391 out of 610 stations that are affiliated with the top 4 networks. Among them, there are 103 ABC affiliates, 109 CBS affiliates, 107 NBC affiliates, and 72 Fox affiliates. Such a distribution pattern is quite similar to that of the whole population of the U.S. commercial stations.[8]

There are some notable connections between network status and the DTV format choice. Stations that are not affiliated with the top 4 networks have shown strong preference of SDTV format to HDTV format. Such preference is also true for stations that are affiliated with the Fox network. In contrast, CBS affiliates seem to prefer HDTV format to SDTV format. The NBC affiliates have shown equal interests in both SDTV and HDVT formats.

The second control variable is the station's local market. In the United States, television markets were historically classified by the Nielsen Media Research. It is Nielsen that has designed and developed the Designated Market Areas (DMAs) to measure media markets. According to Nielsen, the country is divided into 210 DMAs, with each DMA including a group of counties. The size of DMAs is not uniform. Because cities are closer together in the east than in the west, DMAs in the East tend to be smaller than those in the west. Traditionally, the DMAs are ranked by the number of television households. The No. 1 DMA is New York City, with more than seven million television households. The smallest DMA is Glendive, Montana, with about 5,000 television households.

The ranking of DMAs is relevant in this study mainly because the FCC associated the DTV transition timetable with stations' market rankings. A clear line was drawn between top 30 DMAs and other smaller markets, as the FCC required all top-4 network affiliates in top 30 markets to finish the DTV transition in 1999 while the deadline is in 2002 for other stations.

Table **5.3**

---

[8] Refer to Table A.3 in Appendix A.

Table 5.3: Station market ranking distribution

DMA	top 30	31 through 100	101 through 210	Total
Population	352 (26.8%)	516 (39.3%)	444 (33.8%)	1312 (100%)
Sample 1	248 (40.7%)	238 (39.0%)	124 (20.3%)	610 (100%)

One issue needs to be noticed about the sample distribution with regard to market ranking. In the whole population of commercial full power stations (n = 1312), 26.8 percent are in the top 30 markets; 39.3 percent belong to markets 31 through 100; and 33.9 percent are in markets 101 through 210. This pattern is not exactly matched by the sample of 610 stations. While there are similar proportions of stations in markets 31 through 100 between the sample and the population; there are a bigger percentage of stations in the top 30 markets and a smaller percentage of stations in markets 101 to 210 in the sample compared to the population,. In other words, the sample on the DTV transition is a little skewed towards stations in the bigger markets. While the majority of stations have already adopted DTV, many of them chose not to reveal their DTV-on-air dates when completing the surveys for the Factbook. Since business strategies are also associated with the DTV adoption, some stations may want to be secretive on this issue for competition concerns.[9] The problem of missing data is especially significant for stations in minor markets.

Independent Variables

According to previous studies (Rose and Joskow, 1990; Karshenas and Stoneman, 1993) on technology adoption, firm size is an important explanatory factor. In this study, a station's annual revenue is used as the key indicator of firm size. The 2006 Television Market Report by BIA financial network provides the gross revenue estimates for most of the commercial full

[9] This is based on a conversation with an editor from Warren Communication News.

power stations across the United States. The estimates are generated from direct mail surveys, telemarketing, market contacts and computer modeling (BIA, 2006).

Among the 1,092 stations that are listed with revenue estimates, WNBC—a station from New York City—has the highest revenue—more than three hundred million dollars. In contrast, the revenue of KPXO—a station located in Kaneohe, Hawaii—is only seventy-five thousand dollars. The average revenue of the one-thousand-plus stations is $18,679,050. Again, there is a notable issue that the stations with missing values on revenue tend to be low-revenue stations. The available data skews the sample by eliminating stations with small market shares.

Note that revenue appears in logarithmic form in all the models. While survival models can accommodate the non-normality in the distribution of time to event, these models still assume that the covariates can be modeled by normal distributions. The distribution of revenue is not normal; it is very much positively skewed.[10] After log transformation, the distribution of the new variable ln(revenue) is close to a normal distribution. In general, the log transformation makes it easier to interpret the estimation, while the basic features of revenue data still hold when the logarithmic form is incorporated in the model.

Also discussed in Chapter 3, a station's business grouping is another important factor which can affect the DTV transition. It is believed that ownership is a good indicator of business grouping. In terms of financial resources, group ownership even more than network affiliation may be more indicative of the amount of resources a station can command. Both Television & Cable Factbook and BIA Television Market Report have recorded the owner of each station.

---

[10] In general, if the mean is larger than the median, the distribution is likely to be positively skewed. If the mean is less than the median, the distribution tends to be negatively skewed. The mean of revenue in the population is $18679.05, while the median is $7525.00. The graph of revenue distribution further confirms that it is positively skewed.

It is shown that many stations across the U.S. belong to large group owners like ION Media Networks, Sinclair Broadcast Group, and Univision Communications. In the population of 1,313 stations, ION Media Networks is the largest group owner that owns 57 stations. In contrast, there are 153 stations that are individually owned. Based on a station's ownership, a number is assigned to every station equal to the number of stations owned by the station's owner including that station. This variable is named as "group ownership". Thus, the smallest score of group ownership is one, while the largest score is 57. Based on this operationalization, "group ownership" becomes a numerical measurement.

However, the score of this variable does not necessarily reflect the power of the business grouping. Because the simple fact that ION Media Networks (57) owns more stations than Sinclair Broadcast Group (50) cannot prove that the former group is more powerful in the market than the latter group. It is more reasonable to believe that the two station groups have similar scale and can be similarly powerful. Moreover, a measurement of group ownership based only on the ownership of television stations ignores the group's possible ownership of other types of properties, media and non-media. An ordinal variable represents an alternative way to measure the impact of group ownership; and a transformation from numerical to ordinal scale is conducted.

According to the distribution of "group ownership", the scores can be separated into five categories: first, super large group owners—it includes station groups that own 50 or more than 50 stations; second, large ownership—it includes groups that own 30 to 49 stations; third, medium ownership—it includes groups that own 10 to 29 stations; fourth, small ownership—it includes groups that own 3 to 9 stations; last, local ownership—local owners with one or two stations. The new variable is named as "ownership5". For numerical estimation, the five groups are labeled with different scores: local ownership is coded as 1, small ownership is coded as 2, medium ownership is coded as 3, large ownership is coded as 4, and super large ownership is 5. Thus, the variable “ownership5” is regarded as the proxy of business grouping.[11]

The BIA Television Market Report (2006) also records the year when a station first went on the air. An age variable is established to incorporate such information and to indicate how old a station is by 2007. The Chicago station—WBBM—is the oldest station recorded by the BIA (2006), which is 67 years old since its birth year is 1940. In contrast, WZRB—a station from Columbia, South Carolina—is the youngest station, which is only two years old. The average age of 1,308 stations recorded by the BIA (2006) is 34 years and 10 moths. Station age is relevant to the DTV transition because older stations are well established; have more name recognition; and are more likely to be the market leaders. At the same time, other things being the same, older stations are likely to have older technology and physical facilities requiring greater expenditure for digital upgrades. Nevertheless, we may expect these old but established stations to be the leaders in the transition due to their market presence.

Having described all the variables involved in this study, the following sections will focus on the statistical analysis. As discussed in the previous chapter, survival analysis is the primary method to analyze the data. In section 5.2, both nonparametric and parametric approaches will be applied to examine the timing decisions on the DTV adoption. In section 5.3, logistic regression (instead of survival models) will be employed to analyze the DTV format choices by individual stations. In section 5.4, competing risks model will be employed to examine SDTV versus HDTV adoption patterns.

---

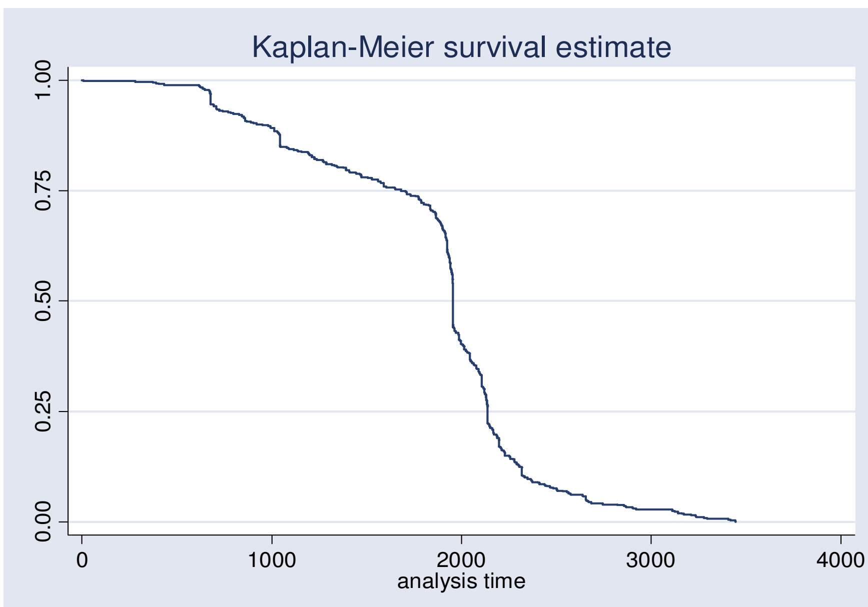
[11] Refer to Table A.5 in Appendix A.

5.2 DTV adoption times: Survival analysis

5.2.1 Nonparametric approach

The nonparametric approach is firstly applied to the sample because of its merit of letting the data speak for itself. Specifically, the Kaplan-Meier estimator is employed to primarily focus on the distribution of time variable with regard to the DTV adoption. Several plots are generated based on the Kaplan-Meier estimation.

Figure **5.1**



Note: t_0 is December 24, 1996; time is measured by number of days.

Figure **5.1**: DTV adoption times—Kaplan-Meier estimator

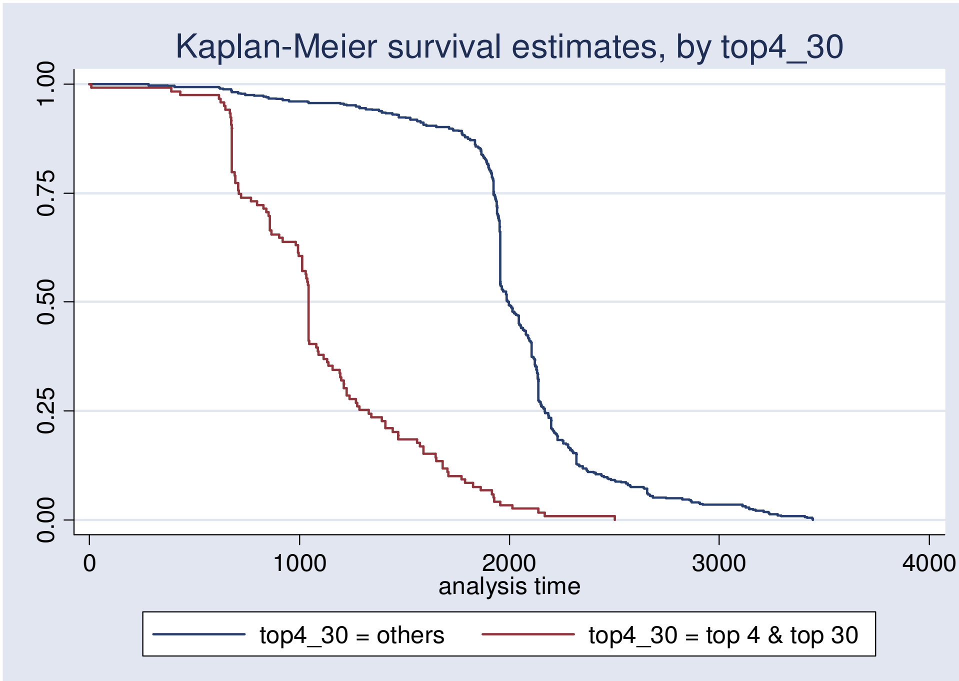
Figure 5.1 indicates that the digital television diffusion has experienced three different stages. In the first stage, the digital adoption rate was low; and the technology diffused gradually. In the second stage, the digital adoption rate grew dramatically, which resulted in a rapid and extensive diffusion. In the third stage, the adoption rate became slow again. The digital diffusion slowed down as well, but the installed base kept increasing.

The DTV transition timetable established by the FCC separates stations into three groups: i) top-four-network affiliates in top ten markets, ii) top-four-network affiliates in markets 11 through 30, iii) and other stations. Considering only a small number of stations falls into the first group, it is reasonable to divide the stations into two groups: first, top-four-network affiliates in top 30 markets; second, all other stations. Obviously, stations in the former group are subject to much more stringent regulation than those in the latter group. It is worthwhile to examine the difference with regard to the DTV transition between the two groups.

