Estimating Possible Subsidy Effects in Broadband Services and Deployment

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Abstract

In this work, the dynamic competition between firms providing internet services is studied. The framework is Markov equilibrium whereby structural parameters are obtained using two-step estimations, allowing for analyzing the situation in case of subsidies for service upgrade. The results show that such subsidy has little effect on the number of firms while increasing the number of fast firms.

Keywords: structural estimation, dynamic competition, Markov perfect equilibrium, investment in Internet provision, subsidies

JEL Codes: L13, L86, L50, D25, C73

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*The original paper was written in Persian as the author's master thesis. This English version was written by first machine-translating the original paper and afterwards fixing the various issues that resulted and then rewording what was lost in translation. I sincerely apologize if the discourse may sometimes seem unclear as a result.

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1 Introduction

Figure 1.1 shows the number of high-speed Internet service providers in the US state of Texas and in certain cencus areas of it (tract). High-speed service providers are more concentrated in specific locations. What could be the cause of such a situation? While firms can potentially provide high-speed services, they are present in fewer numbers or with slower services instead. And what regulatory act, and to what extent, can shift the balance toward high-speed Internet service delivery? How effective will changing these conditions be to this aim?

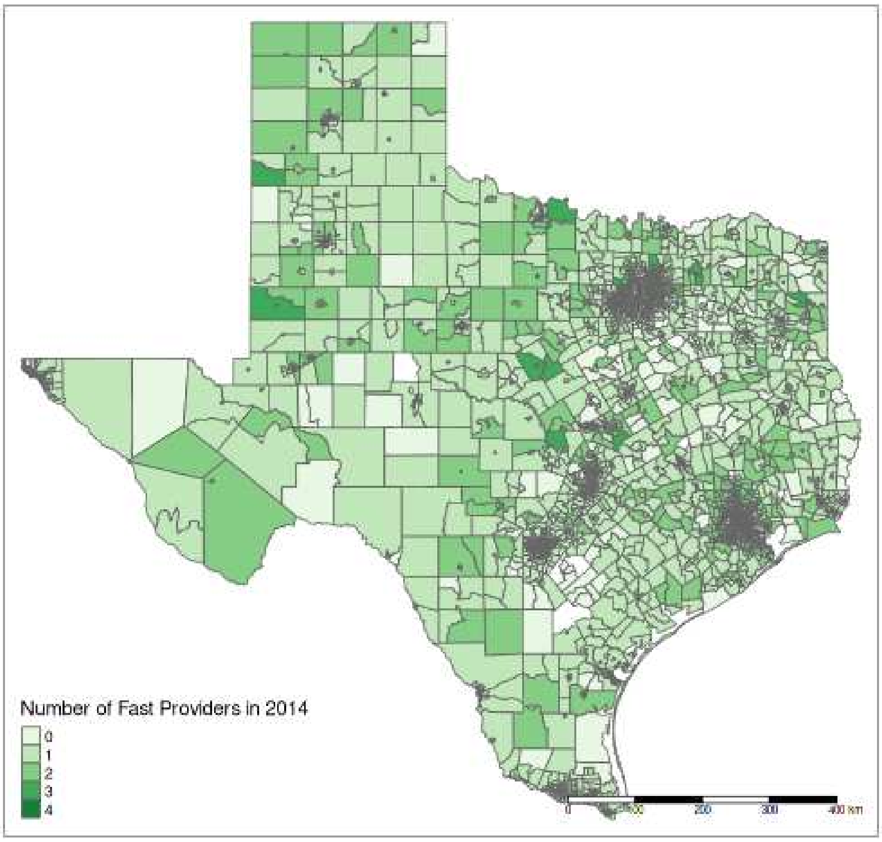

Figure 1.1: Scheme of fixed high speed broadband services in various tracts of the US state of Texas. High speed is identified as speed greater than the median between firms in the FCC data.

Previous research has attempted to answer similar questions in a variety of ways, especially reduced-form measurements. But as will be seen, the answer to the entire picture posed above is in the structural estimation of the situation. The results obtained from such an approach will have a higher accuracy thus providing the Internet market regulatory with suggestion on possible policies to take.

The Internet service industry is important in many ways and has therefore seen some of the most serious regulations (Beard et al. 2016). Some of the effects of Internet services are general, such as their effects on productivity and are evident in works such as Timothy F Bresnahan et al. 1992; Majumdar et al. 2010. Another effect that is discussed in more recent works is the benefits it can bring to rural areas Briglauer, Durr, et al. 2018; Prieger 2013. Also, the works of Fornefeld et al. n.d.; Koutroumpis 2009 regarding the role of Internet services at the macro level and GDP growth indicate another aspect of such effects. The issue of Internet service delivery is becoming increasingly important, including the issue of basic service provision and its universality in terms of being a [1] per the work of Lim et al. 2018. A variety of services are available at a lower cost using the infrastructure of the Internet. Especially with the outbreak of the Corona virus, the importance of access to services provided by the Internet, and therefore the issue of high-speed and more secure Internet access, has become further clear. In such a situation, the important question is what effects can be expected from specific subsidies for the development of fixed Internet services?

Despite the serious regulation of the Internet in most of the world, the regulator usually does not have the right answer to this question and the right idea of what policy to take in this regard (Jerry A. Hausman and William E. Taylor 2013). Various theoretical and experimental works have tried to provide the correct answer, but they are mostly faced with fundamental shortcomings and limitations.

Answering such a question requires an analysis of the market structure and the prevailing competitive environment. The competition in the Internet industry is oligopolistic (Faulhaber et al. 2000). Therefore, the factors influencing the decision of each firm in any given market, in addition to market characteristics, should depend on the mutual behavior of other firms both incumbent as well as entrant. Also, these decisions are

[1] utility

dynamic and each firm considers its long-term profit, not just the profit of the period. On the other hand, to answer the question, it is necessary to anticipate the effects of changes in market structure and competition, which may be in the form of subsidies. One way is to look at the issue from a theoretical perspective. But the dynamics of competition and prevailing oligopolistic conditions, especially in an industry with high investment costs, will have many complexities. In this case, theoretical works, due to their mostly limited scope and framework and relatively simple assumptions, will not be able to consider many aspects of such conditions. [2]

Numerous articles have been published in recent years to estimate the oligopoly dynamic competition in different industries. These include an article Ryan 2012 on the cement industry, and work on airline competition (Aguirregabiria et al. 2012). Both of these works are based on the estimation method of Bajari et al. 2007. Of course, there are simpler estimation methods with similar machinery, including Pakes, Ostrovsky, et al. 2007. These estimates allow firms to examine the entry and exit of firms, and then change the layout of competition and the market, after matching the data with the proposed model, even under other hypothetical conditions. Therefore, the possible impact of policies, including centralized subsidies, on the important industry of Internet service providers could similarly be estimated. An example of the application of this approach is especially the article of Fan et al. 2015.

[2]What is meant is the entry of more companies or the provision of better services. Clearly, this is a dynamic issue; Each firm does not only examine the consequences of its one-time presence in a particular market, but also its post-entry conditions, and in terms of the possibility of other firms entering, the possibility of exiting the market, the possibility of upgrading its services in the market, and so on. It thinks about the whole path after making a decision. Also, the profitability of the market is not clearly defined for each firm; Entry, exit and upgrade costs are only generally specified, and the firm can only see its draw if it meets the conditions: The firm that decides to enter the market may realize the higher advertising costs it has to pay to know or attract competing subscribers, or realize higher installation costs, due to the infrastructure that the firm itself has, and therefore its entry cost is more or less than what is generally ”expected” compared to another firm. These are the aspects that should be considered in a model that wants to provide a proper answer to the question posed.

1.1 Necessity of research

The Internet, and telecommunications industry in general, is subject to numerous regulatory interventions. In the absence of such regulations, we are faced with an industry with only one or a limited number of large firms that provided their services separately and exclusively (Faulhaber et al. 2000). The reason for this is the existence of a natural monopoly in this industry: The high costs that existed for the creation and promotion of the service platform, made the activity of virtually any company, except large companies, as well as their development almost impossible. In such a situation, the regulator felt the need to intervene.

Regulation and intervention took place in different ways, in different countries. It is no surprise, then, that most of the paper on the industry's situations are about finding evidence of the effectiveness of the regulatory's present policies or otherwise of the various alternative policies that can be pursued by the regulatory. In this regard, limited empirical work has been done, focusing only on specific policies ((Cambini et al. 2009)).

Restrictive theoretical assumption (according to ibid. and the rest of the literature onwards) such as limited number of firms both incumbent and entrant, so that theoretical results can be obtained, as well as empirical works on specific policies where evidence is only of the reduced-form variety, whereby direct discussion and analysis of the issue of competition are avoided, are among the most important shortcomings of the literature on the competition in the Internet industry.

