An Empirical Model of Investment by Cable Operators in Broadband Digital Services*

under journal submission

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July 2009

Abstract

This paper provides an empirical analysis of the investment decisions of individual cable television operators in the U.S. I examine the cable operators' decisions to diversify into offering broadband digital services such as high-speed Internet access and digital cable television over the period from 2000 to 2005. Using a panel data set of 269 geographically-segmented markets, I estimate a dynamic programming model of these investment decisions and quantify how ownership, local market characteristics, economies of scope, economies of scale and sunk costs in this industry together impact firms' investment decisions by affecting the discounted expected profits of different choices. The model accommodates the fact that many firms choose sequential diversification into more than one broadband digital service by first initiating one service and adding the other one at a later date. After estimating the model using the nested pseudo-likelihood estimator, I find that the entry costs and unobserved shocks of offering different broadband digital services significantly affect cable operators' entry decisions. The entry cost for offering two digital services simultaneously is substantially greater than the cost of offering only one digital service as well as the entry cost when sequential diversification is undertaken. In addition, I find that the probability of offering digital service rises with local basic cable prices, and economies of scope and economies of scale encourage cable operators to eventually diversify into offering two digital services. This study provides an explanation for the delayed broadband diffusion and predicts that policies to lower entry costs can help the cable operators to accelerate broadband diffusion. Several counterfactual policy experiments are also implemented using the estimated model.

Keywords: Broadband diffusion, cable system operator,dynamic discrete choice, sunk costs, nested-pseudo loglikehood estimation.

Classification: L0, L1, L5, L9.

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*This is from one chapter of my doctoral thesis at the Pennsylvania State University. I am very grateful to Herman Bierens, Edwards Coulson, Shane Greenstein, Jayakar Krishna, Joris Pinkse, and Mark Roberts, for their continual support, helpful comments and encouragement. All errors are my own.

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1 Introduction

Since the late 1990s, a growing body of empirical research in telecommunications economics has focused on the U.S. broadband market. Though broadband technologies have been widely acknowledged as the backbone of an information economy and many countries invest heavily in this industry, the US has lagged behind in its broadband deployment since 2000. A recent report by the OECD ranked the U.S. 15^{th} in its broadband penetration rate by the end of 2008. Moreover, the "digital divide" in broadband availability between urban and rural areas in the US is recognized as a top-issue on the regulator's agenda. Many studies attribute the phenomena to insufficient demand or a lack of competition in the market[1]. Though this line of research highlights certain demographic or regulatory variables that are of great significance on broadband availability, the importance of a large amount of investment costs for expansion into broadband products has not received much attention in most of the analyses. Large sunk investment in the U.S. may be one of the reasons for the slow broadband diffusion. For example, the network upgrading cost of a large cable company to employ broadband services in Japan is less than 10% of that in the U.S.[2]. In addition, the broadband deployment data used in most research was collected by the Federal Communications Commission in the early 2000s, and no specific firm-level information is publicly available. Therefore, the plausible causality conclusions may be inadequate for current policy evaluation in this dynamic industry.

This paper furthers current understanding of broadband diffusion by fully investigating the role of sunk cost in investment decisions by an important group of broadband access providers, "individual cable operators"[3]. In the broadband market, cable television companies and telephone companies are the main providers and long-standing incumbents in the traditional analog cable television service market and the public switch service market, respectively. To both firms, the broadband diffusion decision is not independent of their traditional video programming or voice services, and the different broadband product decisions are not independent of one another. Especially for cable operators, broadband technologies allow them to provide both digital video programming services and high-speed Internet access service using the same infrastructure along with their traditional analog cable television services. There exists economies of scope in providing as many digital services as possible to share large sunk costs in the infrastructure investment. As a result, the benefits from economies of scope can encourage the incumbent firms to invest more to enter new businesses even in the presence of a large sunk entry cost. Therefore by incorporating various new broadband digital services and traditional services, I can generate a more accurate assessment of the role of sunk costs in broadband diffusion among individual cable operators, and improve the counterfactual policy analysis based on the model.

More specifically, in this paper I examine investment decisions, by cable television operators in the U.S., to diversify into offering broadband digital services such as high-speed Internet access and digital cable television over the period from 2000 to 2005. I develop a dynamic programming model of the cable operators' digital product decisions using a panel data set of 269 geographically-segmented markets, and quantify how local market characteristics, economies of scope, economies of scale and sunk costs in this industry together impact the firms' investment decisions by affecting the discounted

[1] Hausman, Sidak, and Singer(2001), Crandall, Sidak, and Singer(2002), Rappoport et al.(2003a, 2003b), Clements and Abramowitz(2006), Grubesic(2003,2004), Grubesic and Murray(2004),Prieger(2003), Hu and Prieger(2005)

[2] According to a recent report, Jupiter Telecommunications, the largest cable company in Japan need to invest $20 per home passed in the network infrastructure to provide 160 megabits-per-second. However, Verizon has to spend more than an average of $800 per home passed to wire neighborhoods for its FiOS fiber optic network and another around $700 for equipment and labor in each home that subscribes. Source: *The New York Times*, by Saul Hansell, April 30, 2009.

[3] A recent paper by Xiao and Orazem(2007) adopts Reiss and Bresnaham's framework, and address the importance of sunk costs in assessing firms' competitive conduct in the market between 1999 and 2003. Their results support the use of a dynamic entry model to assess market evolution and competition, though their model is not a dynamic structural model.

expected profits of different choices. The model accommodates the fact that many firms choose sequential diversification into more than one broadband digital service by first initiating one service and then adding the other one at a later date. After estimating the model using the nested pseudo-likelihood estimator(Hotz and Miller(1993), Aguirregabiria and Mira(2002)), I find that the entry costs of offering different broadband digital services significantly affect cable operators' entry decisions. In particular, the entry cost of simultaneously offering both digital cable and high-speed Internet access services doubles that of offering only one digital service, and also significantly more than the total sum of entry costs when sequential diversification is added later. The entry costs for offering both digital services are greatly reduced if the cable operator undertakes sequential diversification. This provides an explanation for the slow broadband diffusion during the early 2000s.

Consider some broadband policies implemented by other countries, I also conduct several interesting counterfactuals that attempt to capture certain features of these policies and investigate how these policies may affect broadband diversification in current setting by using the estimated model. When lump-sum subsidy to offering two digital services are introduced, the cable systems start their digital offering earlier and more systems end up offering two digital products throughout the sample period. When a non-discriminate subsidy is provided through basic cable service to all firms, more firms start to offer two digital services earlier, but this trend does not continue for the last two years of the period. However, if an ongoing incentive is provided to firms who offer digital services, the broadband diversification can be accelerated. If competition policy is introduced to reduce the profit gains from broadband services,the broadband diversification is slower in the beginning. Depending on the size of the gains reduction in these services, we may still have more firms are likely to provide two digital services. At the same time, competition may also disqualify some firms from entering broadband market. As a result, more firms will not offer any digital service than the baseline result at the end of the period[4]. I also investigate the role of Top MSO ownership in the broadband diversification between 2000-2005 given the model estimates. This counterfactual suggests that Top MSO ownership does help the broadband diversification in the later period not in the beginning. Therefore, a policy to encourage municipality or other firms such as power utilities in medium-sized market to enter into broadband market in the early period may help accelerate the broadband diversification.

In addition, this paper contributes to the study on firm diversification in the media and telecommunications industries. During the past fifteen years, these industries have witnessed rapid technological changes, and many firms have chosen to expand their productions into new businesses to reduce risk, gain access to essential resources, and remain competitive in the market. Researchers have studied various aspects of a firm's diversification such as determinants of diversification, the firm's performance before and after diversification, and a corporate structural analysis of diversified firms [5]. Unlike the cross-industry diversification studies in previous literature, my paper studies the cable operators and recognizes the large amount of sunk cost as one significant feature in the diversification decision of cable firms. Two recent papers similar to my research by Liu(2007) and Seo(2007) use cross-sectional data in 2004 to examine the various determinants of cable firms' diversification. By incorporating the factor of sunk cost in cable firms' diversification decisions, my paper further explains the different diversification paths that cable operators choose, after controlling for market characteristics and cable systems' characteristics, and empirically assesses the effect of economies of scale and economies of scope on the cable operators' diversification.[6]

[4]As the adopted dynamic model is a nonlinear model, the simulated results from these policies are not as straightforward as those simulated by a static model.

[5] Chan-Olmsted and Chang(2003), Martin and Sayrak(2001),Delios and Beamish(1999).

[6]In this paper, the term "diversification decision" and the term"entry decision" are interchangeable since the cable system operators have more than two investment alternatives and broadband digital services are provided along with traditional analog video programming services.

The remainder of this paper includes 7 sections. In section 2 I will present the background knowledge about the broadband market and the cable industry. In section 3, I describe the data for this empirical analysis to lay down a starting point for the empirical model introduced in section 4. Section 5 describes in detail the estimation steps and section 6 reports the estimated results. Several policy experiments are implemented and discussed in section 7. Section 8 concludes the paper.

2 Broadband Diffusion and the Cable Television Industry

This section summarizes the broadband market and the cable industry, and highlights several features that will be important in the empirical modelling of a firm's product decisions.

2.1 Broadband

Broadband, a set of digital communication technologies and infrastructures with the capacity to transit large amounts of data at high speed, has become the backbone of the information economy. On one hand, broadband can support the delivery of a wide range of simultaneous digital services, such as digital video programming, digital voice transmission, high-speed internet, and other two-way digital communication services. It can facilitate the birth of new businesses with new ideas and services by reducing transaction costs and increasing the dimensions of a business. On the other hand, households increasingly rely on this fast, always-on broadband connection to the Internet for education, health care, personal banking, shopping, digital high-definition streamed television service and many other services. Therefore, to receive the benefits of these services, it is crucial to have the broadband access service available in private residences.

Though being the leading economy in the world, the U.S. has lagged behind many other countries in deploying broadband technologies in recent years. A report from the International Telecommunications Union (ITU) ranked the US 24^{th} in broadband penetration among top 30 economies at the end of 2007[7]. In another more recent OECD report on broadband penetration as of Dec 2008 it was found that although the US has the largest number of broadband subscribers among all OECD countries, it has a penetration rate of 25.8% and is ranked 15^{th} behind Denmark(37.2%), Canada(29%), France(28%) and other countries.[8] The slow rate of broadband diffusion in the U.S. is also manifested in data transmission speeds and prices(Prestowitz,2006; Turner, 2005). For instance, in Japan and Korea, broadband refers to a data speed of 100 megabits per second. In the U.S., however, the FCC defines the advanced high-speed internet access is the line with data transmission speed above 200Kbps, which is far below the technical requirement to deliver quality video services[9]. In the best case in the US, we credit cable modem service a broadband service when it provides download speeds up to 6 megabits per second. When it comes to

[7] Broadband penetration used by ITU is measured in terms of broadband subscribers per 100 population. In the report, the U.S. obtained a penetration rate of 19.8%. Data online source: http://www.itu.int/ITU-D/ict/statistics/at_glance/top20_broad_2007.html.