Figure 5.2 represents the estimation that employs a combined indicator: "Top4_30". Based on this indicator, one curve belongs to top-four-network affiliates that operate in top 30 markets (Group 1); the other stations' adoption pattern is shown by the second curve (Group 2). Figure 5.2 shows that a large gap exists between the two curves. This indicates that there is great difference between the two groups with respect to the DTV transition and the direct effect of the FCC regulation. Responding to the FCC's stringent requirement for group1 stations, these stations indeed adopted the DTV much earlier than Group 2 stations.

Figure 5.2 shows that at the beginning of the first stage of the transition, the DTV adoption rate for Group 1 stations was similar to that of the stations in Group 2. But later, Group 1 stations started to accelerate the transition while the transition rate for Group 2 stations remained low. The gap between the two groups grew towards the end of stage 1 and peaks at the middle of the stage 2. The size of the difference decreases through stage 3, although a small gap remains till the end of the observation period.

Figure **5.2**



Note: Group1—stations that are affiliated with top 4 networks and operate in top 30 markets ($n_1 = 119$); Group2—other stations ($n_2 = 491$)

Figure **5.2**: DTV adoption times with regard to both network affiliation and market ranking

The Kaplan-Meier estimation has provided some general ideas about the DTV transition patterns. In the following section, semi-parametric and parametric approaches will be used to offer more details on how the DTV transition is affected by firm- and market-specific factors.

5.2.2 Semi-parametric and parametric survival analyses with stratification

First of all, a Cox model is applied to the data. Without restrictive assumptions about the baseline hazard, the Cox model has the advantage of being guided by the data. The resulting estimations can be a valuable guide for the subsequent parametric analyses. Secondly, a proportional hazard (PH) model with Weibull distribution is applied to the data. Due to the versatile nature of the Weibull distribution, it is commonly used in PH survival models. If the estimation shows that the shape parameter $p > 1$, it indicates that the hazard rate of the DTV transition is accelerating along the time axis. The PH survival model assumes that the hazard rate is constant across different covariate values. But in the case of DTV transition, rich stations are likely to lead the transition. Similarly, stations in major markets tend to adopt DTV sooner than those in minor markets. Thus, it is reasonable to suspect that the interaction exists between covariates and hazard rate. The proportional hazard assumption therefore may not be sustainable.

Thirdly, as an alternative, an accelerated failure time (AFT) model is employed, which directly parameterizes the time to transition rather than the hazard rate of the transition. Log-logistic distribution is used under the AFT model because of its atypical features. If its shape parameter $\tau < 1$, it indicates that the hazard rate of the transition increases at first; and then decreases after reaching a peak. Comparing the two parametric models, log-logistic distribution seems to be more attractive than Weibull distribution for the DTV transition. In the early stage of the transition, the tendency to adopt DTV is increasing as the FCC deadline is approaching. In the later stage, after many stations have switched to digital, the likelihood for remaining stations to adopt DTV will decrease because the more capable stations self-select themselves to make the transition earlier, leaving a residual group increasingly handicapped by lack of resources. Table 5.4 shows the results from the three survival models—Cox, PH-Weibull and AFT-log-logistic—respectively.

Note that the coefficient signs in the AFT model are different from the other two models. This is because both Cox and PH-Weibull models parameterize hazard rate while AFT-log-logistic model parameterizes time to transition. A positive sign in a PH model indicates that the covariate has positive effect on the adoption rate, while a negative sign in an AFT model indicates that the covariate can decrease the time to adoption. Thus, a positive sign in a PH model has similar effect as a negative sign in an AFT model.

Table **5.4**

Table **5.4**: DTV adoption times—Survival models

	Cox	PH-Weibull	AFT-log-logistic
Intercept		-34.28***	7.81***
		(1.63)	(.090)
$\ln(revenue)$	.20**	.14*	-.025*
	(.062)	(.059)	(.010)
Age	.0030	.0053	-.0016*
	(.0037)	(.0038)	(.00067)
Ownership5	.0070	.0030	.011
	(.047)	(.047)	(.0071)
DMA rank	-.0017	-.0025*	.00065**
	(.0012)	(.0012)	(.00021)
Top4_30	2.17***	1.86***	-.60***
	(.26)	(.18)	(.038)
ln (parameter)		1.46***	-1.98***
		(.044)	(.074)
parameter		4.30	.14
		(.19)	(.010)
Likelihood	-2676.18	-54.07	-49.00
Wald χ^2	275.14***	223.24***	430.24***
df	5	5	5
N	534	534	534

Note: ^- significant at .1 level, * - significant at .05 level, ** - significant at .01 level, *** - significant at .001 level.

The estimation based on the Cox model shows that revenue has a significant positive influence on a station's DTV adoption rate, while station age and market ranking are not significant. The signs of the coefficients indicate that older stations and stations in major markets are likely to adopt DTV sooner. The results from PH-Weibull and AFT-log-logistic models are consistent with the Cox model, the only difference being that the significance of some variables increases in the parametric models. The change is more obvious in the AFT-log-logistic model.

The effects of age and market ranking become significant at the .05 level. The estimation from the AFT model indicates that rich stations wait a shorter time before the adoption. Older stations and stations in the major markets tend to adopt DTV earlier.

The effect of ownership is a little unclear in the three models. Both the Cox model and the PH-Weibull model show that such an effect is not significant at all. The significance of ownership's effect increases in the AFT-log-logistic model; it is indicated that stations owned by large groups are likely to lag in the DTV transition. The direction of ownership's effect is only available in the AFT-log-logistic model. The other two models fail to identify the effect of business grouping.

Comparing the value of maximum likelihood, the AFT-log-logistic model seems to fit the data better than the PH-Weibull model. The AFT model is more attractive also because it increases the significance of several covariates. Moreover, the shape parameter τ is found equal to .14. It indicates that the hazard rate increases at first, but decreases later. Overall, the AFT-log-logistic model seems to be closer to the real pattern of the transition.

Across the three models, the indicator variable "top4_30" shows an outstanding effect on DTV adoption.[12] This reflects the effect of the FCC timetable. To further examine the effect of firm size, business grouping and firm age on the DTV transition, the effect of top4_30 needs to be controlled. Thus, stratification is applied to the survival models. Note that indicator "top4" is added to the stratified survival models, while top4_30 is excluded. Because the effect of the stratified variable—top4_30—is analyzed under the intercept and parameter estimation, the

---

[12] If a station is a top-four-network affiliate in a top 30 market, top4_30 = 1,; otherwise, top4_30 = 0.

variable can no longer be a covariate in the survival models. Meanwhile, the indicator "top4" is added to the model to differentiate stations in markets 31 through 210.

Table **5.5**

Table 5.5: DTV adoption times—Stratified survival models

	Cox	Cox	PH-Weibull	PH-Weibull	AFT-log-logistic	AFT-log-logistic
Intercept			-39.34***	-39.18***	7.77***	7.74***
			(2.09)	(2.09)	(.078)	(.088)
Intercept-top4_30			16.91***	16.95***	-.62***	-.61***
			(2.56)	(2.58)	(.039)	(.040)
$\ln(revenue)$	.15**	.12*	.13*	.11	-.020*	-.017^
	(.053)	(.056)	(.063)	(.066)	(.0091)	(.010)
Age	.0042	.0022	.0071^	.0057	-.0012*	-.0010
	(.0036)	(.0038)	(.0042)	(.0044)	(.00062)	(.00065)
Ownership5	-.018	-.022	.0052	.0023	.010^	.011^
	(.041)	(.042)	(.053)	(.053)	(.0062)	(.0062)
DMA rank	-.0022*	-.0039*	-.0032*	-.0042*	.00053**	.00067**
	(.0011)	(.0015)	(.0014)	(.0019)	(.00020)	(.00024)
Top4		.28^		.18		-.024
		(.16)		(.20)		(.025)
ln (parameter)			1.60***	1.60***	-2.19***	-2.19***
			(.050)	(.051)	(.082)	(.082)
ln (parameter)-top4_30			-.53***	-.53***	.68***	.69***
			(.097)	(.098)	(.16)	(.16)
Likelihood	-2548.46	-2547.00	-28.15	-27.55	-16.71	-16.29
Wald χ^2	23.28***	24.47***	62.27***	61.18***	443.30***	444.11***
df	4	5	5	6	5	6
N	534	534	534	534	534	534

Note: The stratification variable is top4_30; ^- significant at .1 level, * - significant at .05 level, ** - significant at .01 level, *** - significant at .001 level.

Table 5.5 shows the results from stratified survival models. The stratification enables comparison between two categories: Category 1— the top-4 network affiliates in the top 30 markets; and Category 2—all other stations. Comparing Table 5.4 and Table 5.5, it may be seen that the significance of many variables have increased slightly because of stratification. For covariates like revenue, age and ownership, the direction and size of their effects have barely changed between stratified survival models and non-stratified survival models.

While the effects of the covariates are not subject to changes caused by different strata, the stratified models indicate that both the baseline hazards and the shapes of the hazard function are different between the two groups. Two differences between the two groups have been identified by the AFT-log-logistic model: first, the intercept for top market network affiliates is smaller than that for other stations; second, the shape parameter for top market network affiliates is bigger than that for the other category, while both are less than one. This implies that a top market network affiliated station tends to wait a shorter period before the transition, while the non-monotonic variation of transition rate happens earlier for top market network affiliate category than for the other stations category. The values of maximum likelihood indicate the stratified survival models fit the data better, while the stratified AFT-log-logistic survival model fits the data the best.

To answer the question whether the transition is affected by network affiliation, four indicators—ABC, CBS, NBC and Fox—are added to the analysis. Table 1.2 (p. 8) shows the average number of days to the DTV adoption under different network affiliation status. It indicates that there is a significant difference in time duration between top-four-network affiliates and other stations—in a one-way ANOVA test, $F=11.09$, $p<.001$. However, it is found that there is no significant difference in terms of time duration between ABC, CBS, NBC and Fox network affiliates. Independent-samples t tests fail to show any significant difference on time duration between stations affiliated with the four major networks. The survival analysis also agrees with the findings from the means-comparison tests. Consistent results are found between

PH and AFT models. The affiliation status (ABC, CBS, NBC or Fox) leads to similar impacts on both hazard rate and time duration.

In summary, station revenue is found to have a significant impact on the timing of DTV transition. The stratified survival models show that there are significant differences between two groups of stations: top-four-network affiliates in top 30 markets and all other stations. Despite the fact that group1 stations tend to adopt DTV earlier than Group 2 stations, firm size and firm age are found to have positive effects on DTV adoption while business grouping is found to have negative impact on the transition. The latter phenomenon may be associated with the behavior of network owned and operated (O&O) stations. The largest, richest stations in the top markets would be those O&O stations. Due to network station ownership limitations, the number of O&O stations with each network would be small – so all these O&O stations would be categorized as belonging to small-medium groups. By the same logic, stations in the super-large group ownership category would have a greater number of small stations (because all the O&Os are the biggest stations in the biggest markets), with a proportionately higher number of independents (because all the O&Os are affiliated). The theoretical framework discussed in Chapter 3 suggests that horizontally integrated firms have greater financial resources. However, the theory has to be adjusted when to be applied to the broadcast television industry because of station ownership regulations. Although the estimation on the effects of ownership contradicts theories on scope economics and transaction cost, it does reflect the peculiar features of broadcast television industry.

While this section is exclusively about the timing decisions of the DTV adoption, the sole focus of the next section is the DTV format choices. Accordingly, the method used in the following analysis is no more survival models but logistic regression.

5.3 Digital television format choices: Logistic regression

Depending on how the dependent variable—format choice—is operationalized, two types of logistic models can be applied to the data. As discussed earlier, stations have adopted HDTV format, or SDTV or a combination of the two. Therefore, one operationalization is to divide stations' format choices into HDTV and SDTV. In this categorization, the adoption of both HDTV and SDTV formats is classified with HDTV. The other option is to categorize DTV adoption into HDTV, hybrid and SDTV. The adoption of both HDTV and SDTV formats is then labeled as hybrid.

In the first approach, the dependent variable can be HDTV. Thus, stations that choose HDTV or adopt the hybrid format would score one on the variable HDTV; while stations that adopt SDTV will score zero. In the second approach, the dependent variable is format. Since HDTV adoption requires more financial investments, the format indicator is coded with value 3 for these stations. Accordingly, stations that adopt the hybrid format will score two on the format variable, while stations that choose SDTV would score one.

Firstly, regular logistic regression is applied using the first operationalization where the dependent variable is HDTV—a binary variable. Then, ordinal logistic regression will be employed using the second operationalization where the dependent variable is format, which is coded with values 1, 2 and 3. Besides, it is suspected that major network affiliates in major markets may behave differently from other stations in the DTV transition. Therefore, analyses are conducted for the two groups of stations respectively: Group 1 includes top-four-network affiliates in top 30 markets; and Group 2 includes all the other stations.