Existing studies are usually restrictive and completely unrealistic. Since this industry is a natural monopoly, most works have only tried to analyze the monopoly problem of this market, while the current situation, as will be shown in the data, is in reality, now a state of oligopolistic competition and needs to be analyzed in such a framework.

In the present literature, firm interactions are limited and unrealistic assumptions that are practically unreliable to determine the right policy for the regulator. The framework of an incumbent firm and only one round of entrant firms in the work of Jerry A Hausman, Sidak, et al. 2001, is completely unrealistic given the conditions of oligopoly competition and the dynamics of firm decisions. Focusing on policies that should be considered with respect to the monopolist as in the work of Gans 2001 is no longer widely usable in the present situation where many other firms are competing in different markets. Simple measurement methods such as the work of Jerry A. Hausman and Sidak 2004 do not allow the alternative policy to be examined and can only provide conjectures without empirical evidence.

An example of this is the various decisions of the FCC [3], the regulator of the US telecommunications market (Boliek et al. 2019). But the fact is that most of the decisions that the regulator makes in these circumstances can simply be considered as a kind of subsidy (Fan et al. 2015; Jerry A Hausman and William E Taylor 2012).

In terms of approach, this research is close to the topic of estimating dynamic oligopoly competitions. This method started in Pakes, Ostrovsky, et al. 2007 and Bajari et al. 2007 and has been used recently in works such as Fan et al. 2015, Ryan 2012 and Collard-Wexler 2013. In this work, I use the Bajari et al. 2007 method and the model that is presented for the industry is simplified and estimated according to said work's guidelines. The first application of estimating dynamic oligopoly competition to the Internet industry is perhaps the paper Wilson 2017 which is based on Pakes, Ostrovsky, et al. 2007. The present research framework based on Bajari et al. 2007 has far fewer limitations than the aforementioned work and applies even fewer hypotheses: Moments, alternative policies, etc. can all be selected in modelling. This flexibility comes with the more explicit cost of modelling, more complex implementation, and the lack of direct choice in approaching the various stages of estimation. Undoubtedly, the complexity of estimating dynamic oligopoly competition, despite its usefulness, is one of the reasons why such works have been so limited thus far, not just in the Internet industry.

[3] Federal Communications Commission

But one of the reasons that experimental work of any kind has been limited in the field of Internet competition has been the lack of access to competition data before. In this research, using FCC data in form 477, it is possible to examine market conditions and firms. Having relevant data is especially important in the Internet industry: investment costs are high, technological advances and industry innovations are intense, and the industry is highly dynamic. Therefore, the studies must be intermittent, which is not the case in most of the past experimental works (Distaso et al. 2006). Thus, although the present research is part of the experimental work in the analysis of the Internet industry, it is different in terms of considering the dynamics and movements of this industry and structural estimates.

Many theoretical works have been done in the analysis of Internet companies, some of which are mentioned Cambini et al. 2009. In the present study, analysis is based on a limited structure that does not focus on the theoretical method, and instead allows firms to act on a data basis and provides a data-driven analysis of firm behavior.

1.2 Internet industry

The Internet can be accessed in a variety of ways. What is more common today is the provision of this Internet access through the technology called broadband. The term broadband refers to any high-speed alternative to low-speed dial-up Internet. Even in the FCC data based on form related to ”broadband”, satellite internet is included in this category, although technically it may not be correct. So for our purposes, broadband is just the current common Internet, which is different from dial-up.

But in this study, the focus is on the provision of the Internet broadband of the two general categories of DSL and cable. These two categories themselves have branches, all of which we consider under the two categories. In the United States, companies that are in serious competition with each other are generally of these two categories, whether competing between each category or with their counterparts and within each category (Bourreau and Doğan 2006). Satellite Internet and others, although in data, are not considered because of the fundamental differences in their service and their target population. A description of this aspect of the data is in the appendix.

DSL and cable services are different in terms of Internet access infrastructure. In DSL, Internet access is possible for households or businesses via telephone wires. For the household, this service is usually ADSL and for the enterprise, it is purely DSL. But cable service is done only with own cables that are not mounted on the telephone infrastructure. In general, it can be said that cable service is faster.

In cable, a line usually passes between many houses and is shared between them. Therefore, with the increase of customers, we will have a decrease in the quality and speed of service. In DSL, telephone lines are connected to each household separately from the center, and in general, it can be said that there is no congestion problem due to the increase in number of customers. But the problem is that the speed of service slows down by moving away from the center that delivers telephone lines to every household. With these differences, we expect the behavior of firms that fall into either of these two categories to be different.

Another aspect of fixed internet services is mobile internet. With a mobile Internet subscription, much less data is available for the same price. That is to say, the average allowable data of mobile internet subscribers is very low. For example, Bourreau, Sun, et al. 2018 reports an average of only 622 MB per month in the 14-zone zoning from France from the end of 2011 to the beginning of 2015. This volume is much smaller than the volume offered by fixed internet and is not suitable for many tasks. Apart from that, most households use a combination of fixed and mobile internet and little replacement between the two services is fully expected (Grzybowski 2014).

The US Internet regulator is the FCC. In the retail sector of the market, which provides services to households and businesses, the FCC has set price ceil, which is also common worldwide (Cambini et al. 2009). But at the wholesale level and in buying, selling, and leasing the infrastructure of Internet service providers, the FCC has taken different approaches over the years (Jerry A. Hausman and William E. Taylor

2013).

One of the issues that the FCC has made various decisions in regard to over the years is the issue known as the LLU [4]. This regulation is that the incumbent forcibly give its telecommunication center to the entrant and its logic is that the entrant with the help of these infrastructures can create and develop its own service delivery network. This process is called the *ladder of investment.* (Cave 2006). In this regard, the study Fan et al. 2015 considers LLU-assisted regulation as a kind of subsidy to entrant and the similar article Jerry A Hausman and William E Taylor 2012 considers it as a contribution to the entrant. Much of the Internet competition debate revolves around the LLU topic. The FCC's latest decision in this regard is to abolish the mandatory access of companies to the incumbent's infrastructure and centers. The FCC now exercises less oversight in the wholesale of the Internet market and focuses more on approaches to improving the quality of service delivery.

Two components are important in the Internet industry, especially from the perspective of its market regulator: Service and competition. The FCC's definition of Internet access is essentially based on the speed of service, to the extent that some (mostly rural) areas of the United States have no Internet access at all (Prieger 2013). Another component is the competition in facilities (cables versus DSL) and services, which is expected to lead to better services (Cambini et al. 2009). Issues of speed of service and quality and reliability, competition between cable and DSL to create Internet access, competition between service providers themselves in both cable and DSL, and combining different services to be provided by firms, such as cable and targeting different consumer tastes are recurring pattern in the Internet industry.

The Internet industry is a network industry, and like other network industries that provide basic public services, it is very important to users. Nevertheless, its costs are very high, and this importance and complexity has led to strict regulatory policies. The intensity and scope of regulation in telecom has been so great over the years, to the extent that many network industries have turned to regulatory experiences in

[4] Local Loop Unbundling

telecommunications and the Internet to formulate their own regulation (Beard et al. 2016). Among similar industries, there are debates about providing access to other companies to the railways of existing companies (ibid.). In power and grid networks, the issue of connecting power plants and small local distribution networks to the main grid, and purchasing and recombining part of the grid, is discussed with the help of telecommunications regulatory experiences due to the increasing trend towards local energy production (Pollitt 2010). Regarding airline airport networks, the use of airports is now more in the hands of governments due to security issues, which with the development of security practices, the discussion of transfer of use and licenses of new airports also hopes to benefit from telecommunications regulatory ideas (Borenstein et al. 2014).

However, this is accumulated attention to the regulation of the Internet service provision, while the regulator of the Internet industry itself is hesitant about many policies (Jerry A. Hausman and William E. Taylor 2013). What policy and at what cost will be able to meet the regulator's goals, and to what extent, has no clear answer either from the regulator's point of view or from studies on this issue. In this regard, even some countries have succeeded in developing their Internet infrastructure, while keeping the industry fundamentally unregulated; such as South Korea, which has relied on direct subsidies (Cambini et al. 2009). Similarly, the FCC has been planning in recent years to provide direct subsidies to Internet service providers (Wilson 2017).