[8] Broadband penetration is defined as broadband subscribers per 100 inhabitants. source: OECD website (http://www.oecd.org/dataoecd/21/35/39574709.xls). The data used by OECD may include business subscribers. Another research institute Information Technology& Innovation Foundation(ITIF) considered three most important factors i.e. household penetration, average download speed, and lowest monthly price per megabits to measure broadband across countries, and the U.S. was ranked no.15 by the end of 2008.

[9] See Turner(2006) for comparison on broadband services between the US and other countries.

price, however, the price per megabit in Japan is only around one twentieth that of the U.S.[10].

There are two main broadband technologies in operation today, digital subscriber lines(DSL) and cable modem connections. DSL is implemented by telephone companies through their traditional telephone networks. Cable modem access is offered by cable television companies over their hybrid-fiber coaxial networks. Though DSL is the majority of broadband access technology among most countries in the world, the cable modem has dominated the US market since the late 1990s. In Dec 1999, the Federal Communication Committee (FCC) reported that 51.25% of the more than 2 million high-speed lines in the U.S. were cable modem service,while only 13% of the lines were DSL. The rest were wireless high-speed Internet access services. The difference in market share between cable modem and DSL is even higher when we only consider advanced high speed lines with a transmission speed over 200kbps in both directions serving residential users. Figure 1 shows that in Dec 1999, 84% of the 1 million advanced high speed lines were cable modem and 11.2% were asymmetric DSL (ADSL). By Dec.2005, of the 45.9 million such advanced lines, though ADSL has increased its market share to 35.8%, cable modem still represents 59.9% and has the dominant stakes in the broadband access markets in middle-sized cities and towns. Furthermore, if we consider advanced high-speed access services, the cable company takes close to 80% of the market share.[11]

Therefore, understanding how cable companies decide to upgrade their network infrastructures and offer digital broadband products is one key to understanding the slow broadband diffusion in the U.S. between 2000 and 2005.

2.2 Cable Industry

Since its inception, cable television has been a monopoly, providing cable video programming services through its own coaxial cable network. A cable licensee owns and operates the local cable system, providing the same group of video programming services, interactive data services and other services to all residents in the franchised area at the same prices, and paying certain license fees to the local municipality. By the end of 2005, about 8,000 cable systems passed over 109 million homes with television and served around 66 million household subscribers in the US. Most of these systems are the only multiple-video-programming-services provider in the local franchised area. Since the late 1980s, cable systems have invested to replace the original coaxial cable trunks with optical fiber. Between 1996 and mid-2005, cable has invested nearly $100 billion to upgrade its systems infrastructure.

Providing broadband services usually involves the cable firm making two stages of investment. The first stage of investment requires the firm to decide whether or not to reconstruct the extant network to be broadband-capable. The second stage of investment involves the firm investing further to activate new advanced services, such as digital video programming, and high-speed Internet access, that are only available using the new infrastructure.[12] Though this stage does not involve as much investment as the first stage, it is the second stage that critically realizes the benefits of broadband diffusion and affects the social welfare. More explicitly, if the cable company decides not to provide any digital service after the system is upgraded, the capital invested in the first stage will be depreciated greatly and broadband

[10]Data source: ITIF 2008 Broadband rankings, http://www.itif.org/files/2008BBRankings.pdf.

[11]Kimmelman, Cooper and Kerrera, 2006.

[12] There are also other broadband services such as voice over IP (VoIP) or cable telephony offered by the cable company. However, high-speed internet access and digital cable television service are the two earliest broadband services offered by cable.

diffusion will be delayed. If the cable company decides to provide either high-speed internet access service or digital cable television service, or both, the social welfare increases because consumers have more choices, and returns to the capital invested are realized. In particular, according to the Congress' definition on broadband–"enabling users to originate and receive high-quality voice, data, graphics and video telecommunications services", only when the system provide both digital services shall we consider the deployment of broadband is complete[13].

This paper focuses on a cable company's decision at the second stage. To be more specific, in each time period, each cable system operator has to make a choice among three investment alternatives, including providing no new digital services, providing only one kind of new digital service, and providing both new digital services.[14] The investment cost of the last two choices varies and is irreversible, i.e. the system cannot disinvest and recoup its capital expenditure later once the capital has been invested. Therefore, there is great value in waiting until a later period to invest. In consequence, the question of how the cost and demand factors affect the decision of when and how to diversify into digital services needs to be addressed using a dynamic framework.

Though competition in both digital video programming service and broadband Internet access service started gradually, I have considered cable companies to be the only dominant player in broadband service markets between 2000 and 2005, and thus I employ a single-agent decision model to analyze the investment decisions by cable system operators for the following reasons.[15]

First, competition from Direct Broadcast Satellite(DBS) companies was limited in both digital video programming and high-speed Internet access services during the early 2000s. On one hand, although the barrier to local television market was nominally removed in 1999, satellite subscribers need to pay $5-10 extra monthly fee to receive the local television channels. In addition, the high installation fees were still far beyond general residential consumption budget. On the other hand, high-speed Internet access through DBS is technically limited and far from mature even today.[16] Turner(2005) reports that as of 2005, the start-up costs of subscribing broadband through satellite were $400-600, and the monthly fee was above $60. The maximum upload speed was as low as 50Kbps. In fact, DBS technology restricts satellite companies' ability to provide services to markets geographically unfavorable to receiving satellite signals.

Second, competition from local telephone companies in providing broadband digital services has been crippled by regulatory unbundling policies during the period from 1996 to 2005. According to several specific rulings issued by the Federal Communications Commission to implement the 1996 Telecommunications Act, the incumbent telephone companies must provide requesting competitors access to their

[13]Congress's definition on broadband is from 1996 Telecommunications Act. See the executive summary in Turner(2005). In fact, the best case is include all three services: VoIP, digital video programming, and high-speed Internet service. However, the data for VoIP throughout the sample period is very limited.

[14]I do not distinguish between high-speed internet service and digital cable television service here. I leave the discussion in more detail in data section.

[15]Hausman, Sidak and Singer(2001) conclude the cable's dominant market power will not change within 2 or 3 years. Derek Turner(2005) confirms that in many advanced high-speed internet access services markets, the "fierce competition" among the broadband platforms(i.e. cable, DSL, wireless, and satellite) is seriously overstated and in many rural areas, there is only one broadband access service provider.

[16]What happens today in the broadband service market is the emergence of a strategic alliance between DBS and large incumbent local telephone companies. DBS companies such as DirectTV or Dish provide digital video programming services, which are also marketed to the public in a bundle with DSL service provided by Verizon or other large local incumbent telephone companies. Therefore, DBS companies and large local incumbent telephone companies launch their own "triple-play " product, a bundle of satellite video, DSL data and traditional voice services to compete with cable companies' digital cable, cable modem and cable telephony services.

unbundled network elements at cost-based prices even if they spent their own money upgrading the old network system, and some of these network elements can be used to deliver DSL service.[17] Telephone companies also face various unsolved regulatory issues in providing digital video programming services. In addition, cable modem service during the early 2000s is technologically more favorable than DSL service in providing high-speed Internet service, because the latter is limited to reaching customers within $15,000$ to $18,000$ feet from the central office of the local telephone company.

Third, cable operators also enjoy their monopolistic power in the video programming service market in almost all middle-sized cities or towns where the municipality issues only one cable license. In addition, since 1996, except for some regulatory monitoring of basic cable service prices, both extended-tier and pay-per-view cable television services and advanced data service have not been under rate regulation by the local franchising authority. Moreover, there is consumers' immobility in consuming broadband digital services, because residents in the cable integrated service area cannot travel to other places to purchase the high-speed Internet access service or digital video programming services and consume them at home. Therefore, the cable company can enjoy all the benefits from its infrastructure investment by delivering new broadband products to its customers and charging them accordingly.

Although neither DBS companies nor DSL telephone companies can produce perfect substitutes for cable broadband products, the threat from these competitors does stimulate the whole cable industry to extend traditional analog video programming services to advanced digital services. This "competitive effect" can vary across markets and over time. Due to the unavailability of data on DBS and DSL at the market level, I am restricted to the single-agent decision model and have ignored the competitive effect by studying non-metropolitan markets. In fact, using a multinomial logit model, my early research includes the information on both high-speed internet access service competition and DBS competition[18]. However, after controlling for a time trend, the high-speed internet access competition does not have significant impact on cable's diversification choice.[19] Therefore, in this single-agent dynamic model, the possible "competitive effect" from the indirect competition from DSL and DBS is incorporated into the stochastic evolution of state variables which I will discuss in later sections[20]. In the next section, I describe the data for the empirical modelling and estimation where important profit determinants in the dynamic modelling are discussed.

3 Data

The main data used in this research are collected from Warren Factbook 2001 $\sim$ 2006. Each year, Warren Communication News, Inc., collects information from various sources on all the services that a cable franchisee offers in an integrated cable area and publishes the "Television & Cable Factbook".[21]

[17]See Johannes Bauer(2005) for more detail about the unbundling policy in the U.S.

[18]The information on high-speed internet access service competition is collected from FCC web at zip-code level and I aggregate them to the cable-system level. The DBS competition information is a nationwide DBS penetration rate over the years.

[19]Another research by (Hu and Prieger(2006)) estimate the demand for DSL and they do not find evidence that the presence of competitive local exchange carriers affects the incumbent local exchange carrier's entry into DSL. Their finding indicates a leader-follower strategic entry model in the broadband access market.

[20]Though the high-speed internet access service competition does not have significant impact, the DBS competition does even after controlling for the time trend. This result guides me to choose proper variables in my dynamic model later.

[21] Warren Communications News defines one cable system as a community or group of communities which receive essentially the same service at the same price from the same company, regardless of the number of headends used to deliver the service. These communities are usually geographically contiguous. This definition is different from that of the FCC.

The Factbook data consist of various characteristics of the cable system, including the cable operator's identity, ownership, location, franchise award date, two-way operation or not, miles-of-plant, number of homes passed, and availability of services.[22] In this study, I collect the data during the period from 2000 to 2005 on 269 local cable systems in ten states Arizona, California, Florida, Illinois, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Texas. Each cable system operates in a geographically-segmented market.[23]

The data shows substantial heterogeneity at the geographic market level. Table 1 gives summary statistics of some important variables over all observations. We observe substantial dispersions in all these variables across markets. For example, the market size ranges from a low of 167 homes passed in the cable franchise area up to a market of over 640,000 homes with a mean of 47,500. The cable television services in these geographic markets are operated by a total of 50 cable system operators. Some of them own more than one cable television system and are thus called Multiple System Operators(MSOs). Some are not typical MSOs and are operated by municipalities or competitive telecommunications companies. Large public cable companies also own a substantial proportion of these cable systems, such as Comcast, Time Warner, Mediacom, Charter, Cox, and Adelphia. The table shows the mean of the top 10 MSO ownership dummy is 0.78, because it is calculated over all observations across both markets and years. Substantial dispersion is observed in both the price and quantity for basic cable television services. The basic-tier cable service prices range from \$3 to \$46.99 per month, and the network subscriber base ranges from less than 100 to 332,300 basic cable subscribers.