Table **5.6**

Table 5.6: DTV format choices—Logistic model

Dependent variable: HDTV			
	Group1	Group2	All
Intercept	6.90	5.85*	-4.88*
	(6.89)	(2.39)	(2.07)
$\ln(revenue)$	.49	.43^	.32
	(.65)	(.25)	(.22)
Age	.054*	.025*	.032**
	(.026)	(.012)	(.011)
Ownership5	-.43	.023	-.045
	(.34)	(.13)	(.12)
DMA rank	.069^	-.0031	-.0028
	(.046)	(.0053)	(.0046)
Top4		1.08*	.87*
		(.45)	(.40)
likelihood	-44.29	-149.35	-197.45
Wald χ^2	9.62*	34.63***	53.16***
df	4	5	5
pseudo R^2	.12	.17	.18
N	82	266	348

Note: ^- significant at .1 level, * - significant at .05 level, ** - significant at .01 level, *** - significant at .001 level.

When all the stations are included in the analysis, it is found that older stations are more likely to choose the HDTV format. The effect of revenue is found to be less significant, while the sign of the coefficient indicates that rich stations tend to prefer HDTV. The effect of ownership is found to be irrelevant to the DTV format choice. For stations that are affiliated with top four networks in top 30 markets, age still has a significant and positive effect on HDTV adoption. The effects for both revenue and ownership are not significant. But the signs of the coefficients suggest that rich stations from Group 1 are likely to choose HDTV, while stations owned by large group owners may opt out of HDTV adoption. Yet, it should be noted that different patterns on HDTV adoption may exist between O&O stations and other group-owned stations.

For stations in Group 2, both revenue and age are found to have positive effect on HDTV adoption. That is, richer and older stations have shown strong preference of the HDTV format. Again, the effect of ownership is found to be insignificant.

Overall, it is found that rich stations are likely to adopt HDTV. The positive effect of revenue is found most significant for Group 2 stations. Age is found to be a significant factor associated with HDTV adoption. That old stations tend to pick HDTV is true for both Group 1 and Group 2 stations. While ownership is found to be irrelevant to Group 2 stations' HDTV adoption, it is found that Group 1 stations that belong to large group owners are unlikely to pick HDTV (this is likely to be true for non-O&O stations).

The results based on the ordinal logistic model are very similar to the estimation from regular logistic model. Comparing their maximum likelihood values, the regular logistic model seems to fit the data better than the ordinal logistic model. Therefore, the discussion of the latter model is skipped. The results can be found in Appendix B.

In the previous logistic model, the top-four-network indicator is found to be significantly associated with HDTV adoption. To provide a more detailed interpretation the relationship between DTV format choice and network affiliation status, four additional indicators—ABC, CBS, NBC and Fox—are added to the logistic model. The results are presented in Table 5.7.

Table **5.7**

Table 5.7: DTV format choices—Logistic model with network indicators

Dependent variable: HDTV			
	Group1	Group2	All
Intercept	6.25	-6.28*	5.10*
	(6.81)	(2.55)	(2.19)
$\ln(revenue)$	.28	.56*	.43^
	(.65)	(.26)	(.23)
Age	.047	-.0081	.0034
	(.037)	(.018)	(.014)
Ownership5	-.37	.045	-.012
	(.42)	(.14)	(.13)
DMA rank	.075	-.0033	-.0052
	(.051)	(.0057)	(.0049)
ABC	1.31	2.23**	1.73**
	(.80)	(.67)	(.52)
CBS	3.95**	2.56***	2.56***
	(1.19)	(.69)	(.57)
NBC	2.71**	1.63*	1.65**
	(1.00)	(.68)	(.56)
Fox		-.96	-.70
		(.85)	(.57)
Likelihood	-33.48	-137.05	-176.97
Wald χ^2	25.99***	52.26***	84.49***
df	7	8	8
pseudo R^2	.34	.23	.26
N	82	266	348

Note: ^- significant at .1 level, * - significant at .05 level, ** - significant at .01 level, *** - significant at .001 level.

After more specific network indicators are added to the model, the age variable becomes insignificant. This is because the top-four-network affiliates are very likely to be old and established stations. Yet, the results show that age still has a positive effect on HDTV adoption for Group 1 stations. Revenue is found to have similar effect for Group 1 stations as station age, but ownership seems to have a negative effect on HDTV adoption for Group 1 stations. Also in Group 1, it is found that CBS affiliates are most likely to choose HDTV, NBC comes second, and ABC follows right after them. For Group 2 stations, revenue is found to have a significant and positive effect on HDTV adoption. But factors like age and ownership become irrelevant for Group 2 stations' choice of HDTV format. Similarly, CBS affiliates have shown strong preference for HDTV compared to other Group 2 stations. Different from the pattern shown in Group 1, ABC affiliates have shown a stronger preference for HDTV than NBC affiliates in Group 2. But CBS affiliates still lead in HDTV adoption among Group 2 stations. The pattern with regard to DTV format choice in the whole sample is very similar to the pattern found for Group 1 stations. While it is shown that revenue has a positive effect on HDTV adoption, the effects of age and ownership are not significant at all.

Overall, Table 5.7 shows that rich stations are more likely to choose HDTV. This effect is most significant for Group 2 stations. While age is found to be a significant factor in the previous logistic model, its effect has been cancelled out by network indicators due to the high correlation between age and ABC, CBS and NBC affiliates. If a Group1 station belongs to a large ownership but is not an O&O station, the station is unlikely to adopt HDTV. However, the effect of ownership is not significant at all for Group 2 stations. This finding is consistent with the previous logistic model.

Among Group 1 stations, CBS affiliates are most likely to adopt HDTV, NBC affiliates are the second most likely, and ABC affiliates follow behind them. But the order is a little different among Group 2 stations. CBS remains the leader of HDTV adoption, but ABC is the second, and NBC becomes the third. When all stations are included in the analysis, ABC and NBC affiliates are likely to favor HDTV format to the similar degree. In contrast, the Fox affiliates are lagging far behind on adopting HDTV format.

Due to the same reasons discussed above, the ordinal model is skipped here—the results are reported in Appendix B.

Logistic models are employed in this section to study stations' DTV format choices. It is found that market ranking is not an influential factor on stations' DTV format choices. The age factor seems positively associated with standard adoptions that include HDTV. But this effect becomes insignificant when detailed indicators on network status are included in the model. This can be interpreted to mean that the age factor is merely channeling the positive effects of the network indicators—ABC, CBS and NBC, because stations that are affiliated with those three networks usually were established much earlier than other stations. In contrast, the revenue factor has shown a significant positive effect on the HDTV adoption. The results also show that the CBS affiliates are leading the race of adopting HDTV, while their ABC and NBC counterparts are following right behind. In contrast, the Fox affiliates, independent stations, and other network affiliates have shown a stronger preference for the SDTV format than anything else.

5.4 DTV standard choices: Competing risks model

In the previous logistic regressions, the focus is solely on stations' DTV format choices. In this section, the competing risks analysis model will be used to analyze not only the stations' format choices but also the stations' decision on the DTV adoption timing. The previous logistic models seemed to generate better output by defining the dependent variable dichotomously—combining the HDTV and hybrid format choices into the same category and SDTV into the other. To simplify the analysis, the same categorization approach is used in this section. Thus, a station basically faces two options, either the SDTV format or a HDTV-included standard, when it has decided to adopt DTV. The competing risks model turns to be a perfect match for the DTV transition case, because rather than making the simple decision to adopt DTV, stations have to choose among several available DTV formats. Station's adoption pattern with regard to HDTV destination is analyzed first.

5.4.1 HDTV adoption pattern

Based on the results presented in section 5.2.2, the stratified survival models fit the data better and produce more useful results for this study. Thus, only stratified survival models are employed and combined with competing risks model. Because the AFT-log-logistic model is more meaningful for the DTV transition than the PH-Weibull model,[13] the latter is omitted in this section. The Cox model is kept because, without assumptions about the baseline hazard, the model is more reflective of the data. Thus, the Cox model serves as the reference for the parametric survival model. Table 5.8 shows the survival functions for HDTV destination.

According to Table 5.8, the results of the AFT-log-logistic model and the Cox model reinforce and support each other. The stratified Cox model indicates that both firm size and firm age are significantly positively related to HDTV adoption rate. It is also found that business grouping has a negative effect on HDTV adoption. According to the AFT-log-logistic model, both revenue and age are estimated to shorten the time to HDTV adoption. But stations that belong to super large group owners may not adopt HDTV. The shape parameter indicates that the

[13] The log-logistic distribution allows the hazard to increase first and then decrease if $\tau < 1$. In contrast, the Weibull distribution only allows the hazard to increase or decrease monotonically.

HDTV adoption rate increases first, and later decreases. Those patterns are similar to the general DTV adoption.

Table **5.8**

Table **5.8**: HDTV adoption—Stratified survival models (top4_30 is the strata)

	Cox	Cox	AFT-log-logistic	AFT-log-logistic
Intercept			8.82***	8.63***
			(.28)	(.31)
Intercept-top4_30			-.46***	-.40***
			(.063)	(.063)
ln(*revenue*)	.41**	.33*	-.080**	-.073*
	(.13)	(.14)	(.029)	(.032)
Age	.0023**	.014^	-.0056**	-.0038*
	(.0078)	(.0073)	(.0016)	(.0016)
Ownership5	-.088	-.10	.015	.018
	(.076)	(.079)	(.018)	(.018)
DMA rank	-.0020	-.0079**	.00075	.0017*
	(.0022)	(.0030)	(.00052)	(.00069)
Top4		1.05**		-.17**
		(.31)		(.060)
ln (parameter)			-1.86***	-1.87***
			(.11)	(.11)
ln (parameter)-top4_30			.33*	.34*
			(.14)	(.14)
Likelihood	-741.84	-736.32	-174.64	-170.98
Wald χ^2	43.47***	54.46***	170.48***	169.41***
df	4	5	5	6
N (adoption)	534 (161)	534 (161)	534 (161)	534 (161)

Note: ^- significant at .1 level, * - significant at .05 level, ** - significant at .01 level, *** - significant at .001 level.

The stratified AFT model shows that: first, the intercept for Group 1 stations is significantly smaller than that for Group 2; second, the shape parameter for Group 1 is bigger than Group 2 as both are less than one, while such a difference is only significant at .05 level.

This implies that Group 1 stations tend to wait a shorter time before the HDTV adoption; but the variation in transition rate is not that different between Group 1 stations and Group 2 stations.

Table **5.9**

Table 5.9: HDTV adoption—Stratified survival models with network indicators

	Cox	AFT-log-logistic
Intercept		8.64***
		(.31)
Intercept-top4_30		-.41***
		(.064)
$\ln(revenue)$	.36*	-.082*
	(.14)	(.032)
Age	-.00042	-.00091
	(.0080)	(.0017)
Ownership5	-.060	.011
	(.081)	(.018)
DMA rank	-.0093**	.0019**
	(.0031)	(.00069)
ABC	1.46***	-.26***
	(.36)	(.069)
CBS	1.71***	-.29***
	(.34)	(.073)
NBC	1.52***	-.24**
	(.38)	(.074)
Fox	-.056	.11
	(.45)	(.099)
ln (parameter)		-1.91***
		(.11)
ln (parameter)-top4_30		.40**
		(.14)
Likelihood	-723.44	-157.94
Wald χ^2	71.59***	192.59***
df	8	9
N (adoption)	534 (161)	534 (161)

Note: ^- significant at .1 level, * - significant at .05 level, ** - significant at .01 level, *** - significant at .001 level.

Since the previous model indicates that top-four-network indicator has a strong and significant effect on HDTV format choice, specific indicators of network affiliation are added to the models to find the detailed transition pattern with regard to different networks. The results are shown in Table 5.9.

The results shown in Table 5.8 and Table 5.9 are mainly in agreement except that the sign on the age coefficient are not consistent between the models. Before network affiliation indicators are added to the analysis, age is significantly and positively associated with HDTV adoption rate. But after incorporating the additional indicators, the effect of age becomes not significant at all. This can be explained by the fact that the majority of ABC, CBS and NBC affiliates are also much older than other stations. They tend to be well established in their local markets. The strong correlation between age and major network affiliates confounds the effect of station age on HDTV adoption. Since the impact of age becomes insignificant, the different signs of age in the two models in not really an issue.