2 Literature review

The broadband Internet industry, and telecommunications as a whole, is so highly regulated that, for example, the 1996 act of unbundling is considered one of the most complex regulatory measures in recent decades (Beard et al. 2016). Accordingly, in the study of this industry, much attention has been paid to various regulatory issues. This analysis includes both retail pricing and access pricing. The problem of market price regulation is almost solved according to Cambini et al. 2009, although there are some new theoretical works. But the fundamental issue is the issue of pricing for access to incumbent firm infrastructure, on which, according to the same source, there are conflicting theoretical conclusions. For example, in the work Jerry A. Hausman and Sidak 2004 while the authors critique the pricing method for such an access, they propose a gradual increase in this price to address the inefficiencies of the previous method. However, in the work Bourreau and Doğan 2006, the authors refer to the previously mentioned work, rejecting this proposal in their modeling of the problem, and show that neither the gradual increase nor the total elimination of access after a certain period (sunset clause) increase the competition in the facilities.

Another study on the 1996 U.S. act and the entry of firms is the paper of Jerry A Hausman and William E Taylor 2012 in which it is argued that such an order was essentially a pro-competitive firm order (entrant) that led to unnecessary entry [5]. Thus, the conclusion of Beard et al. 2016 in a situation that the benefits of such an order have been insufficient, is that unbundling did not work even at subsidized prices for entry. Subsequently, much of the literature discusses entry through the LLU and examines the "investment ladder" hypothesis, the fundamental question of which is the possibility of advancement and the possibility of competing in facilities for the entrant via LLU.

The most important recent empirical work on LLU entry can be considered the work of Nardotto et al. 2015. This study shows many results but except for the simple use of the method of Timothy F. Bresnahan et al. 1994, is still based on evidence that

[5] gold-rush-style

is in reduced form. Of course, important conclusions can be drawn about the effect of the entrant on the market and competition therein. Although this work does not provide conclusive evidence of the investment ladder hypothesis, the work of Bourreau, Grzybowski, et al. 2018 on a similar basis has evidence of entrant firm investment in implementing the fiber-optic functionality [6], which can be used as evidence for that hypothesis. In any case, one of the most important results of Nardotto et al. 2015 is that the entrant provides higher quality services (especially speed) which, given the growing demand for Internet services (according to the ITU), shows the importance of entering through the LLU.

LLU entry itself is just a subsidy to reduce entry costs. Few analyzes have examined the issue in terms of subsidies in the context of dynamic oligopoly competition. One of the reasons is the unavailability of data and the complexity of the analysis. But in recent years, the necessary data has been comprehensively collected, including relevant data that the FCC has been collecting since 2010. So far, most of the literature has focused on (more managerial) details of pricing, law, investment decisions, and so on. While a more comprehensive analysis of the competitive situation, taking into account sunk costs, firm entry, upgrade decisions, etc., as strategic responses, has largely been absent from the literature and limited only to hints and sometimes reduced form evidence.

In this regard, the limited recent work that has been done in the field of structural estimation of telecommunications competition has been able to provide new evidence to the literature. The research of Bourreau, Sun, et al. 2018 suggests that the creation of secondary business brands for Internet service providers may be a sign of the failure of tacit collusion. The work of Xiao et al. 2011 concludes the same result of Timothy F. Bresnahan et al. 1994 that the market approaches a situation similar to full competition, from oligopoly competition, relatively quickly, with only three or more firms entering the US Internet service market. The two works of Fan et al. 2015; Wilson 2017 examine the impact of subsidies in a more general context than just LLU by applying a

[6] fiber-to-home

model of dynamic oligopoly competition to telecommunications and Internet services. Nevertheless, the literature on the dynamics of oligopoly competition and structural estimates in broadband Internet services is still in its infancy.

An overview of the surrounding literature and the place of the present research in the literature is in Figure 2.1:

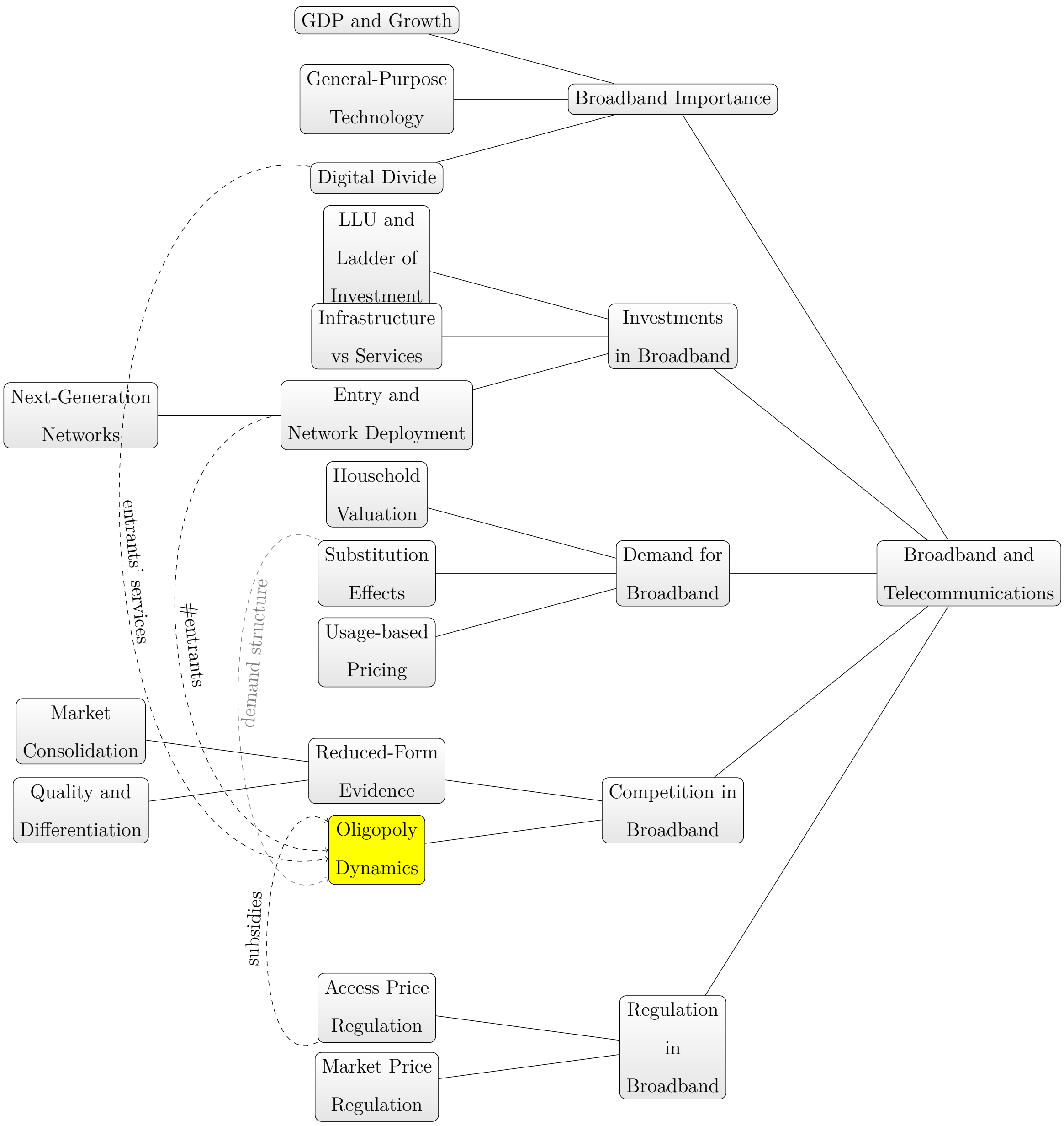

Figure 2.1: An overview of the surrounding literature and the place of the present work

The discussion of the study of dynamic oligopolistic competition on the Internet is related to the discussion of the service delivery gap in urban and rural areas (digital divide) in terms of new services that a new firm can provide. Present research, according to the figure, is related to the entry of the firm and the development of its network, through estimating the number and types of the firms. In terms of access pricing, it is related to the study of subsidies in the literature. Finally, although the relationship is weaker, it can be considered related to the discussion of substitutes created by different services, although the purpose of the work is not to estimate demand and the impact on it, only that companies can offer different services.

2.1 Categories of literature

2.1.1 Importance of broadband internet

The work of Koutroumpis 2009 and Fornefeld et al. n.d. are examples of research that show the impact of broadband Internet on macroeconomic growth by methods that are reduced form. Works such as Timothy F Bresnahan et al. 1992 also emphasize its effects on productivity, as a technology that different firms can benefit from. However, regarding the importance of broadband Internet, on the heterogeneity of access in urban and rural areas and measures to reduce it, the work of Prieger 2013 claims that access and choice of broadband Internet in urban and rural areas is not the same rate, instead what is obtained from FCC data is that fewer firms are in rural areas with lower levels of service (although low speeds are available in almost all areas still). The work also highlights the importance of mobile internet for rural areas and reports greater disparity in provision of fixed services. To reduce this gap, the more recent paper Briglauer, Durr, et al. 2018 examines the possibility of compensating for it with government aid and in a framework of reduced-form analysis, showing that government-assisted areas have about 20 percent more broadband coverage, which on average leads to an increase of 6 jobs in these areas compared to similar areas that have not received government assistance. Thus the work shows the importance of government assistance, in the form of various facilities and subsidies to improve services and Internet access.