The system's age is calculated from the date when the cable company received its franchise license from the local municipality to 1999. The youngest system is 4 years old and was built in 1995. The oldest one is 54 and was built in 1945. Most of the systems are aged 28 or 29. In addition to the system age, the miles-of-plant in both coaxial cable and optic fiber characterizes the system size to measure the maintenance costs and one-time entry cost, and this also shows sizeable variation. Some systems have large miles of plant in coaxial cable only whereas some have purely optic fiber architectures. The average size of plant is 588 miles per system and the standard deviation is 940 miles.

Table 2 summarizes the changes in basic cable monthly price, homes passed in the local franchised area, and miles of plant of each cable system during the sample period. The last two columns give the mean test results where test value is zero. We observe substantial variation in all these variables for all 269 systems on average. The standard deviation of basic cable monthly price of each cable system between 2000 and 2005 is on average \$3.05 with the maximum of \$19.30. On average, the number of homes passed in each cable franchised area can change 2,492 from year to year for all these cable systems, and the total miles of plant of each system can vary 52.54 miles over the years with the maximum of 3,693 miles. For all these variables, we also observe the minimum of the changes over the years are zero, which means there exist some systems that do not observe changes in these variables throughout the sample period.

To study the cable systems' diversification, I examine the diversification patterns over the sample

[22] Warren obtains the subscriber count information through the FCC or the Copyright Office.

[23] Some data screening is taken to remove those cable systems with a lot of missing information. First, the areas with overbuilt cable systems are not included in my data, so the cable operator is a monopoly in the market. I do not include the large metropolitan areas such as Chicago and Philadelphia, which are usually divided into several cable systems, because of the difficulty in delineating the geographic market for each system from the source data available. Second, there have been many mergers and acquisitions in the cable industry during the sample period. Cable companies swap their cable systems with one another or merge their contiguous systems into a larger one. I delete observations that witness enormous increases in subscribership and keep only the systems with detailed and complete information on merger or acquisition, and reasonable changes in the number of homes passed in the franchised area during the sample period.

period. Table 3 reports the number of cable systems in a particular year diversifying into broadband internet access service only, digital cable services only, or both services over the years[24]. It shows a noticeable gap between cable systems providing broadband internet access service only(22.3%) and those providing digital cable service(6.4%) throughout the sample period. Either demand, or cost, or both factors may drive this pattern to occur. I collect census demographic data at the market level, combine the cable systems information, and apply a multinomial logit model to investigate the diversification choices. On one hand, most of demographics do not show much significant impact on cable systems' diversification except for the median household income and the employment in professional vocations[25]. This result comes with no surprise empirically. Hu and Preiger(2006) study the broadband entry by DSL in five states as of March 2000. They found that income affects DSL entry significantly and other demographics with mixing effects[26]. On the other hand, the multinomial logit regression shows that systems' characteristics such as ownership, miles of plant, basic cable price, and other variables capturing time trend and DBS competition, have significant effect on the systems' diversification.

Given these findings at hand, I consider not distinguishing high-speed internet access service and digital cable service in my empirical structural modelling and study how demand and cost factors affect the number of digital services offered by cable systems. For one reason, the demand factors do not differ significantly for these two services though it is quite counter-intuition. Second, from the logit model, it is clear that cost factors have more significant impact on diversification. My ultimate goal is to investigate whether sunk cost can provide some explanation on the slow broadband diffusion in the U.S., particularly, why some cable companies differ in offering only one digital service not both since they share the same upgraded network infrastructure[27]. Given that very few observations on cable systems choosing to provide digital cable service first, the empirical model will not produce very meaningful sunk cost estimates for digital cable service when these two services are treated separately. In fact, the cost parameter of offering one digital service essentially measures the cost of offering high-speed Internet service, and the cost parameter of adding a second digital service captures the additional cost of adding digital cable service when high-speed Internet service is in place.

Table 4 shows the averages of some variables in cable system characteristics by the chosen diversification path. The first column gives the averages of these variables when the cable firms do not offer any digital service, called "no diversification". The second column gives those when firms initiate only one digital service,–"limited diversification"; the third column shows those variable averages when firms initiate two digital services simultaneously,–"simultaneous diversification"; and the last column presents these averages when firms initiate only one digital service and sequentially add the other one at a later date,–"sequential diversification". Table 4 describes two observations. First, comparing basic cable monthly prices charged by all systems of these four diversification paths, we find that except for limited-diversified systems(column 2), both simultaneously-diversified systems(column 3) and sequentially-diversified systems(column 4) have greater basic cable prices on average than "undiversified" systems(column 1). Second, considering the market-size and the plant-size variables across all these four columns, we find that diversified systems (column 2∼4) have greater means in both homes passed and miles of plant than "un-diversified" systems. Among all diversified systems, sequentially-diversified cable systems have the largest means of both variables, followed by limited-diversified systems in the second

[24] Digital cable services include basic digital cable services,and digital pay services both reported in Warren Fact Book.

[25] Demographic information is obtained from Census 2000. I include local population density population race, education profile, employment profile(industry specific), age profile, gender profile, and poverty level in the multinomial logit model. The dependent variable is the cable system's diversification choice, which distinguishes broadband internet and digital cable service. In addition to median household income and employment in professional vocations, other demographics such as population density and education also have some effect on the diversification, however insignificantly.

[26] For example, they found that less than high-school education is positively and significantly related to DSL entry, and the race effect can disappear or even switch the sign when other demographics are included in the regression.

[27] True broadband includes high-speed internet access service, digital cable service, and voice service.

place and simultaneously-diversified systems in the third place.

To examine the dynamics of cable systems' digital diversification, I count the number of cable systems in each diversification status for every year during the sample period shown in Figure 2. The total number of firms that do not offer any digital service has decreased over the sample period. The number of firms that offer only one digital service started with a greater number and faster speed than the number of firms that offered both digital services in 2000 and 2001, and then the latter increases greatly whereas the former declines. The divergence occurs between 2002 and 2003 and it grows larger throughout the rest of the sample period. In addition, the diffusion speed of two digital services being offered is faster than the declining speed of no digital services being offered during 2003 $\sim$ 2005, which implies many of those firms which had offered only one digital service have added the other digital service during these years. At the end of 2005, among all 269 cable systems that have completed an upgrading of their infrastructures, 76.2% have diversified into offering both digital services, 20% offered one digital service and less than 5% have not offered any digital service. These observations suggest that substantial cost differences exist between offering one digital service and two digital services, which may be greater than the economies of scope in offering both digital services. Moreover, these cost differences may vary across markets and can be essential to the firm's decision on how to diversify into digital services. Therefore, it is interesting and important to estimate these differences.

The evidence for the substantial cost differences can also be supported when we investigate the diversification paths chosen by cable systems and find that sequential diversification is the main path for cable systems' diversification. Figure 3 breaks down the group of cable systems offering two broadband digital services in each year ($D = 2$ in Figure 2) into one group of simultaneously-diversified cable systems and the other group of sequentially-diversified cable systems. It depicts the number of firms in each year by the diversification path they choose, and gives a clear picture of the group of firms and how they sequentially diversify into two digital services. It shows that most firms that offer digital service in the early 2000s offered only one digital service. The majority of these firms added the other digital service later around 2003 or 2004. Though the number of firms that initiate two digital services increases in 2002 and 2003, most of firms that offer two digital services by the end of 2005 adopted sequential diversification. During 2000 $\sim$ 2005, 72 cable systems diversified into simultaneously offering two digital services, and 133 cables systems sequentially diversified into offering digital services. For all these systems that sequentially diversified into both digital services, the average time lag between offering one digital service and offering both digital services is 2 years, and 24% of the cable systems waited 3 or 4 years to add the other digital service to their offering.

4 An Empirical Model of Cable's Digital Product Decision

My objective is to explain the observed diversification pattern of cable systems and especially to compare the cost of sequentially diversifying into the digital services, i.e. initially adding one product followed by the other one at a later date, with that of simultaneously diversifying into both digital services. I consider each cable system as an individual decision maker deciding how to invest in new broadband digital services and earn relevant profits. When the cable system chooses to initiate one kind of digital service in the current time period, sunk costs related to this choice are incurred. In the next time period, if it chooses to stay with the same offering as in the last period, it only incurs a regular maintenance cost associated with the last period's choice. The system can also choose to add the other digital service into its current offering by investing more capital. Once the system has diversified into offering two kinds of digital services, it enters a terminal state and maintains that level of services.

To develop an empirical model of a cable company's dynamic investment decision, I start with the per-period profit function specification, and then identify those state variables that are crucial to the dynamic problem. Later I define the value function of the cable operator for each diversification decision.

4.1 Profit Function Specification

As I discussed in Section 2, cable systems have several advantages in providing new broadband digital services to customers residing in their franchised areas, such as the incumbent advantage in video programming services, technological advantages in high-speed Internet service, and full pricing flexibility in all services except for the basic cable service. In addition, due to immobility in consuming all these services, cable systems can enjoy almost all the benefits from their investment. Therefore, I specify the one-period profit of the cable system i as a function of variables that characterize revenues from both traditional analog cable television services and advanced broadband digital services, costs from both regular operating expenses and relevant investment decisions, and an unobserved choice-specific revenue shock[28].

$$\begin{aligned} \pi_t(\tilde{G}_t, HM_{it}, BCP_{it}, INCOME_i, MP_{it}, AGE_{it}, D_{it}, D_{it-1}) = \\ \pi^1(Ownership_t, HM_{it}, BCP_{it}, \tilde{G}_t, INCOME_i, D_{it-1}) - C(MP_{it}, AGE_{it}, D_{it}, D_{it-1}) + \epsilon_{D_i t} \end{aligned} \tag{1}$$

Here $\pi^1(.)$ characterizes the total revenues from both traditional analog cable television services and new broadband digital services. It is derived from general market characteristics, such as market size HM_{it}, basic cable price BCP_{it}, market growth rate for broadband digital products $\tilde{G}_t$, median household income $INCOME_{it}$. I avoid using extended cable service prices to replace basic cable service price in the profit function, because they are highly endogenous which breaks down the assumption of the dynamic model in estimation and requires me to explicitly model the pricing decision of the systems. D_{it-1} is the diversification choice from the last period for the firm i[29]. $D = 0$ means no digital product is being offered, $D = 1$ means only one kind of digital product is being offered, and $D = 2$ means both digital products are being offered. Implicitly, I assume the payoff for offering new digital service(s) has a one time-period delay. Therefore, the system's period profit in time t depends on its diversification path up to time $t-1$. More specifically, π_t^1 is taken the following form:

$$\begin{aligned} \pi_t^1 = \alpha \cdot Ownership_{it} + \beta_1 \cdot INCOME_{it} + \beta_2 \cdot HM_{it} + \beta_3 \cdot HM_{it}^2 \\ +\beta_4 \cdot BCP_{it} + \beta_5 \cdot BCP_{it}^2 + \beta_6 \cdot \tilde{G}_t \\ +\beta_7 \cdot \mathcal{I}(D_{it-1} = 1) + \beta_8 \cdot \mathcal{I}(D_{it-1} = 2) \end{aligned} \tag{2}$$

The first term captures the ownership effect on the profit. $Ownership_{it}$ is a firm dummy vector and equals 1 if the system is owned by a top10 MSO. The last two terms measure the digital effect on the

[28] I impose linear restrictions on both revenue and cost structures to get analytical expression to simplify the estimation. I use a quite flexible specification, including quadratic terms for market size, plant size, and basic cable price, to smooth the final estimates across states.