The AFT-log-logistic model shows station revenue has a significant effect in shortening the time to HDTV adoption. The effect of ownership remains unchanged. The direction of the effect indicates stations under large ownership are unlikely to adopt HDTV. Again, O&O stations may tend to adopt HDTV sooner, but the operationalization of ownership fails to capture the difference between O&O stations and other group-owned stations. The significance of market ranking’s effect has increased in the model with additional indicators. It indicates that stations in major markets tend to adopt HDTV sooner than those in minor markets. A more interesting pattern is revealed with regard to network affiliation. CBS affiliates are found to be most likely to adopt HDTV, with ABC and NBC following right behind. Affiliates of the three networks tend to adopt HDTV sooner than other stations. In contrast, Fox affiliates are unlikely to adopt HDTV; their preference of DTV format is similar to independent stations and stations with minor networks.

The stratified AFT model shows that the survival functions from the two groups are significantly different. In general, it is found that Group 1 stations are more likely to adopt HDTV and their transitions to HDTV are sooner than Group 2 stations. Yet, the transition rates for both groups increased in the beginning and decreased later.

So far, the analysis only covers the HDTV adoption pattern. Similar techniques will be employed to analyze SDTV adoption in the following section.

5.4.2 SDTV adoption pattern

The estimation of stratified models on SDTV adoption is illustrated in Table 5.10. The pattern revealed here is quite different from HDTV adoption.

The results from the Cox model and the AFT model are not quite consistent. While the effect of revenue is insignificant in both models, different signs for the coefficient emerge from the two models. Both models indicate younger stations tend to wait a shorter time before they decide to adopt SDTV. Yet, the effect of station age decreases in the AFT model. No significant effect of ownership is found in either model, but the sign of the coefficient indicates that stations under large group owners are more likely to adopt SDTV (note that O&O stations may show a different pattern).

Both models indicate that stations in major markets are more likely than not to adopt SDTV. The stratification analysis shows that the intercepts are significantly different between the two groups, but the stratification does not cause much difference in the shape parameter between the two groups. This indicates that Group 1 stations tend to adopt SDTV sooner than Group 2 stations, but the rates of transition to SDTV are similar between the two groups.

Table **5.10**

Table **5.10**: SDTV adoption—Stratified survival models

	Cox	Cox	AFT-log-logistic	AFT-log-logistic
Intercept			7.64***	7.67***
			(.14)	(.15)
Intercept-top4_30			-.39***	-.40***
			(.071)	(.074)
ln(*revenue*)	.042	.053	.0018	-.0010
	(.084)	(.086)	(.015)	(.016)
Age	-.017*	-.016*	.0022^	.0021^
	(.0065)	(.0069)	(.0012)	(.0012)
Ownership5	.031	.032	-.0013	-.0018
	(.063)	(.064)	(.012)	(.012)
DMA rank	-.0032	-.0026	.00076^	.00032
	(.0020)	(.0027)	(.00040)	(.00050)
Top4		-.095		.022
		(.28)		(.047)
ln (parameter)			-1.96***	-1.96***
			(.10)	(.10)
ln (parameter)-top4_30			.31	.30
			(.19)	(.19)
Likelihood	-874.06	-874.00	-158.67	-158.57
Wald χ^2	19.28***	19.61**	42.80***	43.05
df	4	5	5	6
N (adoption)	534 (176)	534 (176)	534 (176)	534 (176)

Note: ^- significant at .1 level, * - significant at .05 level, ** - significant at .01 level, *** - significant at .001 level.

Overall, the effects of covariates are not very significant in either model except for age. It seems that firm size and business grouping do not have much explanatory power on the SDTV adoption. Yet, it is found that younger stations prefer SDTV and tend to adopt SDTV sooner. The difference between Group 1 stations (top-four-network affiliates in top 30 markets) and

Group 2 stations is simply that Group 1 stations tend to adopt SDTV earlier than Group 2 stations. This is merely a refection of the FCC timetable. In terms of SDTV transition rate, no significant difference is found between the two groups.

After adding the indicators of network affiliation to the survival models, fewer covariates are found to have significant effects. Besides, no further interesting pattern is revealed by the more specified models. Thus, the results from those models are not discussed further.

5.4.3 Competing risks model

In this section, results presented in previous sections will be combined together to complete the competing risks model. As discussed earlier, the stratified AFT-log-logistic model seems to fit the data the best. Thus, only this model will be presented here to illustrate the outcome of the competing risks model. Having assumed that multiple destinations are conditional independent, the key of competing risks model is to compare the different or similar effects of the same group of covariates on the hazard rate or time duration of different destinations. Table 5.11 combines the time duration patterns for HDTV and SDTV destinations, while the general DTV adoption pattern is also included for the sake of comparison.

Different effects with regard to DTV adoption are found for firm size, business grouping and station age. In general DTV adoption, revenue has shown significant negative effect on the time to transition; similar effect of revenue is found in HDTV adoption. However, the effect of revenue becomes insignificant in SDTV adoption, as the sign of the effect also changes. Across the three destinations (general DTV, HDTV and SDTV adoption), revenue has the strongest effect on HDTV adoption. Rich stations are expected to adopt HDTV much sooner. They are also expected to lead in the general DTV transition. In contrast, revenue is found irrelevant in SDTV adoption. While it is true that rich stations tend to lead the DTV transition, this is truer for HDTV adoption. For the cheaper SDTV adoption, revenue hardly has any impact.

Table **5.11**

Table **5.11**: DTV adoption—Competing risks model
(Stratified AFT-log-logistic survival models)

	DTV	DTV	HDTV	HDTV	SDTV	SDTV
Intercept	7.77***	7.74***	8.82***	8.63***	7.64***	7.67***
	(.078)	(.088)	(.28)	(.31)	(.14)	(.15)
Intercept-top4_30	-.62***	-.61***	-.46***	-.40***	-.39***	-.40***
	(.039)	(.040)	(.063)	(.063)	(.071)	(.074)
ln(*revenue*)	-.020*	-.017^	-.080**	-.073*	.0018	-.0010
	(.0091)	(.010)	(.029)	(.032)	(.015)	(.016)
Age	-.0012*	-.0010	-.0056**	-.0038*	.0022^	.0021^
	(.00062)	(.00065)	(.0016)	(.0016)	(.0012)	(.0012)
Ownership5	.010^	.011^	.015	.018	-.0013	-.0018
	(.0062)	(.0062)	(.018)	(.018)	(.012)	(.012)
DMA rank	.00053**	.00067**	.00075	.0017*	.00076^	.00032
	(.00020)	(.00024)	(.00052)	(.00069)	(.00040)	(.00050)
Top4		-.024		-.17**		.022
		(.025)		(.060)		(.047)
ln (parameter)	-2.19***	-2.19***	-1.86***	-1.87***	-1.96***	-1.96***
	(.082)	(.082)	(.11)	(.11)	(.10)	(.10)
ln (parameter)-top4_30	.68***	.69***	.33*	.34*	.31	.30
	(.16)	(.16)	(.14)	(.14)	(.19)	(.19)
Likelihood	-16.71	-16.29	-174.64	-170.98	-158.67	-158.57
Wald χ^2	443.30***	444.11***	170.48***	169.41***	42.80***	43.05
df	5	6	5	6	5	6
N (adoption)	534	534	534 (161)	534 (161)	534 (176)	534 (176)

Note: ^- significant at .1 level, * - significant at .05 level, ** - significant at .01 level, *** - significant at .001 level.

Station age is found to have significant effect on the time to adoption across three destinations. In general DTV adoption, older stations are predicted to wait shorter period before the transition. In HDTV adoption, the effect of age becomes stronger in shortening the time to adoption. But in SDTV adoption, younger rather than older stations are expected to adopt SDTV sooner. It is interesting to find that the effects of age have opposite directions in HDTV and SDTV adoption. This finding suggests that while older stations prefer HDTV format, younger stations tend to pick SDTV format. It further supports the argument that older stations are more established and better equipped; thus, they are better prepared for the demanding requirements associated with HDTV format.

Compared to firm size and firm age, business grouping has shown less significant effect in DTV adoption. The only significant effect of ownership is found in general DTV adoption. That is, stations under large group owners tend to lag in the DTV transition. While the effect of ownership becomes less significant in HDTV adoption, the direction of the effect is the same as that in general DTV adoption. In SDTV adoption, the effect of ownership becomes totally insignificant. It suggests that ownership hardly has any effect on SDTV adoption. However, the different effects of ownership on HDTV adoption and SDTV adoption should not be overstated, because the operationalization of business grouping may not really reflect the degree of horizontal and vertical integration associated with individual stations. In other words, O&O stations are likely to have the opposite DTV adoption pattern compared to other group-owned stations.

The stratification analysis shows that Group 1 stations have transited sooner in all the three destinations. The two groups' differences in intercepts across the three destinations are all significant and very alike. The shape parameters are all less than one across the three types of transitions. Thus, the same pattern of the transition rate increasing initially and decreasing later is observed in both HDTV and SDTV adoptions. But in general DTV adoption, the shape of Group 1's survival function is significantly different from that of Group 2. The significant of such difference decreases in HDTV adoption, but is still sustained. In contrast, such difference disappears in SDTV adoption. This indicates while the HDTV adoption rate varies earlier for Group 1 station than that for Group 2 stations, there is not much difference between the two groups with regard to SDTV adoption patterns. The stratification pattern suggests that the difference between the two groups simply reflects the FCC regulation. Group 1 stations are required to adopt DTV much earlier than Group 2 stations; and that explains the significant intercept difference between the two groups.

To specify the effects of network affiliation, four network indicators are added to the competing risks model. The results show that CBS affiliates have strong preference of HDTV to SDTV while Fox affiliates tend to choose SDTV over HDTV. Stations that are affiliated with ABC and NBC are likely to adopt HDTV nearly as soon as CBS affiliates. Despite the detailed preference pattern being revealed, the more specified model fails to provide more interesting results compared to the previous model. Thus, it is not discussed further; the results are presented in Appendix B.

5.5 Conclusions

The goal of this chapter was to answer two research questions: (i) how is time to DTV adoption affected by firm- and market-specific factors? And (ii) what is the impact of those factors on stations' DTV format choices? Based on discussion in previous chapters, three firm-specific factors—firm size, firm age, and business grouping—are expected to affect stations' decisions on DTV adoption. Earlier in this chapter, four variables have been identified to operationalize those three factors. That is, station revenue is employed to measure firm size;

station age for firm age; and station's group ownership and network affiliation to represent firm's business grouping status. The key data resources are Television & Cable Factbook and BIA Television Market Report. One limitation of the dataset is that the Factbook failed to record the DTV adoption dates for a number of stations. The missing data have the potential to make the further estimation problematic.

For the first research question, three different survival models—Cox, PH-Weibull and AFT-log-logistic models—have been applied to the data at first. The Cox model does not specify the baseline hazard; thus, it tends to be more truthful to the data than the other two parametric models. The main difference between a PH model and an AFT model is whether there is interaction between hazard rate and covariates. A major difference between Weibull and log-logistic distribution is whether there is non-monotonic variation. In the case of digital television, it is suspected that there is interaction between DTV adoption rate and some covariates. Besides, the DTV adoption rate is unlikely to be either increasing or decreasing monotonically all the time. In fact, the survival analysis with the three models indicates that the AFT-log-logistic model fit the data the best. It is proved that the DTV adoption rate increases in the beginning but decreases later.

According to the survival analysis, firm size is found to accelerate the DTV transition. In terms of business grouping, network affiliation is found to expedite DTV adoption. However, the effect of ownership is a little complicated. While the results indicate that large-group-owned stations may lag in the DTV transition, the adoption pattern for O&O stations is not clear since the information on whether a station is horizontally/vertically integrated can not be captured by the "ownership" variable. The effect of firm age tends to be positive but insignificant. Besides, the market size is also found to have a positive and significant effect on DTV adoption. These are the basic findings with regard to timing of DTV adoption.

For the second research question, two different methods have been used: logistic model and competing risks model. The former approach is a simple regression with dichotomous dependent variables. The sample is separated into two groups before the logistic model is applied: Group 1 includes top-four-network affiliates in top 30 markets, while all the other stations belong to Group 2. For Group 1 stations, both firm size and firm age are found to have positive effects on HDTV adoption, while ownership is found to be negatively associated with the choice of HDTV format. Again, those O&O stations may tend to choose HDTV, unlike other group-owned stations. However, all those effects are insignificant especially compared to the impacts of network affiliation. It is found that, CBS affiliates are leading in HDTV adoption, while NBC and ABC follow right behind. For Group 2 stations, firm size has a positive and significant effect on HDTV adoption, but firm age and business grouping fail to have any impact on stations' DTV format choice. Since the logistic model is a rather simple model, the story revealed here is limited. In contrast, the competing risks model which is built upon survival analysis is a little more complicated, and has the tendency to reveal more patterns with regard to stations' DTV format choice.