2.1.2 Broadband investment

Much of the literature of broadband deals with the LLU and the investment ladder hypothesis, which follows the general theme of broadband investment, and similarly, investment in the network industry. The work Jerry A. Hausman and Sidak 2004 mentions four possible reasons for unbundling: one is competition for price reduction and more innovation in the sales market, the other is the impossibility of competition in the sales market in the absence of unbundling, the third reason is the possibility of creating competition in infrastructure by ladder of investment, and fourth is the tendency to create competition in the general access market. The paper then concludes by examining the situation as well as a limited review of data from five countries, that cable companies easily compete with telephone companies in the sales market. Also, the infrastructure does not seem to have any value in itself other than the final relationship it establishes with the customer. As for the logic of the investment ladder, it has not been successful in increasing access to facilitate entry in a universal and homogeneous way, without taking into account the conditions of the applicant firm and its commitments. The article claims that the entrant firm may have paid more than it should have to attract the incumbent firm's customers, which has resulted in it not being able to invest more in its differentiation, or being able to compete with the incumbent . This study then demonstrates the importance of a more structural study of the economic effects associated with LLU.

Another paper, Bacache et al. 2014 rejects the investment ladder hypothesis empirically, stating that companies seem to be more inclined to create services in contrast to building infrastructure and. This result can be seen in many other works such as Bourreau and Doğan 2006; Nardotto et al. 2015; Reed et al. 2018, according to which the entrant is more focused on differentiating itself from the incumbent and gaining its customers rather than wanting to have and develop its own infrastructure. In particular, the study Briglauer, Ecker, et al. 2013 states that competition in services has reduced competition in infrastructure, and that the continuation of such conditions calls into question the possibility of achieving the goals set by the European Union for the creation of next-generation networks. The research of Kotakorpi 2006 shows that access permission removes the investment incentive for the incumbent, even further than the unfavorable conditions that existed in the absence of competition itself, and the firm's focus will be on competing in services with the competing firms.

Another strand of the literature on broadband investment, is through the study of entry and expansion of the network of each firm, and thus the ultimate increase in the number of firms with better services. The paper of Wilson et al. 2018 shows that in the United States, the firm's behavior to delay entering any market is due to the threat of entry of other firms, and as a result, more competitive conditions do not necessarily result in network entry and expansion. In principle, the entry of the firm is also related to the discussion of dynamic analysis of industry, which can be seen in studies such as Bourreau, Sun, et al. 2018; Fan et al. 2015; Wilson 2017; Xiao et al. 2011 and other works. But this part of the literature is more prominent in the research of Nardotto et al. 2015 as well as the similar work of Bourreau, Grzybowski, et al. 2018 which is somewhat based on the work Xiao et al. 2011. In this study, only evidence of relatively perfect competition is provided by the entry of a third firm, but the work of Nardotto et al. 2015 provides a variety of other evidence of changing conditions and claims that entry through the LLU has at least improved the quality of service. Another issue that this work addresses is under what circumstances LLU entry is more likely, such as the likelihood of the firm entering urban areas as well as the conditions of each particular market. This shows that market size is a key factor in the entry decision, costs of sunk costs are a large part of the cost of investment in broadband services, and that network consolidation plays an important role: A firm is more likely to enter a market when the market is adjacent to its headquarters, which the article argues is due to economic savings in the development of the network, which shows the importance of considering the specifics of network densities in analyses.

2.1.3 Demand for broadband internet

Another discussion in the literature is the demand for Internet services. In this regard, most studies have a questionnaire method and few works have employed market data. However, regarding household demand, the research of Rosston et al. 2010 has taken the approach of combining questionnaire and market data. According to it, both urban and rural households place a relatively high value on the speed and reliability of services, and the rural household has greater value for service reliability. Therefore, it seems that there is sufficient household demand for improved quality and expanded access, should the firm act, although the cost of the firm action may be more than its value, in which case the importance of subsidies can one again be raised.

The research of Bourreau, Sun, et al. 2018 has analyzed the creation of secondary brands and in particular has examined the effect of substitution between different services such as lower quality service but lower price and quality service that are more expensive. The important results of this research are in outlining the market layout and the importance of dynamic approach to the analysis of the competition. Finally, one of the new works is the work in the field of pricing based on the amount of consumption, which with a structural and dynamic analysis of mere demand, and not necessarily competition conditions, examines the dynamic decision of the household in the presence of volume constraints of different service plans (Nevo 2015). The household consumes more at the beginning of the program, and as it approaches the end of the program, it takes its consumption management more seriously, which, of course, is a dynamic situation. It also provides evidence, with no household consumption constraints, that such benefits would be detrimental to households while costly to businesses.

2.1.4 Competition in broadband services

Both tools of modelling, the dynamics of oligopoly competition, and reduced form evidence have been used to analyze competition in broadband services. In the field of reduced form works, the research of Reed et al. 2018 shows evidence of the positive impact of competition on improving the quality of Internet services provided. The research Genakos et al. 2018 shows a correlation between consumer prices and firm investments, such that recent mergers in telecommunications in some countries, has led to an increase in the price of services and at the same time an increase in firm investments. This shows the benefits of the dynamic approach. Regarding structural works, the research Bourreau, Sun, et al. 2018 examines most aspects of demand side analysis, of course, taking into account the market structure and its changes. This work addresses less frequently dynamic issues such as sunk costs and other investment costs, and the firm's decision to enter and exit each market. In fact, Fan et al. 2015 considers their work as one of the first analyses in the context of dynamic oligopoly competition in the field of telecommunications in general, and the research Wilson 2017 may be considered the first attempt to analyze fixed broadband Internet services in the context of dynamic oligopolistic competition. The structural estimation of these two works allows alternative conditions to be considered, for example, subsidy counterfactuals, and in fact, in this way, it offers a relatively complete solution to the problem that can take into account various hypothetical changes in the market. [7]

2.1.5 Broadband industry regulation

Finally, one central and recent result on the policies of the regulatory of the industry, according to Cambini et al. 2009, is the ineffectiveness of pricing based on the rate of return on investment. This puts the firm on the path of creating additional costs so that it can demand a higher rate. On the other hand, the price ceiling approach forces the firm to avoid inappropriate costs in order to be profitable in the retail stage. Despite these cost savings, pricing based on return on investment can be better for infrastructure development. This is because the price ceiling may delay investment in infrastructure due to its propensity to save. In any case, what seems to be the case

[7] It seems that so far the only attempt to use these methods on the Internet industry is the working paper of Wilson 2017. But this is wrong in modelling and for exponential distribution it considers the property of being memoryless in both directions of the distribution. This novel work has not been published yet.

is that market pricing is similar to other public service networks, and it seems to be the price cap approach that is appropriate. But pricing for access to the incumbent's network is still a matter of debate.

3 Data

Present data is what the FCC has been collecting in recent years on the presence of broadband firms and the access they have created. This data provides basic information about each firm and each market situation. Data for fixed-line broadband firms is just a single form called the 477 form that is collected and firms are expected to fill it out each year. This data is updated several times during the year to include data that companies have not yet filled out or whose information, such as the speed of service they provide, has changed. Accordingly, basically this data is sometimes available at intervals of less than a year, but it is only reliable at annual intervals. This data is available in raw form from the FCC website.

The data is available in different US states, and in the present study I only work with Texas data. The volume of the data for each state is high (in the GB category) because of the small level of aggregation: The data is collected at the so-called block group level, which is only slightly larger than the smallest US census data classification, which would be the block. In this work, I summarize the market at the level of tract, which is larger than block group and smaller than county. The population per tract is between 1,200 and 8,000 people. Every observation in the data, in which I put together all the years that the data is available, is a firm-market-year combination. Also, each firm basically has a number of subsidiary whose data is collected at the level of subsidiary which I aggregate at the level of the owner firms. This is fairly straightforward in the FCC data, as the main owners of each subsidiary are also known. Under these conditions, the number of active markets and firms will be as follows:

Year	Markets Distinct	Firms distinct
2014	5235	80
2015	5239	81
2016	5245	76
2017	5252	77
2018	5253	81
2019	5252	79

Table 3.1: Number of markets and firms viewed each year

In the data of each company, whether it is subsidiary or the original, it is specified by name. Although the number may seem large, they are all distinct enterprises, many of which operate on a smaller scale and are generally limited to a specific area of the state.