[29] I also tried other model specification, such as use average basic cable revenue per home, or cable penetration rate(cable subscribers divided by homes passed). The main results especially the cost estimates remain. Due to limited amount of data, I can not include both average basic cable revenue and penetration rate into the model because they will enter as state variables and cause "curse of dimensionality" in the estimation.

current profit by different digital diversification in the last period. I consider offering digital products may help reduce the churning-rate in the cable subscribership and give revenue a greater shift to diversified systems than those undiversified systems. This effect may arise as the variety of the digital offering by the cable system increases.

$C(.)$ is the cost function associated with the current diversification status of the firm. It is a function of miles of plant (MP),age of the system (AGE), and diversification choices. To be specific,

$$\begin{aligned} C(MP_{it}, AGE_{it}, D_{it}, D_{it-1}) &= \phi_1 MP_{it} + \phi_2 MP_{it}^2 + \phi_3 AGE_{it} \\ &+ \varphi_1 InitialD1_{it} + \varphi_2 InitialD2_{it} + \varphi_3 LaterD2_{it} \end{aligned}$$

The first two terms in the cost function measure the cost from the observed state variables, miles of plant (MP) and age of the system (AGE), for example the regular maintenance costs for the cable system every period. As the size of the system's plant increases, so do the maintenance costs. The system's age is also expected to increase the maintenance costs. The quadratic term is included to characterize potential economies of scale in production. If economies of scale exist, we expect the estimated coefficient of this quadratic term to be positive. The last three elements define sunk costs from three different diversification paths. φ_1 is the cost coefficient if the firm initiates only one digital service, φ_2 is the coefficient if the firm initiates both digital services simultaneously, and φ_3 is the coefficient if the firm sequentially diversifies into both digital services. *Initial D1*,*Initial D2* and *Later D2* are dummies to distinguish these three diversification paths, and they are defined by

$$\begin{pmatrix} InitialD1_{it} = \mathcal{I}(D_{it} = 1) \cdot \mathcal{I}(D_{it-1} = 0) \\ InitialD2_{it} = \mathcal{I}(D_{it} = 2) \cdot \mathcal{I}(D_{it-1} = 0) \\ LaterD2_{it} = \mathcal{I}(D_{it} = 2) \cdot \mathcal{I}(D_{it-1} = 1) \end{pmatrix}$$

.

Finally, in the profit function, the choice-specific disturbance ϵ captures idiosyncratic unobserved revenue shocks to the firm, such as the potential gains from economies of scope in production. Since both traditional cable television services and new broadband digital services, including digital cable television service as well as high-speed internet broadband service, are provided over the same network infrastructure, there may exist economies of scope when the firm provides additional services. The following equation array gives the period t profits for the firm i when each of the six possible different diversification paths is observed.

$$\pi_{it} = \begin{cases} \pi_{it}^1(D_{it-1} = 0) - \phi_1 MP_t - \phi_2 MP_t^2 - \phi_3 AGE_t + \epsilon_0, & \text{if } D_{t-1} = 0;\ D_t = 0 \quad (i) \\ \pi_{it}^1(D_{it-1} = 0) - \phi_1 MP_t - \phi_2 MP_t^2 - \phi_3 AGE_t - \varphi_1 + \epsilon_1, & \text{if } D_{t-1} = 0;\ D_t = 1 \quad (ii) \\ \pi_{it}^1(D_{it-1} = 0) - \phi_1 MP_t - \phi_2 MP_t^2 - \phi_3 AGE_t - \varphi_2 + \epsilon_2, & \text{if } D_{t-1} = 0;\ D_t = 2 \quad (iii) \\ \pi_{it}^1(D_{it-1} = 1) - \phi_1 MP_t - \phi_2 MP_t^2 - \phi_3 AGE_t + \epsilon_1, & \text{if } D_{t-1} = 1;\ D_t = 1 \quad (iv) \\ \pi_{it}^1(D_{it-1} = 1) - \phi_1 MP_t - \phi_2 MP_t^2 - \phi_3 AGE_t - \varphi_3 + \epsilon_2, & \text{if } D_{t-1} = 1;\ D_t = 2 \quad (v) \\ \pi_{it}^1(D_{it-1} = 2) - \phi_1 MP_t - \phi_2 MP_t^2 - \phi_3 AGE_t + \epsilon_2, & \text{if } D_{t-1} = 2;\ D_t = 2 \quad (vi) \end{cases} \tag{3}$$

From the above, we can see the differences in period profits of firms following different diversification paths. The identification of $\beta_7, \beta_8, \varphi_1, \varphi_2$, and φ_3 comes from the observed history of cable systems' diversification choices not just only a "static" one-time shot decision[30]. For example, the period profit of the firm which diversifies sequentially into offering both digital products (case v) is different from the one

[30]The term "history" refers to the choices made in $t-1$, t and $t+1$ for instance.

which simultaneously diversifies into both products(case *iii*) by $(\varphi_3 - \varphi_2 + \beta_7)$, even though both of them have the same regular period-by-period cost shock ϵ_2 and end up with the same diversification status $D_t = 2$. Comparing the firms which stay with their diversification choice from the last period(case i, iv, vi), the period profits differ in the associated unobserved period shocks ϵ and their digital diversification shift β_7 and β_8 .

4.2 State Space

To describe the state space of the model, we begin with a set of M independent and geographically segmented markets, each with only one cable system operator. I also assume there is no spatial competition among all systems as well, since all markets are geographically separated from each other. Based on the period profit function specified in the previous subsection, the observed vector x_{it} of state variables for each firm consists of the following five elements: $HM_{it}, MP_{it}, BCP_{it}, D_{it-1}, \tilde{G}_t$.

The first and the second state variables are the number of homes passed HM_{it} in the franchised area and miles-of-plant MP_{it} of the cable system. They are exogenous state variables that reflect demand and cost shifters, respectively. To the cable system, new home construction in the franchised area is exogenously determined, thus HM is exogenous. The cable system is obligated to build more miles of plant (MP) to reach those newly-added homes to fulfill its responsibilities in the franchise agreement. The cost involved in such investment is thus exogenous to its diversification decision. Both state variables are assumed to be independently distributed conditional on observed last-period values. The third observed state variable *basic cable service monthly price* BCP_{it} is included to characterize the profitability of traditional non-digital basic services in the market. Since the basic-tier cable television service is required to be offered to all residents and its rate is monitored by the local municipality, BCP evolves exogenously and reflects the market profitability determined by unobserved market heterogeneities, such as the relationship between the monopoly firm and the local municipality, and the demand elasticity for cable services. A market with a lower basic cable price BCP implies a low market profitability, and it may slow down the monopoly firm's diversification decision.

The next state variable D_{it-1} records the diversification status until $t-1$ period, which I have described in the last subsection. It determines which of the regular period costs or sunk costs are relevant for the firm in each time period, as well as affects current profits. The last state variable is a digital product market demand growth rate variable $\tilde{G}_t$. It measures the national diffusion speed in the digital cable television and high-speed internet broadband service market during the sample period, and serves as a time trend to characterize the rapid growth in the market. It is driven by exogenous unobservables such as consumers' increasing awareness of benefits from broadband services, and government-sponsored projects that increase high-speed internet usage in education and public services.

Lastly, all unobserved idiosyncratic shocks to revenues associated with each diversification choice are characterized by ϵ. For example, the revenue for not providing any digital product can be different from those providing only one kind of digital product or both digital products, because there may exist margins due to economies of scope in providing more services through the same cable system infrastructure. The individual revenue shocks are unobserved by the researcher, yet can be observed by individual firms.

4.3 Value Functions

Now let x be a vector collecting all observed state variables in the current period, and let x' denote the vector of next period state variables. In particular, this vector x includes a set of exogenous state variables in each period t such as total homes passed in the local market HM_i, the system's plant size MP_i, the local basic service price BCP_i, the national growth rate for high-speed Internet service and digital cable television service market $\tilde{G}$. It also includes an endogenous state variable, the diversification choice the firm made in the last period D_{it-1}. This variable affects current period profit by adding extra demand if the firm initiates its digital service offering in last period or by changing the likelihood in alternatives the firm can choose in the current period. Other demand and cost shifters such as household income level and age of the cable system are important to determine period profit for each choice. However, I observe the household income for one year only and the transition of age is straightforward. Therefore, I do not consider them as state variables in this model. The whole stochastic evolution of state variables (x, ϵ) is assumed to follow a Markovian transition process, which means the next state solely depends on the current state and doesn't directly depend on the previous states. To simplify the remaining discussion, I will drop the i subscript. All discussion in this subsection will refer to a single firm.

Since initiating diversification cost is one-time, D_t will change the firm's profit stream for all future paths. Therefore, before making its product decision, the firm needs to observe the current realization of x. In addition, given known first-order Markov processes for all exogenous elements of x, the firm has sufficient information to compute the discounted expected payoffs of each choice, and then can make its current diversification decision D_t by choosing the one that yields the highest payoff. In other words, in each time period t, given the state variables (x_t, ϵ_t) the firm needs to choose an optimal path $(D_t, D_{t+1}, \ldots)$,$(D \in \mathcal{J} = \{0, 1, 2\})$ to maximize the value function of the expected discounted sum of future profits over an infinite horizon as given by[31]

$$V_\theta(x_t, \epsilon_t) = \max_{D \in \mathcal{J}} \{\pi^*(x, D|\theta) + \epsilon(D|\theta) + \delta EV_\theta(x_t, \epsilon_t, D)\} \tag{4}$$

where

$$EV_\theta(x_t, \epsilon_t, D) \equiv \int_{x'} \int_{\epsilon'} V_\theta(x', \epsilon') p(dx', d\epsilon' | x, \epsilon, D, \theta),$$

in which it is the expected value of future values given current state variables (x_t, ϵ_t) whose probability density and transition probability density is given by p. The optimal choice sequence is hence defined by

$$\arg\max_{D \in \mathcal{J}} \{\pi^*(x, D|\theta) + \epsilon(D|\theta) + \delta EV_\theta(x_t, \epsilon_t, D)\}.$$

Here $V_\theta(x)$ is the value function of the firm given state vector x and unknown parameters θ. δ is the specified discount factor. θ collects all parameters $(\alpha, \beta, \phi, \varphi)$ to be estimated.

There are four important assumptions that need to be noted here in order to solve the Bellman equation and obtain a tractable estimation algorithm. First, the first two terms in the value function (4) denote the period profit function and it is assumed to have two additively separable parts, an observable part π^* that collects all observed period profit determinants ,and an unobservable part ϵ that is a choice-specific idiosyncratic disturbance term.[32] Second, the Markovian transition probability of (x, ϵ) is assumed to be conditional independent, and x is a sufficient statistic to ϵ, which implies that any interdependence between ϵ_{t+1} and ϵ_t is transmitted entirely by the observed vector x_{t+1}. Third, I assume that the state space for x has a finite domain and can be discretized into finite points. Lastly, ϵ is assumed to be serially uncorrelated and independent across all alternatives, and it has a Type-I extreme value

[31] These definitions are from equation (4.4)−(4.6) in Rust(1987).