The competing risks model shows some interesting patterns with regard to the effect of station age on stations' DTV choice. While firm age is found to have significant and positive effect on HDTV adoption, the opposite direction of the effect is found for SDTV adoption. That is, old and established stations tend to adopt HDTV sooner, while younger stations are likely to adopt SDTV faster. For HDTV adoption, significant and positive effect of firm size is found; while the findings indicate that group ownership is likely to have a negative effect (this is unlikely to be true for O&O stations). But for SDTV adoption, both factors become irrelevant—their effects are not significantly different from zero. Overall, the findings imply that since HDTV requires more financial investments, old and more established stations tend to favor this format, and so do rich stations. With regard to group ownership, O&O stations may tend to adopt HDTV, while other group-owned stations may lag in HDTV adoption. With regard to SDTV format, younger stations tend to show greater enthusiasm towards it, while revenue and business grouping seem to have little impact on SDTV adoption.

Chapter 6

Conclusions

This study attempts to examine the decision-making of American television stations during a government mandated transition to a new standard—digital television. The U.S. DTV transition is a perfect illustration of the interactions between economics, technology, and regulations. Under this framework and based on the theories on firms' choices, three key factors have been identified—firm size, business grouping, and age—which have the potential to impact firms' decisions on technology adoption. In the case of digital television, those factors are specified as station revenue, age, ownership and network affiliation. While the analysis on the relationship between digital television adoption decisions and station- and market-specific factors serves as a major part of this study, a further objective is set to exact lessons from the digital television case and to provide suggestions for another government-mandated standard transition in the future.

6.1 Adopting the new television standard and the aftermath

As discussed in chapter 2, the digital television (DTV) standard adopted by the FCC is an atypical standard. It is regarded as a non-standard standard, since more than one format—high definition (HDTV) and standard definition (SDTV)—are included in the new system. While the HDTV format offers better video quality; the SDTV format requires less spectrum space and thus introduces multiple broadcast feeds. Facing the format choices, this study shows that large and established stations tend to adopt high definition format sooner; while it took less time for small and young stations to switch to standard definition format.

Motivated by profit, every station has calculated the cost and benefit of switching earlier or later to digital, or of selecting HDTV versus SDTV or hybrid. In other words, the adoption timing and format choices of stations are largely associated with economic initiatives. Since the SDTV format is less expensive to implement, stations interesting in reducing cost have captured this advantage and managed to expedite their transition. Though the HDTV format has high facility requirement, it provides a noticeable improvement of video quality. Large stations interested in preserving market power have chosen this format to boost their brand image.

In general, the current technological change is an expensive transition for most broadcast stations. That is why a lot of stations have delayed switching to digital; while several stations are still struggling to obtain the financial resources to fund this transition. In contrast to the prediction that the DTV standard favors big stations and drives the smaller players out of business, rather the multi-format standard has divided stations into two groups. Group 1 is represented by large and established stations and by CBS affiliates; they have adopted HDTV in a timely manner. Group 2 is represented by small, young and independent stations; they managed to smoothly switch to SDTV.

Have the FCC only adopted the HDTV format as the new industry standard; many stations in small markets may be driven out of business because of the high facility requirement associated with HDTV. By including the SDTV format into the final standard, the FCC welcomes new business models based on a multi-format standard. Since the digital technology has largely enhanced the efficiency of broadcast spectrum, many stations are already using the additional spectrum spared by the DTV standard to transmit local information such as weather and traffic. As different digital formats are adopted and experimented by individual stations, new types of revenues will emerge for those innovative stations.

The findings on the DTV standard choices correspond to the arguments proposed by Tushman and Anderson (1986). The authors conceptualize two categories of technological changes: competence enhancing and competence destroying. In the case of digital television, the high definition format can be regarded as competence enhancing because the format itself is simply the improvement of the analog NTSC standard. The two changes provided by HDTV compared to NTSC are: digitalization and increased resolution. In contrast, the standard definition format should be considered as competence destroying, because this format creates discontinuity in broadcast television technology. The essence of the SDTV format is that it allows multiple programs to broadcast on a single channel simultaneously. The advantage of digitalization is best reflected by SDTV since this format indeed offers a new level of efficient deployment of public spectrum.

Therefore, the HDTV adoption—a competence enhancing technological change—tends to build on existing resources and skills in the industry. Old and established stations are in a good position to exploit the opportunities provided by HDTV. The SDTV format is fundamentally different from the analog NTSC standard in the sense that multiple programs rather merely one program can broadcast in the 6 MHz spectrum. This major change greatly challenges the old skills and knowledge in the business. Disruptive changes associated with the new standard may happen to the distribution of power and control in the industry. Referring to the statistical findings, younger and less prominent stations are found to be more willing to adopt SDTV for they notice the possibility of gaining market share by deploying this disruptive new technology. While SDTV has the potential to increase the market share of small stations through creating niche markets, the essential merit of SDTV is that it can foster new business models. In turn, the introduction of SDTV is likely to lead to a more competitive market for broadcast television.

While the technological change has full potential to reshape the television industry, its impact will only be materialized through economic means. The connection then needs to be drawn between the new technology and stations' revenues. As we know, advertising plays a dominant role in financing broadcast. Scholars like Owen and Wildman (1992) claim that broadcasters are in the business of producing audiences. In quest of the impact of digital television on stations' advertising revenues, some broadcasters were quite negative about the new technology. They projected that the new television standard will neither increase a station's or a network's audience nor expand its advertising revenue. It is definitely unwise to simply avoid the risks associated with a new technology and to ignore the possible benefit and values that can be created through technology adoption. Yet, whether the industry will prosper from the technological change depends on how broadcasters are adjusting to digital television. Adopting the digital standard is just the first step. To really take advantage of the new technology, broadcasters have to be aware of and prepared for new business models that are likely to be introduced by the new standard. In general, the new television standard with multiple formats has increased the potential of competition in the industry. Due to this technological change, established stations feel the urge to maintain their edge while young stations are exited to capture the niche market. Thus, it is fair to say that digital television has revived the television industry with new ideas of spectrum management and business models.

6.2 Lessons from the digital television transition

The American case of digital television transition started with a peculiar standard setting process. While in Japan and Europe, government and standard-setting organizations have been heavily involved in seeking the advanced television technologies; the U.S. Federal Communication Commission only serves as an initiator and a referee in the standardization process. In quest of advanced television systems, players from a wide range of industries were welcomed to engage in technology development. It is through the competition of several television systems developed by those players that the digital television standard eventually emerged. In this process, the FCC should be given credit for two parts. First, the Commission initiated and supervised a fair competition between domestic and foreign, television- and computer-manufacturing firms to develop the most advanced television system. Second, instead of letting different television systems compete against each other in the marketplace, the FCC has limited the competition to the testing stage. Through the contribution of and cooperation between players from different industries, digital television emerged as the best technology. Overall, the FCC has taken an atypical committee approach to set the new television standard; the highlight of this approach is the competition and compromise between committee members.

After the standard setting process, the next issue is how to implement the new standard throughout the country. Herein lies a big problem: incompatibility. While the digital system is regarded superior to analog systems; the new standard, ATSC DTV, is incompatible with the old standard, NTSC. To solve the compatibility issue, the FCC introduced a strategy of simulcasting which authorizes broadcasters to transmit analog and digital signals simultaneously. This strategy creates a transition phase for television stations to smoothly switch from analog to digital. While it is criticized that the FCC is favoring the interests of existing broadcasters, the simulcasting strategy, with out a doubt, has made it much easier for television stations to adjust to the new incompatible standard. It is hard to imagine how broadcasters can even make transition without the additional spectrum assigned by the FCC for simultaneous digital broadcasting. The simulcating policy turns out to be necessary because it helps solve the issue of incompatibility between old and new standards. It is a critical step taken by the FCC to enable digital television to successfully replace the dominant NTSC standard.

As discussed above, the FCC has definitely played important roles in hatching the new television standard. Established upon the Communication Act of 1934, the FCC has always been the key force of broadcast regulation. However, it is mistaken to regard the Commission as a regulator with absolute authority. In fact, many FCC decisions are subject to control and influence from Congress and the broadcast television industry. The digital television transition is no exception. On the one hand, the FCC has set a timetable requiring stations to switch to digital in a timely manner. On the other hand, Congress permits transition extensions for many stations that encounter finance difficulties.

The goal is to accelerate the transition when the FCC decided to adopt this market-staggered timeframe. However, repeated delays have appeared in this transition process due to the indulgent regulatory context of the United States. While the U.S. had taken the lead in advanced television development by introducing digital systems, it is unclear if the U.S. is leading the race of the DTV transition. Grimme (2002) highlights the British success of digital television and credits the country’s regulatory environment of encouraging competition from satellite providers and setting designated spectrum for digital services. In contrast, the potentially important role of satellite provides was skipped in the U.S. DTV transition mandate. In the meanwhile, the FCC—all too aware of the confrontational litigious culture in the industry-government relationship—has inevitably relaxed the DTV implementation timetable. However, it should also be noted that the FCC's unwillingness to fast track the transition can be attributed to its sympathetic and cooperative relationship with the broadcast industry.

The relaxed transition timetable suggests that the regulator is industry friendly, but ultimately it is viewers and broadcasters that determine the pace of the transition. First, consumers' awareness can definitely help increase the demand of the new technology. Second, firms' commitment to the new technology and improvement of their products are the key to fulfill the demand. A timely transition to a new technology can be achieved when these two conditions are satisfied. To ease the difficulty introduced by technological changes, it is recommended for regulators to activate a friendly environment for both firms and consumers. In the case of digital television transition, the regulatory authority—the FCC and Congress—has allowed flexible standard and flexible timetable for television stations to complete the digital switch. In other words, friendly regulatory environment has been formed for stations to concentrate on the implementation of digital television. However, there is a short of effort from both the FCC and television stations to grow the demand of digital television. In contrast to stations' adoption speed, viewers' demand of digital television can be viewed as constant over the last decade. To improve viewers' awareness of the new technology, it is wise for television stations to make considerable investment on advertising digital television. In the meanwhile, The FCC is also suggested to help promote the knowledge of digital television especially in rural areas and minor markets.

In the case of government-mandated standard transitions, regulators can play a determining role and optimize the outcome of technology diffusion. Firstly, the standard setting process should not be limited to any of those players alone: government, industry leader, industry coalition, or free-market. Rather, regulators should encourage and welcome ideas from all the possible sources. It is worth to note that regulators are not here to determine the best standard but to create a good environment for the best technology to emerge. Secondly, a critical issue associated standard setting is compatibility. Incompatibility may cause a new technology to fail before it even reaches the marketplace. The FCC has found a feasible solution to solve the incompatibility between the DTV and the NTSC standards. In general, regulators are strongly advised to consider compatibility as a significant factor during the standard setting process. If a new standard is not practical and can never reach the critical mass, it should not be selected in the first place. Thirdly, to promote the adoption of a new standard, it is nice of the regulators to relax the burdens on regulated firms during the transition process. But there is a more efficient way: regulators should introduce economic tools such as competition to motivate the commitment of the firms to the new technology. Obviously, the FCC failed to make this happen to digital television. American broadcasters have been reluctant to accept the new technology and to comply with the mandate. While the FCC may not be quite successful in enhancing the public's awareness of digital television, the local broadcasters have definitely invested little on promoting the new technology. Without viewers' awareness and potential demand, there is always a legitimate excuse for broadcasters to delay their transitions to digital.

6.3 Limitations of this study

Firstly, it should be noted that this study primarily focuses on technology diffusion in the television industry rather than management choice of broadcasters. The analysis on station choice in digital television transition is based on an aggregative perspective. In other words, the study mainly examines the diffusion patterns of the new television standard with regard to the demographics of television stations.

Secondly, one limitation of the analysis is associated with operationalization. According to Armour and Teece (1980), the vertical integration is expected to have a positive impact on technology adoption. In other words, the efficiency generated from business integration can reduce the cost of standard transition; such a factor may accelerate a firm's transition to a new technology. However, the findings show either insignificant or contradicting effects of vertical integration. The inconsistency has to with how vertical integration is measured. In this study, group ownership is employed to measure the factor. While the ownership variable is able to capture how many stations are grouped together under a same owner, it fails to differentiate O&O stations from other group-owned stations. While the former stations serve as a good indicator of vertical integration, such information is left out of the analysis in the operationalization stage.

Thirdly, while the survival analysis has provided valuable insights with regard to stations' standard choices in the DTV transition, there is a limitation associated with the dataset. According to Television & Cable Factbook, there are 1,313 commercial full power stations in the United States. But only 610 of them have been included in our DTV transition dataset; in other words, the Factbook has failed to record DTV adoption date for more than half of the stations in the population. Many of those missing stations tend to be in minor markets and have less revenue. It indicates that our sample—the DTV transition dataset—is skewed toward rich stations in major markets. While this limitation is unavoidable because the Television & Cable Factbook is the only comprehensive and publicly available database on television stations' digital transition; the validity of the sample and the analysis can be improved if the majority of the commercial full power stations voluntarily or enforcedly submit the information on their DTV adoption decisions.