Before I get into the other information in the FCC data, I should mention the other two US data. The first is the US census data. Basically, this data is collected extensively and comprehensively and contains a lot of micro information. But raw access to its information at micro levels such as tract and block group is not directly available. Of course, this is not the case with purely population data, and only with census data.

In FCC data, each observation has the following information: First, which firm is present in which market. Also, the company that owns each subsidiary is identified by name and number for each observation. The type of the company technology and whether it serves the household or the company or both are available. The maximum download and upload speed that it advertises to each household or company in each area is known.

From such a data, it is possible to have the service information that each firm offers in the market, in terms of type and speed (download speed). Another is that the entry and exit and the decision to upgrade for the firms can be seen in the form of increasing speed.

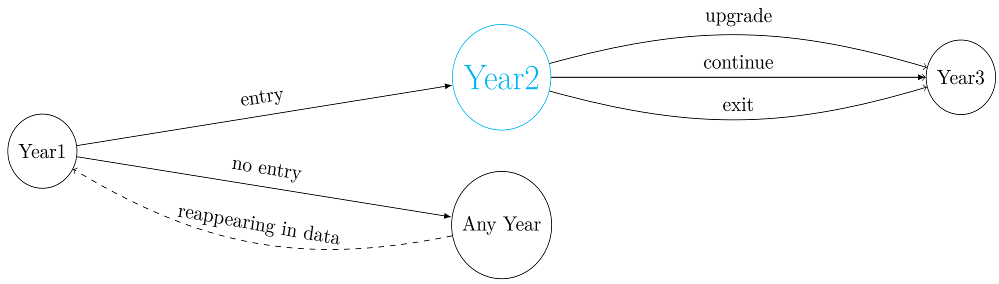

Figure 3.1:

Timing of observing firm's decision

Timing of observations: If a firm is in this time period but not in the previous time period, that firm is considered entrant. Therefore, the number of entries cannot be calculated for the start year of the data since we do not its past year. The opposite is true of exit decisions and upgrades. To do this, we need to know what the market situation will be like next year, while it will not be possible to observe these decisions again in the final year of the data. This situation is evident in the following two tables:

across year.texacross

year.tex

	Entry Counts		
Year	Mean	Median	sd
2014	NA	NA	NA
2015	0.2701	0	0.5086
2016	1.0084	1	0.7596
2017	0.2024	0	0.4568
2018	0.1470	0	0.3855
2019	0.1276	0	0.3611
All	0.3509	0	0.6123

(a) Number of entries over the years

across year.texacross

year.tex

	Exit Counts		
Year	Mean	Median	sd
2014	0.2313	0	0.4386
2015	0.8670	1	0.6786
2016	0.2568	0	0.4648
2017	0.1422	0	0.3866
2018	0.1725	0	0.4111
2019	NA	NA	NA
All	0.3338	0	0.5568

(b) Number of exits over the years

Table 3.2: Number of entries and exits over the years

The above indicators are in line with expectations and have clear and relatively constant values over the years, which shows that each market has experienced an average of about 0.2 entrant firms and similarly for exits. Median may be a better measure because we expect that in the whole process of entry and exit in a well-established market, entry and exit is not so common , and that is what the data indicates as well.

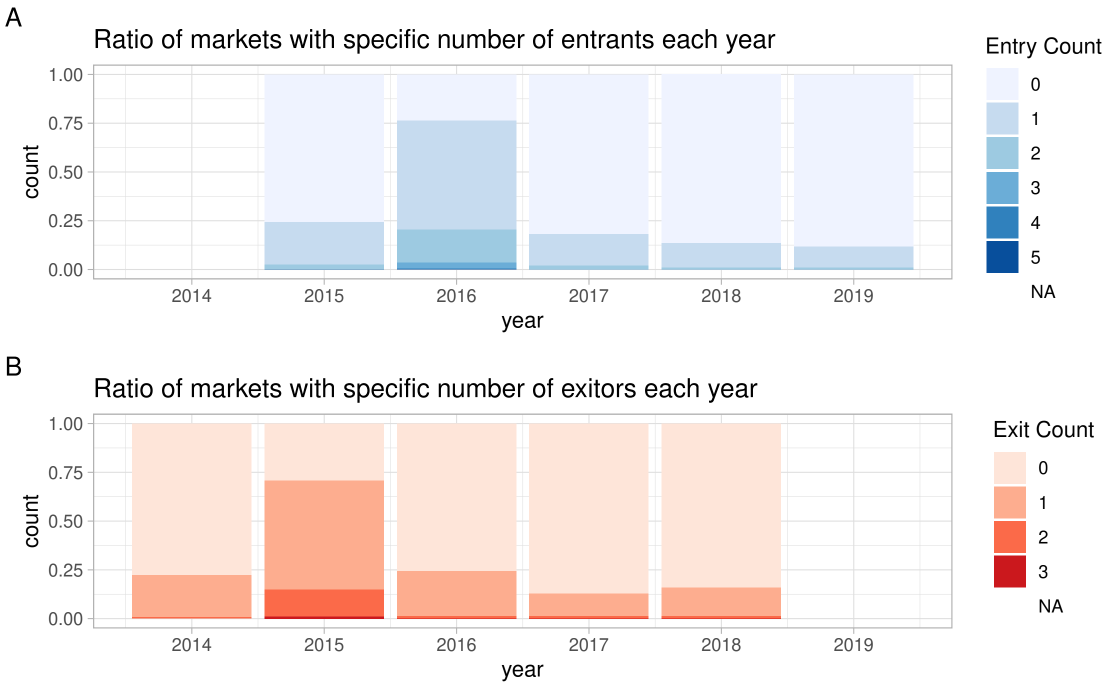

Figure 3.2: Histogram of number of entrants and exitors in the markets per year

These graphs are also in line with our expectation from the industry: we do not have many entry or exit incidents, and if the market has experienced entry or exit, there is no more than one entry or exit each year, and higher values should be much rarer, which is the case.

It is good to take a look at the composition of the market in terms of the firms present in it:

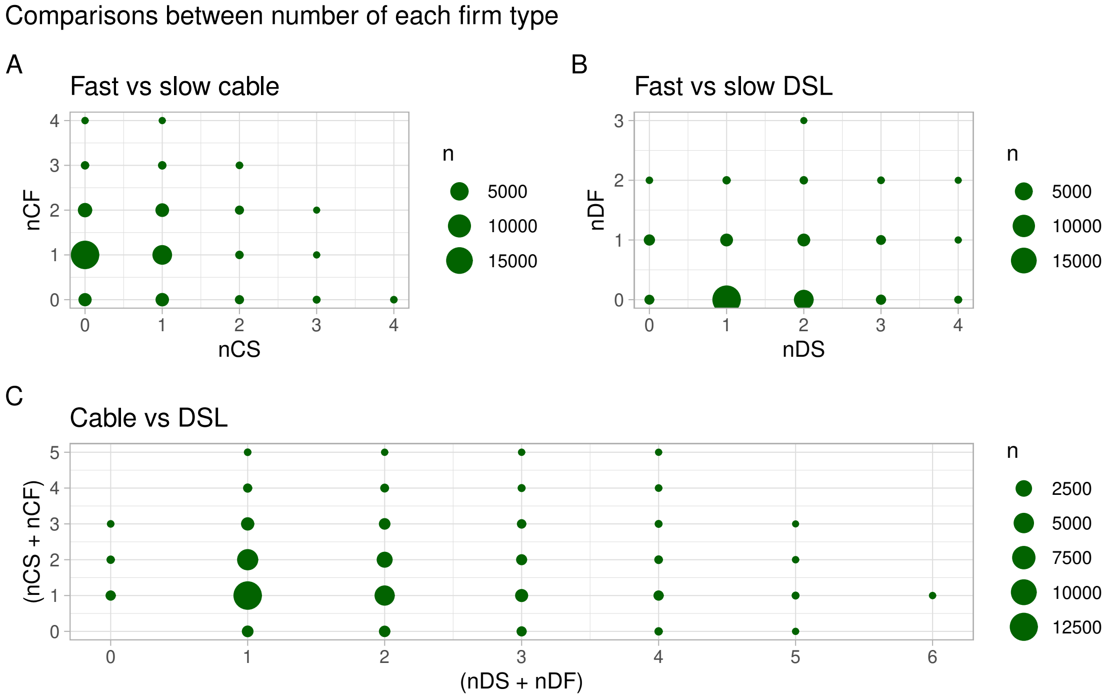

Figure 3.3: Comparison between firms of any kind in the markets. In it, n stands for number, C stands for cable instead of DSL, and F stands for fast instead of slow.