[32] π^* differs from π defined in the previous subsection because the latter includes ϵ, the idiosyncratic disturbance term.

distribution. These assumptions are classic in discrete choice dynamic programming and contribute to a simplification of the calculation of the value function (Rust(1987), Hotz and Miller(1993), Aguirregabiria and Mira(2002)). Given these assumptions, the optimal value function can be rewritten as

$$V_\theta(x) = \int \max_{D \in \mathcal{J}} \left\{ \pi^*(x, D|\theta) + \epsilon(D|\theta) + \delta \sum_{x'} V(x') f(x'|x, D, \theta) \right\} g(d\epsilon|x, \theta) \tag{5}$$

where the term $\delta \sum_{x'} V(x') f(x'|x, D, \theta)$ is the discounted expected future value given the current optimal choice. The last three assumptions allow me to write the transition probability $p(x, \epsilon)$ as a product of the transition probability of state variables x and the conditional choice probability of the idiosyncratic disturbance term ϵ.[33] In particular, f is the Markovian transition probabilities of exogenous state variables x, conditioning on the current values x and choices D. g is the specified conditional probability for an unobserved choice-specific disturbance ϵ with Type-I extreme distribution.

Proposition 1 in Hotz and Miller(1993) establishes a one-to-one mapping from conditional choice probabilities as defined by the optimal choice given observable state vector x to the value function. Hotz and Miller show that this inversion does not depend on any unknown parameters of observed state variables, but it may depend on some unknown parameters of the distribution of unobserved ϵ.

$$P(D|x) = \int \mathcal{I} \left\{ D = \arg\max_{j \in \mathcal{J}} [v(x, j) + \epsilon(j)] \right\} g(d\epsilon|x) \tag{6}$$

$P(D|x)$ is the conditional choice probability, which is the conditional expectation of choosing choice D given state x when D yields the highest payoff flow. $v(x, j)$ is the alternative-specific value function collecting $\pi^*(x, D|\theta)$ and $\delta \sum_{x'} V(x') f(x'|x, D, \theta)$ in equation (5). Therefore, combining equation (6) and equation (5), we derive the following representation of the value function in terms of conditional choice probabilities:

$$V(x) = \sum_{D \in \mathcal{J}} P(D|x) \left\{ \pi^*(x, D) + E(\epsilon(D)|x, D) + \delta \sum_{x'} V(x^{'}) f(x^{'}|x, D) \right\} \tag{7}$$

where $E(\epsilon(D)|x, D)$ is the expectation of unobserved choice-specific disturbance $\epsilon(D)$ conditioning on observed state variables and optimal choice D.

$$E(\epsilon(D)|x, D) = (P(D|x))^{-1} \int \epsilon(D) \mathcal{I} \left\{ \tilde{v}(x, D) + \epsilon(D) \geqslant \tilde{v}(x, j) + \epsilon(j), j \in \mathcal{J} \right\} g(d\epsilon|x) \tag{8}$$

Here $\tilde{v}(x, D)$ is the differential value when D is chosen given state variables x. For example, if we choose $v(x, 0)$ as the base value, i.e. no digital service being offered, $\tilde{v}(x, D) = v(x, D) - v(x, 0)$, for $D = 1, 2$. Given the known distribution of ϵ, we have a closed form for the conditional choice probabilities in equation (6) and thus are able to use the representation formula of value functions expressed in conditional choice probabilities in (7) to estimate the value function parameters discussed in the next section. For example, the extreme value distribution of ϵ helps to get closed form expression for $E(\epsilon(D)|x, D)$ in equation (8) as

$$E(\epsilon(D)|x, D) = \kappa - \ln(P(D|x))$$

where κ is the Euler constant (≈ 0.5772).

[33] Given the discretized state space of x, I employ transition probability instead of transition probability density in the value definition in (5) directly used in the estimation.

5 Estimation

I follow Aguirregabiria and Mira(2002) and apply the nested pseudo-likelihood estimation algorithm to estimate parameters for market size HM, basic cable service price BCP, maintenance cost variables, and one-time diversification costs specified in equation (3) in the dynamic model. The key estimation equations are given by equation (6) and (7). The estimation steps for the structural parameters will be described after I discuss the estimation of transition probabilities for the state variables.

5.1 Transition probability

The first estimation step is to obtain estimates of the transition probability matrix for state variables. $f(x'|x, D)$ in equation (7) is the matrix of transition probabilities of all state variables. Given the exogeneity of all state variables HM, BCP, MP,and $\tilde{G}$, $f(x'|x, D)$ is considered to be same for all D. Therefore, I decompose the transition probability $f(.)$ into a product of marginal and conditional densities as follows:

$$f(x'|x) = f^1(\tilde{G}'|\tilde{G}) \cdot f^2(MP'|MP) \cdot f^3(HM'|HM) \cdot f^4(BCP'|BCP) \quad (9)$$

where f^1 is a transition probability function for digital market growth, f^2 is a transition probability for local physical plant size, f^3 is a transition probability for potential market size in the local area, and f^4 is a transition probability for basic cable service price. Each of the transition probabilities can be estimated independently from the data. I consider that the transition probabilities of HM, MP and BCP are independent as I found none of them has statistically significant impact on predicting next-period values of the other variables, after conditioning on current values. The transition probability functions f^2, f^3, f^4 are all geographic market specific. To estimate them, I discretize HM, MP, BCP into categories and use a simple frequency-counting method to get the transition probability matrix[34]. Table 5 and table 6 give the transition probability estimates for f^2 and f^3 respectively, and they are very similar. I discretize both variables into 3 categories. The median market has 17,705 homes passed and the median size of a system has 280 miles-of-plant. The system that has less than 260 miles-of-plant is considered small and that has more than 494 miles-of-plant considered large. A market with fewer than 8,350 homes is considered as a small market, and that with more than 34,527 homes is considered as large. Both table 5 and table 6 show a strong persistence in the firm's plant size and in the market size, such that very few systems(or markets) have their plant size(or market size) grow or shrink sufficiently that they transit to a higher category or lower category. For example, in table 5, 98.4% currently small-sized plants remain small in the next period, and fewer than 2% of plants in this category transit to medium- or large-sized plants. In the medium-sized category, 97.6% of current medium plants stay in the same category, and fewer than 3% of plants witness transitions into a larger category. There is no transition in the large category. This transition pattern persists even if I increase the number of categories or reallocate the cutoff points for each category.

In defining categories for the local basic cable price, I discretize BCP into 5 categories according to

[34] I have also estimated a more general model which uses average basic cable service revenue per home as state variable instead of basic cable price. Therefore, I have a different transition probability function where f is conditioned on the choice variable D. To obtain a satisfactory estimate of each transition probability function, I need to have more data. Under current choice that the state variables are completely exogenous, therefore given the size of current data set, I have more observations to estimate each of these transition probability functions. However, the main results in both models do not change.

the sample distribution. The left-end cutoff point for BCP is \$7.92 per month with 10% observations of the data allocated. The right-end cutoff point is \$28.17 per month with 12% observations allocated in this region. The other two cutoff points are \$10.59 and \$15.39 and they almost equally split the rest of observations in between. Table 7 presents the transition probability estimates for BCP. In general, the data shows that around 80% of markets in each category remain in the same category in the next period and the remainder transit to other categories, with a higher likelihood of transiting to immediate neighboring categories. For example, about 86% of the markets with the lowest basic cable price([2, 7.92)) stay in the same category in the next period, about 7% transit to the category of one-rank higher ([7.92,10.59)), 4.6% of markets jump to the category of two-rank higher([10.59,15.39)), and 2% jump to the highest rank([28.17, 40.85)).

The final transition matrix in equation 9 is $f^1(\tilde{G}'|\tilde{G})$. The digital market growth $\tilde{G}$ is common to all firms, capturing the time trend of market growth for digital services nationally. I define this as

$$\tilde{G}_t = \hat{G}_t - \hat{G}_{t-1}$$
$$\hat{G}_t = \ln \frac{g_t}{2 - g_t}$$

where $g_t(.) = \frac{\text{\# high-speed internet or digital cable subscribers in } t}{\text{\#total homes passed in } t}$. This variable measures the national growth in the adoption rate of digital services. Recall that the time trend is found to play an important role in cable diversification decision in the logit model regression discussed in the data section, I include this variable as the time trend to capture the maturing of the product and the diffusion and adoption occurring nationally. Because $g(.)$ is bounded between $[0, 2]$, I first take a logarithm transformation to get unbounded variables $\hat{G}_t$ and then take the first-order difference to remove the time trend variable and get $\tilde{G}$. There are several advantages to this transformation. First, it yields a first-order Markov process for the state variable $\tilde{G}$ consistent with the dynamic programming theory, where the stationary assumption of state variables is necessary for the existence of a fixed point solution, and thus eases my application. Second, this transformation has a unique one-to-one mapping between the transformed variable $\tilde{G}$ and the original variable g_t, and thus allows me to use $\tilde{G}$ as an input in the period profit function directly. Moreover, this logarithm first-order difference transformation captures the diffusion speed of these two digital products in the market. In the end, I assume $\tilde{G}_t$ is an AR(1) stationary process with drift:

$$\begin{aligned} \tilde{G}_t &= \eta + \rho \tilde{G}_{t-1} + u_t \\ \eta &= \mu(1 - \rho) \end{aligned}$$

where μ is the mean of $\tilde{G}_t$.[35] I first estimate μ, ρ and σ_u, and then use the method in Tauchen(1996) and Adda and Cooper(2002) to discretize the AR(1) process and derive the transition probability matrix. The results are reported in table 8[36].

[35] I tried different specifications of this market growth variable. Because the number of subscribers in the digital cable television market and high-speed internet access market has increased significantly since 2000, given a limited amount of data the first-order difference in logarithm yields a Markov process closer to stationary that is suitable in this application.

[36] In the estimation of transition probability functions, I treat this AR(1) process as fixed and change the number of categories for $\tilde{G}$ to test the robustness of the model. In general, the number of categories for $\tilde{G}$ cannot be reduced below 5, because it is hard to capture the impact of market growth on the value function of different diversification paths since a small number of categories do not generate enough transitions across states in the data.

5.2 Nested Pseudo-likelihood Estimation

As described earlier the data set used to estimate the model is typical of the plant-level panels in the IO literature. For each cable system operating in a geographic market, it contains both system- and year-specific information. The substantial cross-sectional variations for each cable system are used to identify the profit parameters such as local market size, plant size, and other characteristics. The sunk entry costs are identified by the time series variation of cable systems in diversifying into offering different number of digital products across periods. Given the conditional independence assumption and estimates of the transition probability functions, I construct the likelihood function to estimate the rest of parameters as the sum of the conditional choice probability loglikelihood and transition probability loglikelihood over all firms (i) and time periods (t).

$$l(\theta|\mathbf{X},\mathbf{D}) = l_1(\theta) + l_2(f) = \sum_{i=1}^{M}\sum_{t=2000}^{T=2005} \ln P_\theta(D_{it}|x_{it}) + \sum_{i=1}^{M}\sum_{t=2000}^{T=2004} \ln f(x_{it+1}|x_{it}, D_{it}) \tag{10}$$

In this equation $l_1(\theta)$ is the sum of logged conditional choice probabilities given current state variables defined in equation 6 in the previous section. $l_2(f)$ is the sum of logged transition probabilities of state variables given current values and choices estimated from the last subsection. Clearly, the estimates for structural parameters are not estimated from $l(\theta)$ in one single step, but they are estimated by maximizing $l_1(\theta)$ after transition probabilities $f(x'|x, D)$ are estimated.