However, this limitation is linked to another issue with regard to the DTV transition. As many of those missing stations tend to be less prominent and have less revenue, some of them may choose to exit the industry due to the cost of the transition. According to the GAO (2002b) report, first, many stations perceive little consumer support of the DTV transition; second, the expenditure for the transition can be overwhelming for some low-revenue stations. The report found that about 44 stations were considering sale of the stations as a way to fund the transition. On the one hand, the NAB reports that the majority of stations have adopted DTV; on the other hand, the missing stations in our dataset imply that there are at least a few stations that may choose to exit the industry because of financial difficulties. This problem suggests that more consumer awareness has to be raised by the FCC; in the meanwhile, television stations should engage in more promotion activities for digital television. Nonetheless, it is stations' responsibility to take advantage of the DTV standard—both HDTV and SDTV, to input more creativities in their programs, and to rediscover broadcast television. Thus, the installed base of the new technology would be smoothly achieved since viewers may find television once again attractive.

6.4 Summary

The digital television transition has provided intriguing research materials for many scholars. From the author's viewpoint, the case of digital television has been a showcase of regulators' engagement during technological changes. In many aspects, the Federal Communications Commission had done a good job in introducing the new television standard; but in the process of implementing the new standard stagnation, stagnation happened from time to time. The critical work of flourishing digital television is left to broadcasters but yet to be accomplished. In a government-mandated standard transition, the regulator can incorporate the contribution of the regulated industry to make wise decisions with regard to the new technology. But to successful implement and develop the new technology, it asks even more contribution from the regulated firms. After all, the digital television has brought both challenges and hopes to the broadcast television industry.

Bibliography

Acs, Z. J., and D. B. Audretsch. 1987. Innovation, market structure, and firm size. *The Review of Economics and Statistics*, 69/4, 567-574.

Adda, J., and M. Ottaviani. 2005. The transition to digital television. *Economic Policy*, 20/41, 160-209.

Agarwal, R., and D. B. Audretsch. 2000. Does entry size matter: The impact of the life cycle and technology on firm survival. *Journal of Industrial Economics*, 49/1, 21-43.

Akaike, H. 1974. A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, 19/6, 716–723.

Allison, P. 1984. *Event history analysis: Regression for longitudinal event data*. Newbury Park, CA: Sage Publications.

Anderson, J. 2007. Course notes on Survival Analysis. http://cda.morris.umn.edu/~anderson/math4601/notes/survival.pdf

Anonymous. 1979. Forcing technology: the Clean Air Act experience. *The Yale Law Journal*, 88/8, 1713-1734.

Arimura, T., A. Hibiki, S. Imai, and M. Sugino. 2005. An empirical analysis of the impact that environmental policy has on technological innovation. Paper prepared for The Economic and Social Research Institute, Government of Japan.

Armour, H. O., and D. J. Teece. 1980. Vertical integration and technological innovation. *The Review of Economics and Statistics*, 62/3, 470-474.

Beisea, M., and K. Rennings. 2005. Lead markets and regulation: a framework for analyzing the international diffusion of environmental innovations. *Ecological Economics*, 52/1, 5-17.

Besen, S. M. 1976. The value of television time. *Southern Economic Journal*, 42/3, 435-441.

Besen, S. M., and J. Farrell. 1994. Choosing how to compete: Strategies and tactics in standardization. *Journal of Economic Perspectives*, 8/2, 117-131.

Besen, S. M., and L. L. Johnson. 1986. Compatibility standards, competition, and innovation in the broadcasting industry. Rand Report R-3453-NSF. Santa Monica, CA: Rand.

BIA. 2006. *Investing in Television: Market Report* (1st ed.). Chantilly, VA: BIA Financial Network.

Box-Steffensmeier, J. and B. Jones. 2004. *Event History Modeling: A guide for social scientists*. New York, NY: Cambridge University Press.

Box-Steffensmeier, J. and B. Jones. 1997. Time is of the essence: Event history models in political science. *American Journal of Political Science,* 41/4, 1414-1461.

Brown, A. 2003. The digital future of terrestrial advertiser-supported television. *Prometheus*, 21/1, 41-57.

Brown, A., and R. G. Picard (Eds.). 2005. *Digital Terrestrial Television in Europe.* Mahwah, N.J. Lawrence Erlbaum.

Buis, M. L. 2006. An introduction to Survival Analysis. Unpublished working paper, http://home.fsw.vu.nl/m.buis/wp/survival.pdf

CBO. 1999. Completing the transition to digital television. Congressional Budget Office.

Chandy, R. K., and G. J. Tellis. 2000. The incumbent’s curse? Incumbency, size, and radical product innovation. *Journal of Marketing*, 64/3, 1-17.

Christensen, C. M. 1997. *The Innovator's Dilemma. When New Technologies Cause Great Firms to Fail*. Boston, MA: Harvard Business School Press.

Cleves, M, W. Gould, and R. Gutierrez. 2004. *An introduction to survival analysis using Stata*. Stata Press, TX.

Collins, R., N. Garnham, and G. Locksley. 1988. *The Economics of Television: The UK Case.* London, UK: Sage Publications.

Cole, B., and M. Oettinger. 1978. *Reluctant Regulators: The FCC and the Broadcast Audience*. Reading, MA: Addison-Wesley Publishing Company.

Collins, R., N. Garnham, and G. Locksley. 1988. *The Economics of Television: The UK Case*. London, UK: Sage Publications.

Congress. 1997. Title III--Communications and Spectrum Allocations Provisions. In *The Balanced Budget Act of 1997.*

David, P., and S. Greenstein. 1990. The economics of compatibility standards: An introduction to recent research. *Economics of Innovation and New Technology*, 1/1-2, 3-41.

Dean, T. J. and R. L. Brown. 1995. Pollution regulation as a barrier to new firm entry: initial evidence and implications for future research. *The Academy of Management Journal*, 38/1, 288-303.

Demographics USA: County Edition. 2006. New York, NY: Market Statistics.

Diermeier, D. and R. Stevenson. 1999. Cabinet survival and competing risks. *American Journal of Political Science.* 43/4, 1051-1068.

Dowell, G., A. Swaminathan, and J. Wade. 2002. Pretty pictures and ugly scenes: Political and technological maneuvers in high definition television. *Advances in Strategic Management*, 19, 97-134.

DMA Market Rank and Demographic Rank Report. 2006. New York, NY: Nielsen Station Index.

Dupagne, M., and P. B. Seel. 1998. *High-Definition Television: A Global Perspective.* Ames, IA: Iowa State University Press.

Ekelund, R. B., G. S. Ford, and J. D. Jackson. 2000. Are local TV markets separate Markets? *International Journal of the Economics of Business*, 7/1, 79-97.

Farrell, J. 1996. Choosing the rules for formal standardization. Unpublished working paper, http://elsa.berkeley.edu/~farrell/ftp/choosing.pdf

Farrell, J. Shapiro, R. R. Nelson, and R. G. Noll. 1992. Standard setting in high-definition television. *Brookings Papers on Economic Activity: Microeconomics*, 1992, 1-93.

Farrell, J. and G. Saloner. 1988. Coordination through committees and markets. *RAND Journal of Economics*, 19/2, 235 - 252.

Farrell, J. and G. Saloner. 1985. Standardization, compatibility and innovation. *RAND Journal of Economics*, 16/1, 70 - 83.

FCC. 2007. Third Periodic Review of the Commission's Rules and Policies Affecting the Conversion to Digital Television. FCC 07-70. MB Docket No. 07-91.

FCC. 2006. Twelfth Annual Report: Annual Assessment of the Status of Competition in the Market for the Delivery of Video Programming. FCC 06-11. MB Docket No. 05-255.

FCC. 2005. Eleventh Annual Report: Annual Assessment of the Status of Competition in the Market for the Delivery of Video Programming. FCC 05-13. MB Docket No. 04-227.

FCC. 2004. Second Periodic Review of the Commission's Rules and Policies Affecting the Conversion to Digital Television. FCC 04-192. MB Docket No. 03-15.

FCC. 1998. The development of operational, technical and spectrum requirements for meeting federal, state and local public safety agency communication requirements through the year 2010. FCC 98-191. WT Docket No. 96-86.

FCC. 1997a. Fifth Report and Order: Advanced Television Systems and Their Impact upon the Existing Television Broadcast Service. FCC 97-116. MM Docket No. 87-268.

FCC. 1997b. Sixth Report and Order: Advanced Television Systems and Their Impact upon the Existing Television Broadcast Service. FCC 97-115. MM Docket No. 87-268.

FCC. 1997c. Report and Order: Reallocation of Television Channels 60-69, the 746-806 MHz Band. FCC 97-245. ET Docket No. 97-157.

FCC. 1996a. Fourth Report and Order: Advanced Television Systems and Their Impact upon the Existing Television Broadcast Service. FCC 96-493. MM Docket No. 87-268.

FCC. 1996b. Title II—Broadcast Services. In *The Telecommunication Act of 1996.*

Fisher, F. M., J. J. McGowan, and D. S. Evans. 1980. The audience-revenue relationships for local television stations. *The Bell Journal of Economics*, 11/2, 694-708.

Foray, D. 1995. Coalitions and committees: how users get involved in information technology standardization. In R. Hawkins, R. Mansell, and J. Skea (Ed.), *Standards, Innovation and Competitiveness: The Politics and Economics of Standards in Natural and Technical Environments*. Aldershot, UK and Brookfield, US: Edward Elgar.

Fratrik, M. R. 1989. The television audience-revenue relationship revisited. Paper presented at the meeting of the Broadcast Education Association, Las Vegas, NV.

Funk, J. L., and D. T. Methe. 2001. Market- and committee-based mechanisms in the creation and diffusion of global industry standards: The case of mobile communication. *Research Policy*, 30/4, 589-610.

GAO. 2002a. Additional federal efforts could help advance digital television transition. United States General Accounting Office, GAO-03-7.

GAO. 2002b. Many broadcasters will not meet May 2002 digital television deadline. United States General Accounting Office, GAO-02-466.

Galperin, H. 2004. New Television, Old Politics: The Transition to Digital TV in the United States and Britain. New York, NY: Cambridge University Press.

Gotz, G. 1999. Monopolistic competition and the diffusion of new technology. *The RAND Journal of Economics*, 30/4, 679-693.

Gray, W. B. and R. J. Shadbegian. 1998. Environmental regulation, investment timing, and technology choice. *The Journal of Industrial Economics*, 46/2, 235-256.

Grimme, K. 2002. *Digital Television Standardization and Strategies*. Boston, MA: Artech House.

Grindley, P. 1995. *Standards Strategy and Policy*. Oxford, UK: Oxford University Press.

Gruber, H. and F. Verboven. 2001. The evolution of markets under entry and standards regulation: the case of global mobile telecommunications. *International Journal of Industrial Organization*, 19/7, 1189-1212.

Guerrero, P. F. 2002. History and current issues related to radio spectrum management. Washington, D. C.: General Accounting Office.

Hall B.H., and B. Khan. 2003. Adoption of new technology. In D. C. Jones (Ed.), *The New Economy Handbook*. San Diego, CA: Academic Press.

Hall, P., and I. L. Densten. 2002. Following successfully: Followership and technology adoption. *Prometheus*, 20/2, 87-105.

Hall, R. T. 2002. Stretching the Peacock: From Color Television to High Definition Television, and Historical Analysis of Innovation, Regulation and Standardization. Doctoral Dissertation, Evanston, IL: Northwestern University.

Hart, J. A. 2004. *Technology, Television, and Competition: The Politics of Digital TV*. New York, NY: Cambridge University Press.

Hazlett, T. W. 2001. The U.S. digital TV transition: Time to toss the Negroponte switch. AEI-Brookings Joint Centre Working Paper No. 01-15. http://ssrn.com/abstract=292655

Hemenway, D. 1975. *Industry-Wide Voluntary Product Standards*. Cambridge, UK: Ballinger Publishing Co.

Hougaard, P. 2000. *Analysis of multivariate survival data*. New York, NY: Springer.

Huff, W. A. 2001. *Regulating the Future: Broadcasting Technology and Government Control*. Westport, CT: Greenwood Press.

Humphreys, P., and M. Lang. 1998. Digital television between the economy and pluralism. In J. Steemers (Ed.), *Changing Channels: The Prospects for Television in a Digital World,* 9–35. Luton, Bedfordshire: University of Luton Press.