In the case of cable companies, we see that most markets have at least one fast cable company. Also, it is rare to have only one slow cable company or no cable company at all. Concerning DSL companies, we see that markets are more inclined to have slow DSL companies. Therefore, cable services are generally thought to be faster, while DSL services are provided by slower service providers, which is also expected from a technical view. But when it comes to comparing DSL versus cable, we see that most markets are such that we either have one firm from each of these two types, or one firm from one or two firms and one from the other. This indicates an oligopoly situation that is not necessarily inclined towards one type of service at all, although we still know that cable offers higher speed in general.

Regarding the decisions that each firm makes, we have the following table:

			Firm Action			
Tech. Type	Fast		c	d	u	x
DSL	0	n	23619	2046	4260	3706
		%	70	6	13	11
	1	n	2969	345	0	114
		%	87	10	0	3
Cable	0	n	4473	180	2410	1540
		%	52	2	28	18
	1	n	23065	384	0	3393
		%	86	1	0	13

Table 3.4: Decisions of any firm of any kind. Where x is for exit, u is for upgrade, d for the decision to reduce speed and c is the decision to continue the path as before.

Decision d represents the decision to reduce speed even compared to the firm's previous speed, which indicates a kind of divestment. I combine this decision in modelling with the decision to continue the path, ie c, which is explained in the model section. Therefore, we see that the decisions to upgrade for slow DSL are fewer than those of slow cables. Of course, it should be noted that this comparison is in percentage, otherwise, in number, the slow cable observation was rarer than the previous figure, and therefore the number of decisions is less in total in any case.

The table below shows that a fast DSL firm makes fewer exit decisions that the fast cable but also more divestment. In general, divestment is relatively rare, but from the data it seems to be more important for fast DSL.

Decisions over the years have are also shown for the sake of completeness of the discussion:

yearly.tex

			Firm Action																			
			2014				2015				2016				2017				2018			
Tech. Type	Fast		c	d	u	x	c	d	u	x	c	d	u	x	c	d	u	x	c	d	u	x
DSL	0	n	4186	240	1083	1127	3877	572	1171	960	4213	241	1656	1136	5575	670	88	218	5768	323	262	265
		%	63.1	3.6	16.3	17.0	58.9	8.7	17.8	14.6	58.1	3.3	22.9	15.7	85.1	10.2	1.3	3.3	87.2	4.9	4.0	4.0
	1	n	739	99	0	10	762	105	0	46	559	51	0	36	480	54	0	13	429	36	0	9
		%	87.1	11.7	0.0	1.2	83.5	11.5	0.0	5.0	86.5	7.9	0.0	5.6	87.8	9.9	0.0	2.4	90.5	7.6	0.0	1.9
Cable	0	n	630	68	782	39	594	2	152	917	728	4	646	89	1117	104	430	340	1404	2	400	155
		%	41.5	4.5	51.5	2.6	35.7	0.1	9.1	55.1	49.6	0.3	44.0	6.1	56.1	5.2	21.6	17.1	71.6	0.1	20.4	7.9
	1	n	4918	42	0	35	2400	25	0	2619	5475	29	0	86	5124	276	0	176	5148	12	0	477
		%	98.5	0.8	0.0	0.7	47.6	0.5	0.0	51.9	97.9	0.5	0.0	1.5	91.9	4.9	0.0	3.2	91.3	0.2	0.0	8.5

Table 3.5: Decisions of any firm of any kind over the years

We do not see much difference in decisions over the years.

4 Model

The purpose of this study is to estimate competition in the provision of fixed broadband services, specifically in the state of Texas, where cable and digital companies compete for the provision of fixed Internet services only to households. Texas is the second largest state in the United States after Alaska, and with good geographical diversity, there is hope for good data variations. Analysis in this state is not limited to DSL, and both cable-based and DSL-based firms are considered.

Because households usually have a combination of mobile and fixed Internet services, the substitutions that can occur in this case are not considered and only competition for fixed services is considered.

Finally, once the model parameter has been estimated, it is possible to simulate alternative conditions that could be considered by the market regulator. The focus is on subsidies to improve service.

4.1 General framework of the model

The goal of a firm in a market is to obtain the largest sum of discounted profits over time:

$$V_i(\dots) = \max \mathrm{E}\left[\sum_{t=0}^{\infty} \beta^t \pi_i(\dots)\right] \tag{4.1}$$

Along with the competition that is taking shape with other firms, this will be an infinitely repetitive game between firms.

Throughout the history of the game, h_t there are many combinations of firm decisions that can lead to equilibrium (in the context of Nash equilibrium or even a more limited framework of complete subgame). Decisions are therefore limited to strategies that depend solely on current history. In this case, because the history we are in, according to Markov's rule, influences the future of the game, we have not eliminated the issue of game dynamics, even though the strategy of each player practically puts the players in a state where the structure of each history is completely determined. The assumptions necessary for Markov equilibrium are limited. This is a significant complexity reduction because we have moved from a space of time to a space of states that involves a much smaller number of decision combinations.

In such cases, the equilibrium condition for the game, which is Markov's equilibrium condition, is expressed as follows:

$$V_i\big(s, \sigma_i(s), \sigma_{-i}(s); \theta\big) \geq V_i\big(s, \sigma_i^{'}(s), \sigma_{-i}(s); \theta\big) \tag{4.2}$$

Thus the strategy is merely a function of states (Markovian strategy), the deviation is defined on the discounted profit of all periods, and it is assumed that all actors assume such a strategy.

The first step in using such a framework for problem analysis is to specify the profit, and then to define the terms and decisions.

4.2 Specification of the firm's period profit

To achieve this clarification, there are several ways to proceed with the discussion. Here, first of all, I will discuss the demand aspect, in general, and also point out other ways to specify it.

4.2.1 Ad-hoc study of Internet demand broadband

The approach is the conventional Bresnahan-Reis method, which is a method for specifying static profits in reduced form. The situation in broadband, which is an industry with rapid technological advances and engineering complexities, is probably not a common multi-agent game. Also, the literature on broadband itself focuses more on the relationship between one firm incumbent and several firms entrant (because the industry itself is naturally monopolistic). Another is that calculating an equilibrium, even in a purely quality competition game (such as the example of the work of Bajari et al. 2007 which considers only a limited number of firms), is not an easy task, especially for firms with more than three and oligopolistic competition behavior (e.g. competition in quality is discussed in the paper Baranes et al. 2020 only for the monopolist).

Thus, in contrast to papers such as the paper Ryan 2012 where static profits are easily derived from solving a Cournot game (because it is simply a matter of competing to produce cement, which is a homogeneous commodity with a certain complexity), it is more complicated in broadband. And there is no choice but to use the Bresnahan-Reis specification. Of course, this, as has been said, is quite common in the literature, and for example, even the paper Collard-Wexler 2013, uses an explicit reduced form instead of Cournot competition.

The consumer considers three components of an Internet service: reliability, speed, and method of service.

Of these three cases, it seems difficult to measure impartiality the first case, or at least to collect data for it. The second component is something that is both measurable and the firm can express it itself. The third part is the part that can be important for some consumers: a consumer may not want to have internet with a rented modem, or may not want cable TV. In any case, the problem is that generally the composition of the service of the DSL firm is different from that of the cable firm. Of course, there is a difference in composition of the service provided among the members of each of these two categories of firms as well. It is assumed that this composition is important only to the firm itself, and for instance, in the collaborations that result with other companies such streaming services, and that it does not have a major impact on each firm's market share. Thus for the customer of the market, the broader differentiation among DSL and cable is assumed to be important.

Therefore, in modelling, only the speed and method of service delivery can be considered in the choice of a household. Thus, the individual desiring to choose j will have utility:

$$U = \xi_j + \gamma(h(z_j) - p_j) + \varepsilon_{ij}$$

Where ξ_j indicates the household preference for a particular service, while z_j is the quality of service and h is a function that maps quality to monetary value. As a result, and assuming the logit model for the possibility of choosing one service instead of another, the share of product j that will be provided as a service will be:

$$s_j = \frac{exp(\xi_j + \gamma(h(z_j) - p_j))}{\sum_k exp(\xi_k + \gamma(h(z_k) - p_k))}$$

Thus, the static profit of a firm providing a particular service j will be, in terms of its share of a particular market:

$$\tilde{\pi} = p(z_j)s_j - c(z_j) = \underbrace{p(z_j)}_{regulated,\ service-based} \cdot \underbrace{(s - \sum_{i \neq j} s_i)}_{service-based,\ facility-based} - \underbrace{c(z_j)}_{service-based}$$

What is understood from this relationship is that of all the consumers in a market, some choose certain services, and this reduces the existing consumers for a firm with other characteristics and other services:

$$\tilde{\pi} = \gamma_0 + \alpha_0\, mkt\_size + \sum \alpha_i \left[\#(is\_cable : is\_fast)\right]_i + \gamma_1\, is\_cable + \gamma_2\, is\_fast \quad (4.3)$$

Where γ_0 can be interpreted as fixed costs. The symbol : means "expansion" as a vector on possible values.