Notice the conditional choice probability defined in (6) also implies the decision rule for firms at each state point. Therefore, observed choices in the data can be explained by conditional choice probability functions, which have a unique mapping to differential value functions. This connection between observed choices and underlying choice-specific differential value functions is easily expressed under the extreme distribution assumption of ϵ, and is also the basic idea of the conditional choice probabilities estimator(Hotz and Miller (1993), Aguirregabiria and Mira(2002)). Moreover, it also defines an iterative operator in the estimation. In other words, if there is a fixed point solution for the discrete choice dynamic programming problem, then the *differential value function* for every state point has a unique conditional choice probability mapping when the pseudo-loglikelihood estimates of the structural parameters converge. Therefore, given any initial estimates of conditional choice probability and transition probability for each state point, I can derive unique differential value functions for all choices with unknown parameters. This step is done by using the value function representation in terms of the conditional choice probabilities defined in (7). In the second step, according to the decision rule defined by (6), I use these functions to obtain a new set of conditional choice probabilities which can be used to derive another set of differential value functions in the first step. I repeat these two steps until this iterative process converges to the fixed point when the loglikelihood estimators converge.

6 Profit Parameter Estimation Results

Table 9 presents profit function parameter estimates from the structural model using the nested pseudo-likelihood(NPL) estimator[37]. Most parameter estimates have desirable signs except for the logged

[37]These estimates are results based on 225 state points of $5_{\tilde{G}} \times 3_{HM} \times 3_{MP} \times 5_{BCP}$, and the discount factor δ is fixed at 0.90. I use a relatively high discount factor in the estimation, because the asset amortization percentage has been relatively

median household income[38]. I find all Top MSO ownership variables affect current profits positively, and are also statistically significant, for six out of nine MSOs, i.e., a Top MSO ownership of the cable system can shift current profit upward regardless of any particular diversification choices the system has made. In fact, among these 269 systems, about 200 system are owned by these top MSOs. These firms operate in the market on average with more homes(55,526 homes) and much higher income level($45,499) than other firms(17,694 homes and $41,038 income). This result is consistent with other empirical work on how a cable system's ownership affects its market performance(Liu(2007), Chen and Waterman(2007)).[39] Liu(2007) studies how the system's and market characteristics influence a cable system to diversify into pay-per-view television, high-speed Internet access, and telephony services. She finds that an MSO ownership of a cable system contributes to its degree of diversification.[40]

The estimates for demand shifters show some interesting patterns here. The market size HM measured by the logged number of homes passed in the franchised area positively affects the period profit as expected and the impact is significant. However, the quadratic term has a negative sign, which indicates a decreasing effect on profit increase when the market size reaches above 3813 homes. For the medium- or large-sized markets in our data, an increase in HM has a decreasing effect on the period profit increase. This result can be interpreted as such that, in a larger market, the cable system operator faces more demand uncertainty since people in metropolitan areas have more alternatives for entertainment. The digital market growth effect from $\tilde{G}$ is estimated to be positive, indicating it is a growing market. Considering that $\tilde{G}$ is between 0.3 and 0.09, the magnitude of this impact is relatively small (between 0.50 and 1.68).

Local basic cable price (BCP) is shown as an important factor in the profit function and yields a "convex effect", i.e. the estimate for $BCP(\beta_5)$ is negative while its quadratic term has a positive coefficient. When the local basic cable price (BCP) is below $20 per month, it negatively affects the period profit, however, when the local basic cable price (BCP) is above $20 per month, the period profit increases as BCP increases. This $20 acts as threshold to upgrade or downgrade the effect of local basic cable service rate on the total period profit. In the transition probability estimation, $20 per month basic cable rate is located close to the right-end of the cutoff points. In other words, for only about 27% of the cable systems in the data, the local basic cable services monthly rate has an increasingly positive effect on the period profit. Therefore, if the monthly rate for basic cable service is $15, a 10% increase in the basic service monthly rate results in a 3.1% decrease in current profits. However, when the basic cable monthly rate equals the threshold $20, a 10% increase in the basic service monthly rate results in a less than 2% increase in current profits. This increase rises tremendously when BCP is over $20, where a 10% increase in the basic service rate yields more than a 10% increase in current profits.

The estimates for both lagged diversification choices have a positive effect on current profits. When cable systems choose to provide a digital product in the last period, they will enjoy the benefit from the digital diversification in this period. Therefore, this estimate captures the incentives for cable systems to diversify into broadband digital services. The results also indicate that the more digital products they choose to offer, the higher profits they can earn. Considering the increase in the number of subscribers to

high in the cable industry in recent years. This high discount factor can be interpreted as a high rate of return to capital in this industry.

[38] The estimated coefficient for logged median household income is negative, which is not expected but insignificant, because I have only one year of observation for this variable available in this dynamic model estimation.

[39] Generally, these top MSOs are ranked by the number of basic cable service subscribers. Another paper by Seo(2007) explores the adoption pattern of triple-play services by cable system operators in the U.S.. Instead of directly using the top MSO ownership dummy, he includes the size of local basic cable service subscribers in the model and finds it significantly affect the cable system operator's likelihood to offer the triple-play services.

[40] The degree of diversification in Liu(2007) refers to how many new services are offered among pay-per-view, high-speed Internet, and telephony services.

the digital satellite television services offered by DBS companies in recent years, this result is consistent with the argument that the cable company stays competitive by diversifying into broadband digital services, especially by offering digital cable television and high-speed Internet access to minimize its "customer churning".

When we examine the estimates of cost variables, the system's age (AGE) is found not to significantly affect the every period maintenance cost and has a large standard error. The older the cable firm's system is, the more maintenance costs the firm has to pay every period, but the marginal increment is small. The firm's plant size (MP) is an important cost variable. It is interesting to observe some economies of scale in regular costs when we investigate the estimates for plant size itself (MP) and its quadratic term (MP^2) shown in table 9. In particular, increasing the plant size of a system decreases average cost per mile per period because the quadratic term has a significantly positive effect cancelling the negative effect from MP.[41] However, this effect does not happen unless the plant has already reached a certain size. For example, if the plant size is smaller than 105 miles, increasing the miles of plant by 10% will increase the total cost. Unless the number of homes passed in the market increases more than the total cost increase during the same period, the cable system will not be able to enjoy the economy of scale in this plant expansion. However, if the plant size is greater than the threshold level, a plant expansion can even decrease the cost per mile. In fact, the larger the plant size, the greater the cost per mile saving the system can enjoy even under the condition that the system has invested a large amount of capital in providing broadband digital products. This finding is consistent with the theory that a large economy of scale can exist in network industries with huge infrastructure investment.

Comparing the estimates of sunk cost variables($\varphi's$) results in three observations. First, I find that the one-time startup cost of simultaneously offering two broadband digital services(φ_2) is substantially greater than that of offering only one digital service(φ_1). Given the plant size of the system, the investment cost of simultaneous diversification is around two times what is required for limited diversification. Second, the sum of the estimate of sequential diversification cost(φ_3) and that of limited diversification φ_1 is less than that of simultaneous diversification φ_2. In other words, if a cable system chooses sequential diversification and ends up offering two broadband digital services, the total sunk cost of the sequential diversification path is still less than that of simultaneous diversification. Lastly, the estimate of φ_3 is also less than the estimate of φ_1. Consider that in the data the majority of firms that choose limited diversification provide high-speed Internet access service first, the estimated φ_1 therefore essentially captures the cost of deploying that service, and φ_3 the cost of adding digital cable service given high-speed Internet service is available. The last two observations hence suggest that additional cost of introducing digital cable service is less than the initial cost of deploying high-speed internet service, and the total cost of introducing these two services sequentially is less than the initial cost of introducing them simultaneously. Therefore, the difference in the sunk costs of various diversification paths explains the fact that most cable systems choose sequential diversification when planning to offer two broadband digital services.

Such a cost difference may be a reflection of learning-by-doing and an installation cost reduction from the rapid technological development in the broadband equipment manufacturing industries[42]. Though in reality $\varphi's$ may change over time(particularly for the cost reduction explanation), current treatment of estimating time-invariant $\varphi's$ can obtain better estimates given the short span of the panel. These estimates thus are considered to measure the average costs of deploying these services. Particularly, φ_3 regardless the span length of waiting measures the average of additional costs when digital cable is

[41] I ignore $0.006 \cdot Age$ since the estimated coefficient is small and the product itself ranges [0.18,0.36).

[42] Lacking appropriate measures of these two stories in the data, my model cannot test them or extract one from the other.

introduced given high-speed internet is ready, and the difference between ($\varphi_1 + \varphi_3$) and φ_2 reflects the average cost reduction in broadband services over the period. For the learning-by-doing explanation, since the broadband service market is a brand-new market to cable and requires a large scale of investment in new technologies, new equipment and marketing, previous business experiences in traditional analog cable television services can not guarantee a successful business operation in the broadband services market. In particular, for cable firms, on one hand, a profit-generating high-speed Internet service requires them not only to provide customers the access but also to be able to find Internet service provider(ISP) or Internet content provider(ICP) to partner together in business. For example, in early 2000s, Cox and Comcast partnered with E@Home in providing high-speed Internet service to their cable subscribers. On the other hand, digital cable service requires these cable firms to go through lengthy process of finding cable networks(or easily programming provider) and signing complicated contracts, which involves huge sunk cost. In addition, digital cable service requires a much higher standard on the network infrastructure: a much higher speed and bandwidth in data transmission and advanced compression technologies. It certainly involves a large amount of sunk investment. To alleviate the risk, the cable company can choose to enter only one broadband digital service market first securing a certain portion of the market share, most likely the high-speed Internet access service first which is much cheaper than digital cable, and then enter the other one(digital cable service) after accumulating enough business experience and obtaining more mature technology in deploying these services.

A natural question is how to justify the simultaneously-diversified cable systems if the sunk cost of simultaneous diversification is even greater than the total sunk cost of limited diversification φ_1 and sequential diversification φ_3. The answer lies in the estimates for lagged diversification choices as shown in table 9. The digital effect for two digital products(β_8) is significantly greater than that for only one digital product(β_7). This effect can be attributed to the higher demand stimulated by more varieties in digital products that generates higher profit to the same firm. Therefore, though simultaneously diversified systems pay more sunk cost than sequential diversified systems do, the former enjoy a larger positive digital effect in the local market revenue than both limited diversified systems and sequentially diversified systems.

To explore the overall fit of the model, I compare the predicted average probabilities of each diversification choice in each year during the sample period with the predicted percentage of systems in each group observed in the data. The left panel in table 10 gives the percentage of firms in each digital diversification status in each year computed from the data, and the right panel in the table shows the predicted probabilities of each diversification choice estimated from the dynamic structural model. From these two tables, we can see that the predicted probabilities of each diversification choice are very close to the observed percentages in the data during the sample period except for the year 2000 and 2001 when the model predicts a higher probability in no-digital offering and a little lower probability in one-digital offering.