Ishii, J. 2004. Technology adoption and regulatory regimes: Gas turbine electricity generators from 1980 to 2001. University of California Energy Institute Working Paper, http://www.ucei.berkeley.edu/pwrpubs/csem128.html

Jaffe, A. B., R. Starvins, and R. G. Newell. 2002. Environmental policy and technological change. *Environmental and Resource Economics*, 22/1-2, 41-70.

Jaffe, A. B., S. R. Peterson, P. R. Portney, and R. Stavins. 1995. Environmental regulation and the competitiveness of U.S. manufacturing: What does the evidence tell us? *Journal of Economic Literature*, 33/1, 132-163.

Jankowski, G. F., and D. C. Fuchs. 1995. *Television Today and Tomorrow*. New York, NY: Oxford University Press.

Karshenas, M., and P. L. Stoneman. 1993. Rank, stock, order, and epidemic effects in the diffusion of new process technologies: An empirical model. *The RAND Journal of Economics*, 24/4, 503-528.

Kerr, S. and R. G. Newell. 2003. Policy-induced technology adoption: Evidence from the U.S. lead phasedown. *The Journal of Industrial Economics*, 51/3, 317-343.

Klepper, S., and K. L. Simons. 2000. Dominance by birthright: Entry of prior radio producers and competitive ramifications in the U.S. television receiver industry. *Strategic Management Journal*, 21/10-11, 997-1016.

Kollman, K. and A. Prakash. 2001. Green by choice: Cross-national variations in firms' responses to EMS-based environmental regimes. *World Politics*, 53/April, 399-430.

Koschat, M. A., and W. P. Putsis Jr. 2000. Who wants you when you're old and poor? Exploring the economics of media pricing. *Journal of Media Economics*, 13/4, 215–32.

Koski, H., and T. Kretschmer. 2005. Entry, standards and competition: Firm strategies and the diffusion of mobile telephony. *Review of Industrial Organization,* 26/1, 89-113.

Kruger, L. G. 2005. Digital television: An overview. Congressional Research Service report for Congress.

Levy, J., M. Ford-Levy, and A. Levine. 2002. Broadcast television: Survivor in a sea of competition. The FCC working paper, www.fcc.gov/ownership/materials/already-released/**survivor**090002.pdf

Lieberman, M. B. and D. B. Montgomery. 1998. First-mover (dis)advantages: Retrospective and link with resource-based view. *Strategic Management Journal*, 19/12, 1111-1125.

Lieberman, M. B., and D. B. Montgomery. 1988. First-mover advantages. *Strategic Management Journal*, 9/summer, 41–58.

Loebbecke, C., and R. G. Picard. 2005. The impact of regulatory issues and market structure on the digital television industry: A comparison of the German and Swedish markets. JIBS Working Paper Series No. 2005-2.

Majumdar, S. K., and S. Venkataraman. 1998. Network effects and the adoption of new technology: Evidence from the U.S. telecommunications industry. *Strategic Management Journal*, 19/11, 1045-1062.

NAB. 2007. DTV stations in operation. National Association of Broadcasters, http://www.nab.org/AM/ASPCode/DTVStations/DTVStations.asp

Nelson, R. R., and S. G. Winter. 2002. Evolutionary theorizing in economics. *Journal of Economic Perspective*, 16/2, 23–46.

Nelson, R. R., and S. G. Winter. 1982. *An Evolutionary Theory of Economic Change*. Cambridge, MA: Harvard University Press.

Oberg, J. K. 2000. Facing the digital future, darkly: Television station managers' approach towards the implementation of digital broadcasting. Unpublished working paper, http://www.beaweb.org/bea2000/papers/oberg.pdf

Owen, B. M., J. H. Beebe, and W. G. Manning, Jr. 1974. *Television Economics*. Lexington, MA: Lexington Books.

Owen, B. M., and S. S. Wildman. 1992. Advanced Television. In B. M. Owen and S. S. Wildman, *Video Economics*. Cambridge, MA: Harvard University Press.

Park, R. E. 1975. New television networks. *Bell Journal of Economics*, 6/2, 607-620.

Parker, R. 1999. The Economics of Digital TV's Future. In Darcy Gerbarg (Ed.), *The Economics, Technology and Content of Digital TV*. Boston, MA: Kluwer Academic Publishers.

Pashigian, B. P. 1984. The effect of environmental regulation on optimal plant size and factor shares. *Journal of Law & Economics*. 27/1, 1-27.

Poltrack, D. F. 1983. *Television Marketing: Network, Local, and Cable*. New York, NY: McGraw-Hill.

Popp, D. 2006. Exploring links between innovation and diffusion: Adoption of NOX control technologies at U.S. coal-fired power plants. NBER Working Papers 12119.

Rhodes, R. M. 2004. Analyzing Digital Television: Using the Diffusion of Innovation Theory to Better Inform Policy. Master Thesis, Gainesville, FL: University of Florida.

Rose, N. L., and P. L. Joskow. 1990. The diffusion of new technologies: Evidence from the electric utility industry. *The RAND Journal of Economics*, 21/3, 354-373.

Rosen, B. N., S. P. Schnaars and D. Shani. 1988. A comparison of approaches for setting standards for technological products. *Journal of Product Innovation Management*. 5/2, 129-139.

Sauter, K. 1988. The local television station. In J. Walker and D. Ferguson, *The Broadcasting Television Industry*, 83-104. Boston, MA: Allyn and Bacon.

Schumpeter, J. A. 1950. *Capitalism, Socialism and Democracy*. New York, NY: Harper.

Slotten, H. R. 2000. *Radio and Television Regulation: Broadcast Technology in the United States, 1920—1960*. Baltimore, MD: The Johns Hopkins University Press.

Smith, F. L., M. Meeske and J. W. Wright II. 1995. *Electronic Media and Government: The Regulation of Wireless and Wired Mass Communication in the United States*. New York, NY: Longman.

Snyder, L., N. Miller, R. Stavins. 2003. The effects of environmental regulation on technology diffusion: The case of chlorine manufacturing. Discussion Papers dp-03-25, Resources for the Future. http://www.rff.org/documents/RFF-DP-03-25.pdf

SQAD. 2006. *Media market guide: Local*. New York: Conceptual Dynamics.

Sterling, C. H. 2003. High-definition television as policy failure. J*ournal of Broadcasting & Electronic Media*. 47/1, 146-148.

Stoddard, R., and Smith, M. O. 2002. The transition to digital television. White paper prepared by the National Cable & Telecommunications Association, http://www.ncta.com/ContentView.aspx?hidenavlink=true&type=reltyp1&contentId=201

Sydney, W. H., T. Spann and M. A. McGregor. 2001. *Broadcasting in America: A Survey of Electronic Media* (9th ed). Boston, MA: Houghton Mifflin Company.

Therneau, T. M., and P. M. Grambsch. 2000. *Modeling Survival Data: Extending the Cox Model*. New York, NY: Springer.

Thomas, L., and B. R. Litman. 1991. Fox broadcasting company, why now: An economic study of the rise of the fourth broadcast “network”. *Journal of Broadcasting and Electronic Media*, 35/2, 139-157.

Tilson, D., and K. Lyytinen. 2004. The 3G transition: Changes in the U.S. wireless industry. *Sprouts: Working papers on information environments, systems and organization,* 4/3, 131-150.

Tushman, M. L., and Anderson, Philip. 1986. Technological discontinuities and organizational environments. *Administrative Science Quarterly*, 31/3, 439–65.

Walker, J., and D. Ferguson. 1998. *The Broadcast Television Industry*. Boston, MA: Allyn and Bacon.

Warren Publishing. 2006. *Television & Cable Factbook*. Stations Volume, 1-2.

Webster, J. G., and P. F. Phalen. 1997. *The Mass Audience Rediscovering the Dominant Model*. Mahwah, NJ: Lawrence Erlbaum Associates.

Welch, E. W., A. Mazur, and S. Bretschneider. 2000. Voluntary behavior by electric utilities: Levels of adoption and contribution of the Climate Challenge Program to the reduction of carbon dioxide. *Journal of Policy Analysis and Management*, 19/3, 407-425.

Williams, M. 2007. Researchers craft HDTV's successor. *IDG News Service,* May 28, 2007. http://www.pcworld.com/article/id,132289-c,hdtv/article.html.

Wooldridge, J. M. 2000. Introductory Econometrics: A Modern Approach. Cincinnati, OH: South-Western College Publishing.

Appendix A

Descriptive statistics

A.1 Revenue distribution

Figure **A.1**

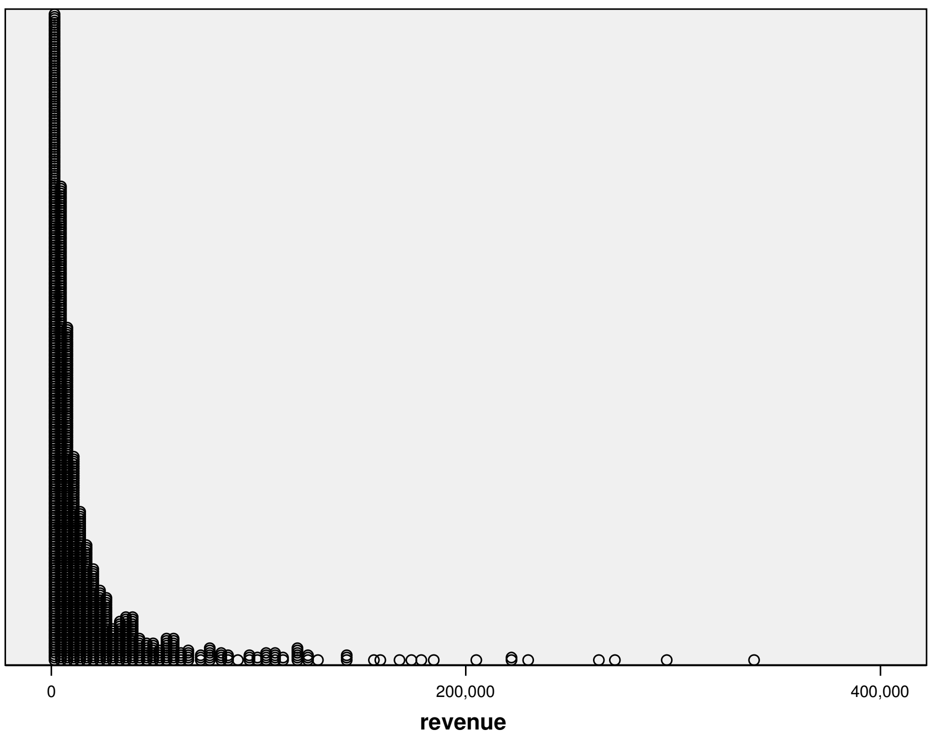


Figure **A.1**: *Revenue* distribution

Figure **A.2**

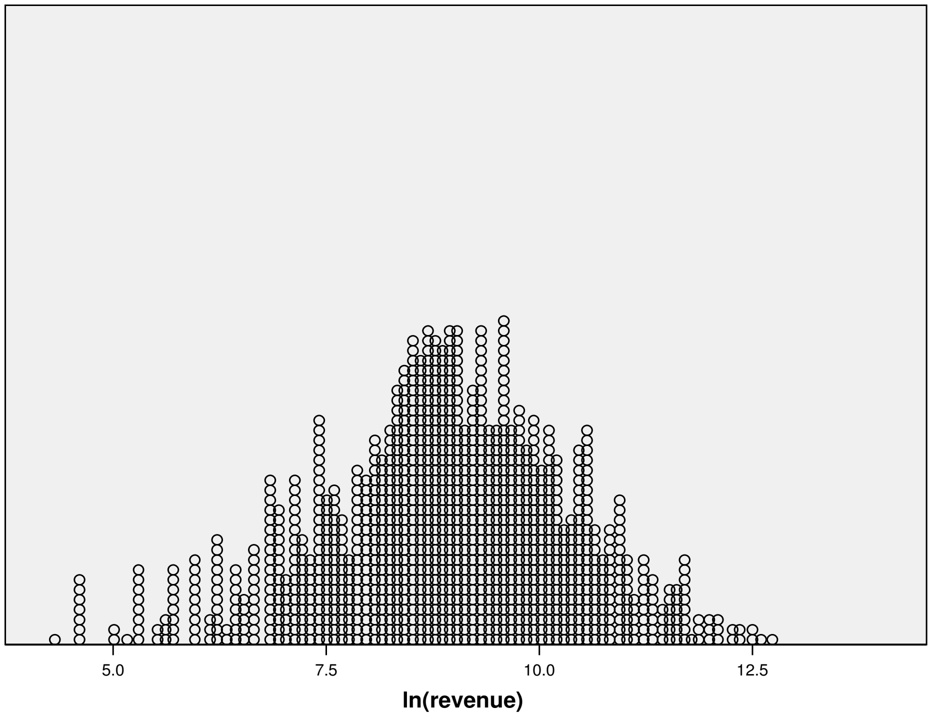


Figure **A.2**: *ln(revenue)* distribution

A.2 Samples and population comparison

Table **A.1**

Table **A.1**: Sample 1 and missing data comparison

	Sample 1	N	Missing	N	Mean difference	t statistics
Revenue (000)	28720.79	534	9069.22	558	19651.566	10.40***
Age	38.64	609	31.54	699	7.10	7.61***
Ownership5	2.96	610	2.57	703	.39	5.81***

Note: ^- significant at .1 level, * - significant at .05 level, ** - significant at .01 level, *** - significant at .001 level.