4.2.2 Investment costs

Another key part that firms are involved with, and the dynamic part of the problem, is entry and exit decisions and investing. Here, the assumption of investment costs is that they are incurred discretely and simply indicate improving the speed of the next period services, I^i_{t+1} at a speed higher than the average market speed, $\bar{I}^{mkt}_t$. The investment cost is:

$$I = \mathbf{1}(I^i_{t+1} > \bar{I}^{mkt}_t) \cdot (\bar{y} + y_{CI}\, is\_cable) \tag{4.4}$$

This means that I do not consider a random term for the investment cost. This is necessary because in the absence of such an assumption, the continuing decision of the firm can be the result of either a low value draw for the exit value or a high investment cost, which complicates the issue of identification. Although in such a case the work of Ryan 2012 provides only general estimates of firms' policy function (with a theoretical discussion of the factors influencing it) to solve this identification issue, the work of Bajari et al. 2007 argues that only one of the two shocks of exits or that of investment can be incorporated in the modelling to solve the identification problem.

4.2.3 Entry fee and exit benefit

Both the entry fee and the exit benefit include random terms. The total cost of entry κ comes from the distribution F_κ and the value of the exit ϕ from the distribution F_ϕ. The specifications are as follows and in general, the entry and exit costs, i.e. Φ are concisely presented as:

$$\Phi = \begin{cases} -\kappa_i - y_{EC}\, is\_cable & if\ entrant \\ \phi_i - y_{IC}\, is\_cable & if\ incumbent \\ 0 & otherwise \end{cases} \tag{4.5}$$

With the above specifications, the firm's profit for the period is as follows:

$$\pi(a; s) = \tilde{\pi}(s) + I(a; s) + \Phi(a; s) \tag{4.6}$$

In the next section, I will first define the states more precisely, then the firms' decisions and the consequences of these decisions, and finally how the next states are determined based on these decisions.

4.3 States, firm decisions and their values

The states are defined In terms of the distinction between entrant and incumbent and the inherent market conditions (where population is merely a measure of the market):

$$\mathbf{s} = \left[n_{c:f}, z_c, m_p\right] \tag{4.7}$$

$n_{c:f}$ is the vector of the number of incumbent firms of each type, and z_d is the vector of the number of entrant firms of each type, and m_p is the size of the market.

According to Timothy F. Bresnahan et al. 1991 and Xiao et al. 2011, the number of firms greater than three does not matter. Therefore, the discretization of the number of incumbent firms can be done based on 0, 1, 2 and > 2. As can be seen in the data section, the number is practically very small for the case > 2 and therefore only three partitions seem to be sufficient. For the size of the market, I consider only two partitions from the middle, because tract itself is defined on the basis of population, and in principle, the segments do not vary greatly in value. For the number of entrant firms, I consider only two levels for the high number and the low number of entrants.

With the previous explanations, and the number of firms considered to be just cable or DSL, and fast or slow, we will have $3^4 \times 2^2$, ie 648 states. [8]

[8] Some methods are proposed to reduce the number of states or at least bypass the effort of calculating some states. Some of these are theories that the work of Collard-Wexler 2013 makes references

Regarding decisions, two issues are raised. The first is whether the cost of the decision is incurred in the current period or the next period, and that the decision changes the conditions in the same period or the next period. These two issues are not greatly important, and for example, if the decision creates a cost in the same period, the only difference is that in this period the cost is not multiplied by the discount rate (β). I make the former assumption for simplicity in writing the terms. And about the timing of the decision's impact on the state, it is a debate that does not arise in modeling, because in any case a time is to pass between the current and future conditions.

Decisions are as follows:

$$a : \begin{cases} Incumbent \begin{cases} exit \\ continue \\ upgrade \end{cases} \\ Entrant \begin{cases} slow\ entry \\ fast\ entry \end{cases} \end{cases} \tag{4.8}$$

The decisions of the incumbent are thus exit, continuation, and upgrade, respectively. For the entrant the decision is to enter slow or fast.

Under these conditions, and using the Bellman method, the value of the incumbent becomes, conditional on state s:

to, but its basic method is related to the discussion of curse of dimensionality, which is the subject of many works, including the work of Pakes and McGuire 2001. Also, some of the methods proposed in other works fail in employing large state spaces, including the framework of Pakes, Ostrovsky, et al. 2007, because it uses frequentistic (rather than structural) approaches to estimating the choice probabilities. The Model has to estimate a greater number of state matrices, naturally with smaller subsets of the data for each, which can result in great errors.

$$
\begin{aligned}
V_i^I(s,\phi_i) =& \tilde{\pi}(s) + \max_{u,c,x}\Big\{ -(\bar{y} + y_{CI}\, is\_cable) + \\
& \int E_{\varepsilon_i'} V_i(s', \varepsilon_i') dP(s_i' * = is\_fast, s_{-i}'; s), \\
& \int E_{\varepsilon_i'} V_i(s', \varepsilon_i') dP(s'; s), \phi_i + y_{IC}\, is\_cable \Big\}
\end{aligned} \tag{4.9}
$$

According to the Markovian strategy assumption, decisions are defined conditional on state including exogenous market and firm' own shocks, and decisions of other firms do not affect the firm's strategy. I use the symbol $*=$ to express "inclusion of decision", with which I simply change the firm's state itself, and for the part that remains of the state, it is as before. There are three firm decisions x, c and u. This relationship works for both fast and slow firms because the comparison between the first and second terms for fast firms only results in the decision to "continue", because its terms do not change but it pays a cost.

For the entrant similarly, the value function is obtained as follows:

$$
\begin{aligned}
V_i^E(s,\kappa_i) =& 0 + \max_{ne,es,ef}\Big\{ 0, (-\kappa_i - y_{EC}\, is\_cable) + \\
& \int E_{\varepsilon_i'} V_i(s', \varepsilon_i') dP(s_i' * = is\_slow, s_{-i}'; s), \\
& (-\kappa_i - y_{EC}\, is\_cable) - \\
& (\bar{y} + y_{CI}\, is\_cable) + \\
& \int E_{\varepsilon_i'} V_i(s', \varepsilon_i') dP(s_i' * = is\_fast, s_{-i}'; s) \Big\}
\end{aligned} \tag{4.10}
$$

5 Estimation method

The work of Pakes and McGuire 1994 first attempted to solve dynamic structural games. The paper Pakes and McGuire 2001 tried to propose a machine-learning solution to the game for larger space states. To be able to compare alternative situations, The work of Ryan 2012 preferred to forgo the complete solution of the game and solve the game only for simpler and more limited conditions to provide the desired evidence.

Solving such games even once can take a long time to reach the solution strategy: The paper of Pakes and McGuire 2001 that significantly improves the speed of computing the solution compared to previous works still takes hours to obtain an equilibrium.

In the estimates of parameters we start with the initial guess and then solve the whole game based on it. Then calculate the moments and compare them with the data moments. Afterwards, if the moments of the model and the ones from data were different, we solve the game again with another guess for the parameters and repeat the previous process (of course, in this second part, there are smarter methods, but in any case, before that, the game must be completely solved once).

In addition to being time-consuming, the main problem is the multiplicity of different strategies that satisfy the Markov equilibrium condition, especially since this equilibrium is merely an inequality. Thus, with different starting points for the initial guess, we are likely to arrive at different estimates of parameters and even policy functions and not arrive at a definite final answer.

These two problems in estimation of the model were so prominent that they led to the introduction of alternative methods, which are two-stage estimation methods. Policy functions or probabilities of transition are generally easy to estimate from data: the data shows what decision each firm has made in each situation, or what market conditions have changed from one particular situation to another. There are clearly two ways to do this. One is a frequentist approach, in which decisions taken each time are considered, from which the possibility of making that decision or transition of the market from one situation to another is obtained. This is the approach taken by Pakes, Ostrovsky, et al. 2007. Another way is to assume a structure for policy functions, albeit limited, for example only in the context of regression, and to estimate these functions directly from the data. The two-step estimation solution proposed in the work Bajari et al. 2007 allows the adoption of both of these methods or a combination of them.

Another advantage of this method is the use of the actual equilibrium that has been in the data (proven in Pakes, Ostrovsky, et al. 2007). In any case, after the policy functions or probabilities of transition in the data are obtained, value functions, which cannot be directly extracted from the data must be calculated. To do this, one can even expect the functions to be obtained directly from the answers of a linear equation system (similar to ibid.); Collard-Wexler 2013 etc.).