7 Counterfactual Analysis

The advantage of estimating a structural model is the ability to conduct counterfactuals once the underlying primitives of the model are known. In the case of a dynamic model, this even describes the dynamics throughout the period which is often missed in a static model. Therefore, it does not only address how the policy change can affect certain features of the market over time, but also point out the importance of the timing of the policy change. My primary interest is to investigate how the diversification choices can be affected by changing the estimated revenue and sunk cost parameters. For example, if the sunk cost for simultaneous diversification is reduced, how will the predicted probability of systems' diversification be affected? If any, in what year do we observe these changes appear to be very noticeable?

The estimation of the probabilities generated by alternative hypothetical policies is based on equation (5). Given the estimated transition probability and profit function parameters, I need the estimates of unobserved choice-specific idiosyncratic terms in equation (5) to compute the value function and get the predicted choice probabilities. In the structural estimation, I have already obtained the mean of the unobserved choice-specific idiosyncratic term ϵ. Under the extreme distribution assumption, I simulate ϵ for each state and choice pair (x, j) given the estimated mean. Then I use equation (5) to compute the value function for each state-choice pair directly and find the fixed point through iteration as Rust(1987). Lastly, given the calculated value function, I use definition (6) to derive the conditional choice probabilities for all states, and match them into the sample data set to obtain the digital diversification dynamics over the sample period.

Before I go into reports of the counterfactual analysis, I first lay out some institutional fact as background for these experiments. As mentioned earlier that the broadband diffusion in the U.S. has fallen behind many other countries in both qualitative and quantitative measures, many factors are identified in cross-country studies. Researchers have found that preferential government policies toward broadband deployment have played a very significant role in those broadband-leading countries. For example, in Japan, the country with the fastest and cheapest broadband in the world, the government has provided preferential loans, tax incentives, and direct involvement in rural broadband project(of which 1/3 investment is subsidized by government). Japanese government also encourages facility-based market competition through a set of policies such as local copper loops unbundling, open access to incumbent carrier's Internet backbone[43]. South Korean government has also provided loans, promotional regulation, and incentives to companies engaging in broadband deployment since early 2000. In Canada, the country most similar to the U.S. with dominant cable penetration over DSL, the government also made direct investment of $250 million in broadband each year between 1996 and 2006, and provided incentives to companies to create online content (See ITIF2008 Appendix for overviews of broadband deployment for more countries).

Therefore, I employ five policy experiments that attempt to capture certain effects of real government policies adopted by other countries[44]. For example, the lump-sum subsidy to the broadband investment can be reflected by reduction in the sunk cost parameters($\varphi_1, \varphi_2, \varphi_3$) . Changes in the digital service revenue shifters(β_7, β_8) can reflect either promotional subsidy or incentives to companies when they adopt broadband services or the effect of market competition on profits. Notice that my model does not explicitly include these policy variables, the changes in model estimates may also be caused by other factors, and therefore the results from these counterfactuals should be taken with caution when one considers real policy implementation.

Tables (11) and (12) report the results of five counterfactuals, each based on 1000 draws for ϵ. There are three segments in these tables and three columns in each segment that presents the average diversification choice probabilities for all cable systems in the sample in a specific year. For example, the first column gives the average probability of choosing no digital product, the second column gives that

[43]Local copper loop unbundling does not apply to high-capacity leased lines for enterprise use.

[44]Notice I do not conduct a cross-country study here, therefore I do not model these institutional differences across countries. All I attempt to do is to see how the cable diversification into broadband will be affected if certain policies are imported through changing parameters of the dynamic model.

of choosing one digital product, and the third column shows the average choice probability of choosing both digital products. The left segment in table (11) shows the benchmark diversification probabilities from the estimated model[45]

The first counterfactual takes 50% off from the cost whenever two digital products are provided($\varphi_2' = 0.5\varphi_2; \varphi_3' = 0.5\varphi_3$, policy 1). This can be considered the lump-sum subsidy to broadband investment regardless the firm takes simultaneous diversification or sequential diversification. The middle segment in table (11) reports the results. Comparing with the baseline probabilities, we observe that the probabilities of offering two digital products increase substantially throughout the period, especially during the first four years. This implies that the lump-sum subsidy reduces sunk cost of simultaneous diversification increases the value of a cable system choosing to offer two digital products instantly, thus the likelihood of that choice increases accordingly and immediately. Therefore, the timing of adoption is advanced earlier. However, the subsidy to firms that choose sequential diversification does not provide as much incentives as that to firms of simultaneous diversification, because the smaller φ_3 also implies a smaller subsidy. Therefore, the probability of adding another digital service by sequentially diversified firms does not increase much. This policy in general does reduce the number of firms that do not provide any digital service.

Policy 2 considers a non-discriminate ongoing subsidy to all cable firms through their basic cable service. It is reflected in the basic cable price increase by 100%. This large increase aims to avoid the "convex" effect in the estimates of basic cable price in the profit function($\beta_5 < 0, \beta_6 > 0$). The results suggest that a non-discriminatory subsidy to basic cable service price does increase the probability of offering two digital products on average in the beginning but not through the end. Therefore by increasing the basic cable monthly price for all cable systems, it accelerates the digital diversification by two years only. Compared to policy 1 which reduces the diversification cost, this policy yields a higher percentage of cable systems with incomplete broadband deployment at the end of sample period.

In next three counterfactuals, I investigate the digital effect β_7 and β_8. Policy 3 increases β_7 by 20% and β_8 by 50%. It can be considered an ongoing incentive to firms that introduces any digital service, yet with different size[46]. The results show that firms are more likely to provide two digital services throughout the period than the baseline case. Comparing with policy 1(lump-sum subsidy to sunk cost directly) and the policy 2(non-discriminate ongoing subsidy), this policy does not increase firms' probabilities of offering two digital services as much as these two policies do in the beginning, because firms only receive the incentive payment after they deploy the services. This policy, however, performs the best in significantly increasing firms' probabilities of providing both digital services by the end of the period and reducing their probabilities with no digital offering at all. Policy 4 is similar to policy 3, but the incentive is only offered to firms that provide two digital services to their customers and the size is smaller than in policy 3(β_8 increases by 20%). The results are not as desirable as policy 3, and very similar to policy 2.

In policy 5, I reduce β_7 by 50% and β_8 by 10%. These changes attempt to capture the possible effect of market competition– more competition in the market, less profit on the product. This treatment ignores other effects from market competition that may not change these $\beta's$. For example, market competition encourages firms to engage in various innovation to keep the profit remain high. However, there exists a

[45] They are computed by using value function iteration method as Rust (1987) after the profit function estimates and simulated errors for ϵ from NPL estimator are obtained. These simulated probabilities are different from the predicted probabilities shown in the right panel of table (10), because I use simulated errors for ϵ and I need to fix them when I conduct all these counterfactuals in order to compare the differences.

[46] Consider it is an incentive to promote the production of high quality good.

non-negligible period from innovation to real production and to sales. Suppose the regulator's policy is to encourage more broadband market competition, the direct impact of such policy is reduce these $\beta's$ and lower the profits from these digital services. Consider the competition is less severe when firms choose to provide more variety to customers, the simulated results suggest that the broadband diversification process is slower and firms are less likely to diversify into broadband digital service in the beginning of the period than the baseline case. However, due to less profit cut in β_8, we observe a higher probability of offering two digital services at the end of the period and a lower probability of offering one digital. In consequence, this yields a higher probability of offering no digital service at the end. In other words, market competition disqualifies some firms to enter into the broadband market.

The last counterfactual is to investigate the role of Top MSO ownership in the broadband diversification between 2000-2005 given the model estimates. The results are reported in table 13. It is interesting to note that in the first two years, by removing Top MSO ownership, the firms are more likely to offer digital service. In other words, removing Top MSO ownership can significantly accelerate the broadband diversification in the first two years. However, this trend does not last long. In 2002, a turning point emerges and reverses the whole trend, i.e. firms are less likely to offer digital services and more likely to stay without any digital offering. This result seems quite counter-intuition at the first glance. However, the data shows that most of these systems owned by a Top MSO operate in a much larger market in both the number of homes and the plant size. I estimate that the home has a negative coefficient for the quadratic term. When removing these ownership dummies, these negative size effects counterbalance the higher payoff that the firm can enjoy from broadband diversification on average. Therefore, only those firms with moderate size are likely to offer digital services. By the end of the period, firms operating in large market are still not providing any digital service. This counterfactual suggests that Top MSO ownership does help the broadband diversification in the later period not at the beginning. Therefore, a policy to encourage municipality or other firms such as power utilities in medium-sized market to enter into broadband market in the early period may help accelerate the broadband diversification.

8 Conclusion

In this paper, I develop a dynamic empirical model of a cable company's decision to offer digital services including high-speed internet access service and digital cable television service. The model embodies both demand factors and plant-level heterogeneity in maintenance costs and the sunk costs for entering these two digital services market. The model differs from conventional entry/exit dynamic models by allowing firms to sequentially enter both markets. In other words, the model accommodates the observation that many cable companies sequentially enter the digital services markets by initiating one digital service first and adding the other one at a later date. Using plant-level panel data for 269 distinct geographic markets over 6 years, I estimate both the cost effect and the demand effect on a cable company's diversification decision.

The results provides an explanation for the slow broadband diffusion in the early 2000s in the U.S. i.e. high entry costs slow down cable companies to diversify into broadband digital products.I find that the entry costs of offering different broadband digital services significantly affect cable operators' entry decisions. In addition, market size, plant size and ownership all have impact on the firms' profit function and thus their diversification decision.

The broadband digital diversification decision from the previous period is found to contribute to the current period profit. Considering the increasing number of subscribers to the digital satellite television services offered by DBS companies, the cable company stays competitive by diversifying into broadband digital services, especially by offering digital cable television services and high-speed Internet access service to minimize its "customer churning". When distinguishing this "digital effect" by the number of broadband digital products a cable system operator chooses to offer, I find that the cable system can enjoy more profits by offering two broadband digital services than if it offers only one digital service. This result also indicates that the "triple-play" marketing strategy by the cable company helps its revenue and market competitiveness.

Several counterfactual policy experiments are implemented using the estimated model. I consider lump-sum subsidy to broadband diversification, non-discriminate subsidy to all firms, and ongoing incentives to broadband diversification. When lump-sum subsidy to offering two digital services are introduced, the cable systems start their digital offering earlier and more systems end up offering two digital products throughout the sample period. When a non-discriminate subsidy is provided through basic cable service to all firms, more firms start to offer two digital services earlier, but this trend does not continue for the last two years of the period. However, if an ongoing incentive is provided to firms who offer digital services, the broadband diversification can be accelerated. I also consider possible effect of a competition policy. At the end, I also investigate the role of Top MSO ownership in the broadband diversification. It is interesting to note that in the first two years, by removing Top MSO ownership, the firms are more likely to offer digital service. This counterfactual suggests that Top MSO ownership does help the broadband diversification in the later period not at the beginning. Therefore, a policy to encourage municipality or other firms such as power utilities in medium-sized market to enter into broadband market in the early period may help accelerate the broadband diversification.