Table **A.2**

Table **A.2**: Station statistics

	N	Min	Max	Mean	SD
Rank	610	1	207	56.90	49.95
Revenue (000)	534	100	339100	28720.79	41380.49
$\ln(revenue)$	534	4.32	12.73	8.90	1.46
Age	609	4	67	38.64	16.63
Group ownership	610	1	57	21.07	16.14
ABC	610	0	1	.17	.38
CBS	610	0	1	.18	.38
NBC	610	0	1	.18	.38
Fox	610	0	1	.12	.32
Top 4 network	610	0	1	.64	.48
Digital on-air date	610	01-JAN-1997	01-JUN-2006	20-JAN-2002	
The FCC deadlines	610	01-MAY-1999	01-MAY-2002	22-OCT-2001	
$time$ (days)	610	8	3446	1853.30	570.03
t_fcc	610	-1492	1673	-89.59	431.09

Note: 1. Television & Cable Factbook has provided the DTV adoption dates for 610 stations; only these stations are included here.
2. $time$ indicates the days between December 24, 1996 and the date when a station starting to broadcast digital signals.
3. t_fcc presents the days between a station's digital on-air date and the FCC deadline.

Table **A.3**

Table **A.3**: Station network affiliation distribution comparison

	ABC	CBS	NBC	Fox	Others	Top4	Total
Population	219	216	217	186	474	838	1312
Sample1	103	109	107	72	209	391	610
Sample2	66	72	69	44	139	251	390

Note: Sample 1 includes stations with information on the timing of DTV adoption; sample 2 includes stations with information on DTV format choice.

Table **A.4**

Table **A.4**: Station ownership distribution comparison

	Local	Small	Medium	Large	Super large	Total
Population	247	325	358	276	107	1313
Sample1	89	118	185	167	51	610
Sample2	53	72	123	105	37	390

Note: Sample 1 includes stations with information on the timing of DTV adoption; sample 2 includes stations with information on DTV format choice.

Table **A.5**

Table **A.5**: Station ownership frequency

Group ownership	Frequency	Cumulative percentage	Ownership5
1	153	11.65	Local
2	94	18.81	Local
3	57	23.15	Small
4	48	26.81	Small
5	25	28.71	Small
6	48	32.37	Small
7	21	33.97	Small
8	72	39.45	Small
9	54	43.56	Small
10	40	46.61	Medium
11	11	47.45	Medium
12	48	51.10	Medium
13	13	52.09	Medium
14	42	55.29	Medium
17	34	57.88	Medium
20	20	59.41	Medium
22	22	61.08	Medium
23	23	62.83	Medium
25	25	64.74	Medium
26	26	66.72	Medium
27	54	70.83	Medium
30	30	73.12	Large
33	33	75.63	Large
34	68	80.81	Large
36	108	89.03	Large
37	37	91.85	Large
50	50	95.66	Super large
57	57	100	Super large

Appendix B

DTV adoption pattern

B.1 DTV adoption times: Survival models

Table **B.1**

Table **B.1**: Sample 1 covariates correlations

	DMA rank	Top 4	ABC	CBS	NBC	Fox	Ownership5	Age	ln(*revenue*)
DMA rank	1								
Top 4	.41	1							
ABC	.14	.32	1						
CBS	.14	.32	-.21	1					
NBC	.14	.33	-.21	-.20	1				
Fox	.10	.30	-.20	-.19	-.20	1			
Ownership5	-.34	-.11	-.087	-.016	-.0038	-.036	1		
Age	-.0024	.57	.23	.34	.34	-.20	.059	1	
ln(*revenue*)	-.47	.36	.098	.16	.18	.0012	.23	.63	1

Note: Sample 1 includes stations that are recorded with the DTV adoption dates: $n = 534$

Table **B.2**

Table **B.2**: DTV adoption times—Stratified survival models with network indicators

	Cox	Weibull	Log-logistic
ln(*revenue*)	.12* (.057)	.11 (.067)	-.017^ (.010)
Age	.0011 (.0041)	.0052 (.0045)	-.00082 (.00081)
Ownership5	-.021 (.041)	-.00071 (.051)	.011^ (.0062)
DMA rank	-.0040** (.0015)	-.0045* (.0019)	.00069** (.00024)
ABC	.31^ (.19)	.22 (.20)	-.027 (.030)
CBS	.32 (.20)	.15 (.23)	-.033 (.035)
NBC	.35^ (.19)	.26 (.22)	-.034 (.035)
Fox	.23 (.18)	.18 (.23)	-.018 (.027)
Intercept strata		16.95*** (2.59)	-.61*** (.040)
Intercept		-39.19*** (2.09)	7.73*** (.090)
ln (parameter) strata		-.53*** (.099)	.69*** (.16)
ln (parameter)		1.60*** (.050)	-2.19*** (.083)
Likelihood	-2546.79	-27.25	-16.29
Wald χ^2	27.23***	64.41***	447.82***
df	8	9	9
N	534	534	534

Note: ^- significant at .1 level, * - significant at .05 level, ** - significant at .01 level, *** - significant at .001 level.

B.2 DTV standard choices: Ordinal logistic model

Table **B.3**

Table **B.3**: Sample 2 covariates correlations

	HDTV	Format	MA rank	Top 4	ABC	CBS	NBC	Fox	Ownership5	Age	ln(*revenue*)
HDTV	1										
Format	.94	1									
DMA rank	-.042	-.054	1								
Top 4	.38	.35	.32	1							
ABC	.17	.075	.063	.33	1						
CBS	.34	.37	.098	.35	-.22	1					
NBC	.14	.15	.25	.34	-.21	-.23	1				
Fox	-.22	-.20	-.017	.26	-.17	-.18	-.17	1			
Ownership5	-.041	-.025	-.25	-.12	-.13	.029	-.041	.063	1		
Age	.43	.39	.12	.69	.24	.36	.33	-.090	-.12	1	
ln(*revenue*)	.38	.38	-.43	.46	.12	.21	.14	.11	.044	.60	1

Note: Sample 2 includes

Table **B.4**

Table **B.4**: DTV format choices—Ordinal logistic model

Dependent: Format

	Group 1	Group 2	Group 2	All	All
ln(*revenue*)	.45	.57*	.50*	.54**	.41^
	(.60)	(.24)	(.25)	(.19)	(.22)
Age	.037	.029*	.018	.031**	.023*
	(.026)	(.012)	(.013)	(.011)	(.011)
Ownership5	.047	.010	-.0033	-.00095	-.0026
	(.31)	(.12)	(.12)	(.11)	(.11)
DMA rank	.038	.0037	-.0015	.0032	-.00065
	(.036)	(.0040)	(.0051)	(.0037)	(.0045)
Top4			.94*		.76^
			(.48)		(.43)
_cut1	6.72	7.23	6.18	6.77	5.51
	(6.38)	(2.19)	(2.37)	(1.82)	(2.04)
_cut2	7.54	7.88	6.83	7.46	6.21
	(6.41)	(2.20)	(2.38)	(1.83)	(2.05)
likelihood	-80.27	-218.17	-216.00	-299.86	-297.94
Wald χ^2	4.90	29.58***	35.08***	46.25***	52.70***
df	4	4	5	4	5
pseudo R^2	.04	.11	.11	.11	.12
N	82	266	266	348	348

Note: ^- significant at .1 level, * - significant at .05 level, ** - significant at .01 level, *** - significant at .001 level.

Table **B.5**

Table **B.5**: DTV format choices—Ordinal logistic model with network indicators

Format	Group1	Group2	All
ln(*revenue*)	.067	.61*	.47*
	(.55)	(.26)	(.22)
Age	.030	-.019	-.0058
	(.034)	(.019)	(.014)
Ownership5	.29	.0027	.022
	(.40)	(.13)	(.12)
DMA rank	.020	-.0025	-.0024
	(.039)	(.0055)	(.0048)
ABC	1.23	1.94**	1.37**
	(.84)	(.68)	(.52)
CBS	3.33**	2.72***	2.59***
	(.98)	(.73)	(.58)
NBC	2.74**	1.78*	1.72**
	(.97)	(.75)	(.61)
Fox		-1.09	-.67
		(.84)	(.60)
_cut1	4.21	6.23	5.26
	(5.71)	(2.49)	(2.10)
_cut2	5.31	6.95	6.06
	(5.76)	(2.49)	(2.11)
likelihood	-67.75	-201.64	-275.02
Wald χ^2	19.59**	57.53***	94.52***
df	7	8	8
pseudo R^2	.19	.17	.19
N	82	266	348

Note: ^- significant at .1 level, * - significant at .05 level, ** - significant at .01 level, *** - significant at .001 level.

B.3 DTV standard choices: Competing risks model

Figure **B.1**

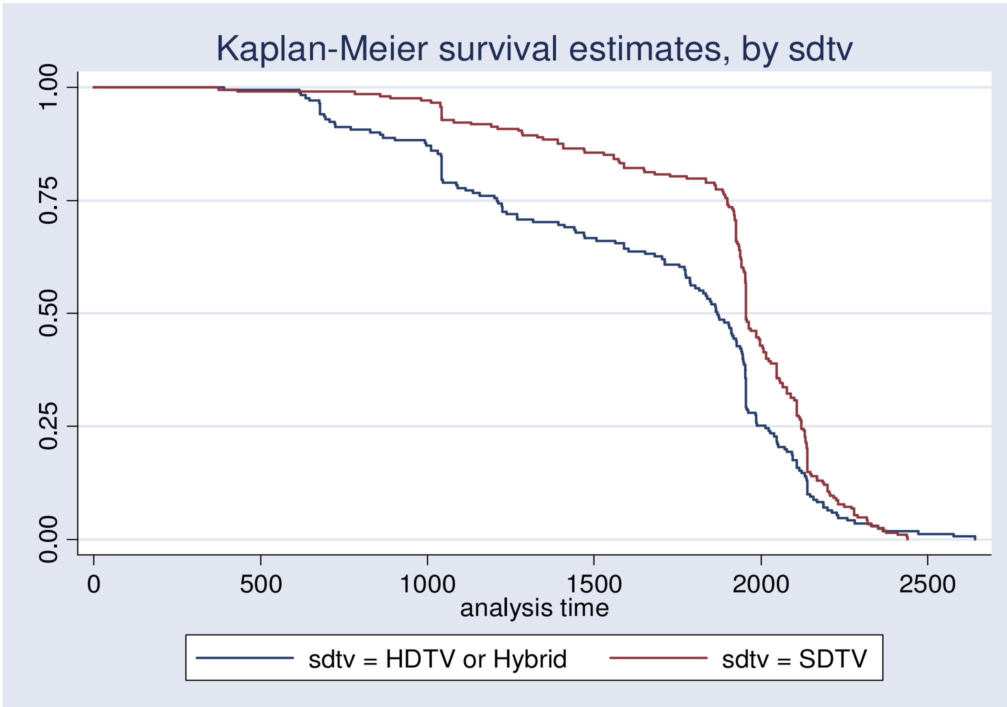


Figure **B.1**: DTV adoption times by format choices

VITA

Pinjia Liao

Education

THE PENNSYLVANIA STATE UNIVERSITY
Doctor of Philosophy, Mass Communications 2003 –2007

MICHIGAN STATE UNIVERSITY
Master of Arts, Telecommunication, Information Studies and Media 2001 - 2003

TSINGHUA UNIVERSITY, BEIJING
Bachelor of Arts, Journalism and Communication 1997 - 2001

Assistantships

RESEARCH ASSISTANT 2005, 2006
INSTITUTE FOR INFORMATION POLICY, THE PENNSYLVANIA STATE UNIVERSITY

TEACHING ASSISTANT 2003, 2004
COLLEGE OF COMMUNICATIONS, THE PENNSYLVANIA STATE UNIVERSITY

TEACHING ASSISTANT 2003
DEPARTMENT OF TELECOMMUNICATION, MICHIGAN STATE UNIVERSITY

Skills

Proficient in SPSS, STATA, AMOS, MINITAB, MS Word, MS Excel, MS PowerPoint, Dreamweaver, and Photoshop.

Has experience and a strong background in regression analysis, multivariate statistics analysis, structural equation model analysis, survival analysis, and time series analysis.