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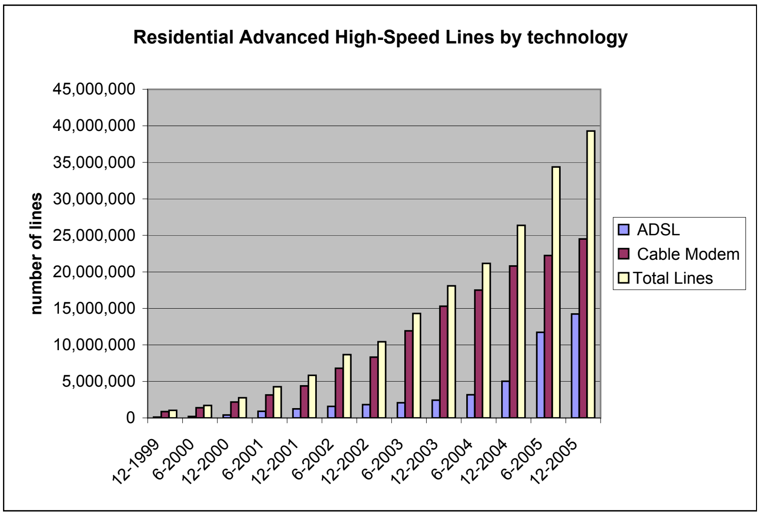
9 Appendix

Figure 1: Broadband Growth by Technology



source: from FCC, *High-Speed Services for Internet Access: Status as of June 2006* , table 4

Figure 2: Cable Systems Digital Services Offering

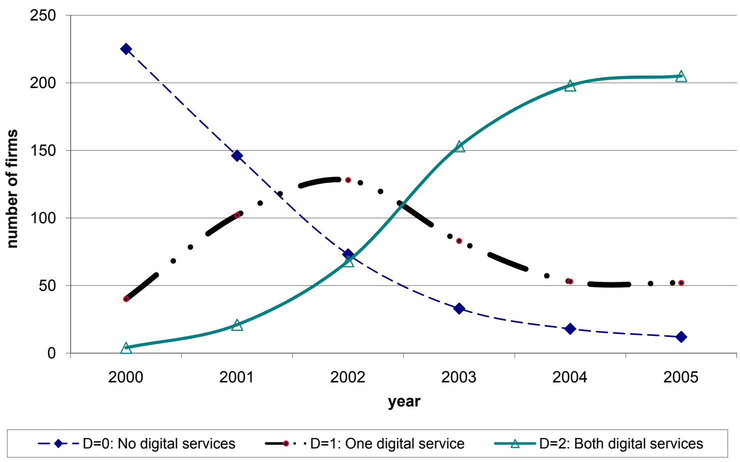


Figure 3: Different Diversification Paths

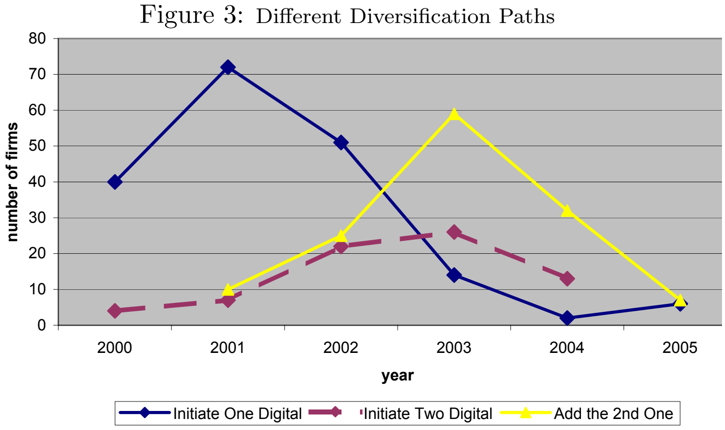


Table 1: Variable Summary Statistics 1

Variable	Mean	Std. Dev.	Min	Max
Homes passed *	47.07	82.60	0.167	640.39
Top 10 MSO ownership dummy	0.78	0.42	0	1
Basic Subscribers*	28.63	45.82	0.045	332.3
Basic Cable Service Monthly Rate**	15.71	8.52	2.71	40.83
Miles of Plant	588.63	940.06	4.00	7,438.3
System Age(years)	29.5	9.78	3.6	54
Income*	44.50	14.24	23.48	110.53

*: numbers are in thousands.

**: The rates are inflation-adjusted dollars.

Table 2: Summary Statistics 2

Variable	Mean Std.Dev.	Min	Max	95% C.I.	P-value
Basic Cable Monthly Price	3.05	0	19.31	(2.56898, 3.53498)	0.000
Home Passed	2492.85	0	113759.2	(1236.11, 3749.59)	0.000
miles of plant	52.54	0	3693.66	(21.9600, 83.1219)	0.001

Table 3: Number of Systems In Broadband Market

Year	Internet Access Only	Digital Cable Only	Both
	(1)	(2)	(3)
2000	34	6	4
2001	88	14	22
2002	108	21	68
2003	61	23	154
2004	33	21	199
2005	36	18	205

Table 4: Means of System Characteristics by Diversification Path

	No Digital	Limited	Simultaneous	Sequential
	(1)	(2)	(3)	(4)
Basic Cable Monthly Price	15.76	14.97	16.82	16.00
Homes passed	25,345	52,750	33,535	70,482
Miles of Plant	336.22	496.11	425.30	830.75
Homes per mile of plant	70.51	80.27	70.43	85.58
System Age	27.5	29.0	29.09	30.4
Obs.	507	185	72	133

Table 5: Transition probability estimates $f^2(MP'|MP)$

		Future plant size: MP'		
		small	medium	large
MP	small	0.984	0.013	0.003
	medium	0	0.976	0.024
	large	0	0	1

Table 6: `Transition probability estimates` $f^3(HM'|HM)$

		Future market size: HM'		
		small	medium	large
HM	small	0.989	0.011	0.003
	medium	0	0.97	0.03
	large	0	0	1

Table 7: `Transition probability estimates` $f^4(BCP'|BCP)$

	Future basic price: BCP'				
Current BCP	1	2	3	4	5
1	0.863	0.069	0.046	0	0.022
2	0.063	0.853	0.063	0.006	0.014
3	0	0.085	0.871	0.021	0.023
4	0.003	0.021	0.098	0.765	0.113
5	0	0.013	0.020	0.099	0.868

Table 8: Estimates of AR(1) process

parameters	estimates	std.	t-stat
η	0.057	0.129	4.41
ρ	0.432	0.049	8.78
σ_u	0.027	0.0045	
obs.	14		

Table 9: Estimates of Profit Parameters

Discrete Choice Dynamic Model				
Revenue Parameters		Estimates	s.e.	z-statistic
α_1	*Adelphia*	1.328***	0.374	3.556
α_2	*CableOne*	0.484	0.429	1.128
α_3	*Charter*	0.237	0.319	0.744
α_4	*Comcast*	1.315***	0.257	5.114
α_5	*Insight*	3.335***	0.471	7.077
α_6	*Cox*	0.065	0.473	0.137
α_7	*MediaCom*	0.728**	0.258	2.827
α_8	*TimeWarner*	1.502***	0.273	5.511
α_9	*AdvanceNewhouse*	1.558***	0.394	3.955
β_1	*Income*	-0.079	0.283	-0.279
β_2	HM	3.546***	0.795	4.458
β_3	HM^2	-0.215***	0.043	-4.958
β_4	$\tilde{G}$	5.613**	2.158	2.601
β_5	BCP	-2.762**	1.276	-2.165
β_6	BCP^2	0.708**	0.296	2.398
β_7	$(D_{t-1} = 1)$	0.417**	0.138	3.027
β_8	$(D_{t-1} = 2)$	1.172***	0.170	6.89
Regular Cost Parameters				
ϕ_1	$-MP$	3.151***	0.657	4.795
ϕ_2	$-MP^2$	-0.339***	0.062	-5.437
ϕ_3	$-Age$	0.006	0.010	0.554
Sunk Cost Parameters				
φ_1	$-InitialD1$	0.581***	0.166	3.498
φ_2	$-InitialD2$	1.206***	0.268	4.496
φ_3	$-LaterD2$	0.485**	0.236	2.057
	Obs.	1614		
	min.Loglikeli	1171.397		

Table 10: Percentages of Firms in Digital Offering

	DATA			**Model Prediction**		
year	**D=0**	**D=1**	**D=2**	**D=0**	**D=1**	**D=2**
2000	0.836	0.149	0.015	0.651	0.270	0.078
2001	0.543	0.379	0.078	0.647	0.270	0.083
2002	0.271	0.476	0.253	0.318	0.445	0.237
2003	0.123	0.308	0.569	0.147	0.312	0.541
2004	0.067	0.197	0.736	0.061	0.204	0.735
2005	0.045	0.193	0.762	0.059	0.201	0.740

Table 11: Policy Experiment:(1)∼(2)

year	**Estimated Probabilities of $D=0, D=1, D=2$**								
	Baseline Simulation			Policy Change (1) $\varphi_2' = 0.5\varphi_2; \varphi_3' = 0.5\varphi_3$			Policy Change (2) Double Basic Cable Price		
2000	0.531	0.332	0.136	0.503	0.316	0.181	0.416	0.302	0.282
2001	0.528	0.331	0.141	0.501	0.314	0.185	0.424	0.302	0.274
2002	0.321	0.404	0.275	0.298	0.370	0.332	0.313	0.442	0.245
2003	0.195	0.331	0.474	0.181	0.304	0.515	0.209	0.326	0.465
2004	0.114	0.269	0.617	0.111	0.263	0.626	0.097	0.288	0.615
2005	0.110	0.267	0.622	0.108	0.261	0.631	0.095	0.286	0.620

Table 12: Policy Experiment:(3)∼(5)

year	**Estimated Probabilities of $D=0, D=1, D=2$**								
	Policy Change (3) $\beta_7' = 1.2\beta_7;\beta_8' = 1.5\beta_8$			Policy Change (4) $\beta_8' = 1.2\beta_8$			Policy Change(5) $\beta_7' = 0.5\beta_7;\beta_8' = 0.9\beta_8$		
2000	0.521	0.331	0.148	0.529	0.331	0.140	0.542	0.327	0.130
2001	0.517	0.329	0.153	0.525	0.330	0.145	0.539	0.327	0.134
2002	0.300	0.396	0.304	0.316	0.398	0.286	0.343	0.389	0.268
2003	0.167	0.304	0.529	0.186	0.316	0.497	0.217	0.314	0.469
2004	0.084	0.210	0.706	0.102	0.240	0.657	0.127	0.253	0.619
2005	0.082	0.207	0.711	0.099	0.238	0.662	0.124	0.252	0.624

Table 13: Policy Experiment:(6)

year	Policy Change (6) Top MSO ownership=0		
2000	0.445	0.340	0.215
2001	0.444	0.335	0.221
2002	0.326	0.321	0.353
2003	0.251	0.349	0.400
2004	0.187	0.325	0.487
2005	0.182	0.323	0.494