Finally, by having the value functions, with the help of the Markov equilibrium condition, structural parameters of the model can be estimated in the framework of satisfying inequalities.

In the following, the value functions depending on the choice are introduced, which themselves play a role in determining the policy functions of the players. Then, from the obtained policy functions, the decision of each firm can be reached in any situation. In any case, it will be possible to simulate competition based on the policy functions and decisions that actors make based on them. What remains is how to move from one situation to another after the firms' decisions are determined, which I will explain below in terms of transition probabilities. I then explain the whole process of simulation to arrive at value functions, and finally explain how we can use the calculated value functions to arrive at an identification for structural parameters.

An intuition for the process of estimating policy functions from data is based on value functions depending on the choice. These value functions are simply the non-random value of the value function per decision, and in fact each of these values, along with their random portion, play a role in calculating the value function. In fact, the function will be the maximum value between each of them plus the random part associated with each.

In other words:

$$
\begin{aligned}
V_i^I(s) &= \bar{\pi}(s) + \max\big\{v_u(s), v_c(s), \phi_i + v_x(s)\big\} \\
V_i^E(s) &= \max\big\{0, -\kappa_i + v_{es}(s), -\kappa_i + v_{ef}(s)\big\}
\end{aligned}
$$

$\nu_\square$ are non-random portions of dynamic benefits, for example $\nu_x(s) = y_{IC} is\_cable$. These values depend on s and are specific to the decision made by the firm i.

Since only three decisions are possible for each firm, binary comparisons are made:

$$
\begin{aligned}
V_i^I(s) &= \bar{\pi}(s) + \max\Big\{\max\big\{v_u(s), v_c(s)\big\}, \phi_i + v_x(s)\Big\} \\
V_i^E(s) &= \max\Big\{0, \max\big\{-\kappa_i + v_{es}(s), -\kappa_i + v_{ef}(s)\big\}\Big\}
\end{aligned}
$$

Since the value functions V_i are optimally defined as above, and since the terms of shock are not observed, the firm's probability of choosing to exit the market i is:

$$
\Pr(exit|s) = \Pr\Big(\phi_i \ \geq \max\big\{v_u(s), v_c(s)\big\} - v_x(s)\Big)
$$

To determine the upgrade policy, it is beneficial to consider the firm's binary decision in the opposite direction until reaching the exit decision: the firm in the state s first observes the value of upgrading and also continuation in previous form, conditional on the state s. And so it presently knows which to choose between c or u. Then, after choosing which decision is more profitable, the firm compares this value with market exit. It is clear that the choice of firm between u and c in s state can only be seen depending on the specified states. Thus, only a classification of firm choice in terms of s gives us firm investment policy for the incumbent.

This makes it clear that firm exit and upgrade policy functions incumbent can be derived directly from the data, since both expressions are merely subject to states and shocks that are non-observable from an econometrician's point of view. Now, what econometric method to use to regress decisions on states is a question with several possible answers.

Given the shocks sections that appear in the exit term, and given the theories of industrial organization that shock in exit generally assumes a normal distribution (Ryan 2012), the Probit estimate is more appropriate for the exit policy. For the upgrade decision, a binomial random framework (or, in a more complex situation, multinomial, similar to the work Collard-Wexler 2013) is used, the common method being the same Binomial Logit (or Multinomial Logit). Therefore, in these frameworks, I estimate the two exit policy functions, $\mathcal{X}^I(s)$ and upgrade $\mathcal{I}^I(s)$ for the firm that is incumbent.

For the firm that is entrant the discussion is the same as before, it should be said that identification is from potential firms entrant (defined on account of proximity of to the market), since the firm that has not entered is not seen in the alternative situation:

$$\Pr(entry|s) = \Pr(0 < -\kappa_i + \max\left\{v_{es}, v_{ef}\right\})$$
$$= \Pr(\kappa_i < \max\left\{v_{es}, v_{ef}\right\})$$

Therefore, with the same logic as before, the functions $\mathcal{X}^E(s)$ and $\mathcal{I}^E(s)$ are obtained.

5.1 Transition probabilities

In the simulation section, every firm's decision is observed, and without having another random section (such as patterns that could occur in the market, such as population growth, shifting demand, etc.), it is only with these decisions that the state changes. This distinction is important: in simulation we no longer seek to find the firm's beliefs of its competitors or state because this part of the policy functions has been previously obtained.

What we are looking for in simulation is the value that comes from the evolution of states. This evolution (with the Markov assumption) shapes the beliefs of the players themselves (which is the very assumption of Markov equilibrium). Therefore, the evolution itself is determined using policy functions.

In other words, the probability of transitions, conditional on observing the decisions are:

$$\Pr\left(n'_{c:f:s}, z'_{c:d}, m'_p | \mathbf{a}_n, \mathbf{a}_z, n_{c:f:s}, z_{c:d}, m_p\right)$$

Where $\mathbf{a}_n, \mathbf{a}_z$ are the decisions of firms both incumbent and entrant. Assuming independent market evolution, we have:

$$= \Pr\left(n'_{c:f:s}, z'_{c:d} | \mathbf{a}_n, \mathbf{a}_z, n_{c:f:s}, z_{c:d}, m_p\right) \cdot \Pr(m'_p | m_p)$$

But the probability of having a certain number of firms that are incumbent, that is, the term $n'_{c:f:s}$, is zero for all values that contradict what is obtained from the state itself. Therefore, the probability of transition to all other states except the state in which this number is determined by the condition in the probability term is also zero. Regarding the evolution of the firm pool size for entrants, It is considered constant due to to its low temporal changes in the data.

5.2 Simulation

Finally, by having the functions of policy and logic of transition from one state to another, simulation can be done.

Our ultimate goal was to calculate the values of the value functions. Which is as follows:

$$V_i(s;\sigma,\theta) = \mathrm{E}\left[\sum_{t=0}^{\infty}\beta^t\pi_i(\sigma(s_t,\varepsilon_t),s_t,\varepsilon_{it};\theta)\Big|s\right]$$

In order to calculate, it is necessary to calculate the profit of the periods following $t = 0$, which is a function of the decision of the firms. Now, with the two-step estimation method, firm decisions are calculated directly from the data, so to obtain the value of value functions, instead of trying to obtain them from an equilibrium condition or maximization condition, we can directly simulate the problem forward for each state. Calculate the value of the value function directly. In fact, since it's possible to estimate the optimal decision of the firm from the data, for the value function we do not need to obtain these decisions ourselves from equilibrium or maximization conditions, which was the principle reason for the complexity of directly calculating the value function.

The research Bajari et al. 2007 suggests that profit is linear in almost all problems of empirical industrial organization in the parameters, and in any case this is a assumption that can be made. The same is true in the present work. But there is a fundamental benefit to this linearity, and that is that parameters are factored out from the sum of profits expression which is a function of the value functions and obtainable from simulation up to parameter. This means that we can calculate the resulting sum we want from the simulation without any obstacles and only with the help of the values of the independent variables. Then the inner product of the parameters of the values of the sum of the variables in the simulation gives us the values of the value functions. This "linearization" separates the simulation from the assumption on the values of the parameters and greatly reduces the number of simulations needed to estimate them.

In other words, profit can be written as follows:

$$\pi_i(\sigma(s_t,\varepsilon_t),s_t,\varepsilon_{it};\theta)=\tilde{\pi}(s;\theta_p)-I(\sigma(s,\phi_i);s,\theta_u)+\Phi(\sigma(s,\phi_i);s,\theta_x)=$$
$$\begin{pmatrix}m_p & is\_cable & is\_fast\end{pmatrix}\cdot\gamma+\left(\#(is\_cable:is\_fast)\right)\cdot\alpha-$$
$$\sigma(s,\phi_i)_{\mathcal{I}}\begin{pmatrix}1 & is\_cable\end{pmatrix}\cdot\begin{bmatrix}\bar{y} & y_{CI}\end{bmatrix}^T+$$
$$\sigma(s,\phi_i)_{\mathcal{X}}(\phi_i+is\_cable\cdot y_{IC})$$

The problem here is still the random parts of the profit, such as the exit shock. Thus, the original statement of Bajari et al. 2007 is that the linearity of profits in parameters is expected to result in value functions that are also linear. For example, the work Pakes, Ostrovsky, et al. 2007, assuming exponential distribution, was able to linearize part of model in parameter, but was forced to ignore shock for the other part in order for the relation to remain linear.

In this case, an additional assumption that is very helpful and is relatively broadly employed in Bajari et al. 2007 is that we consider distributions to be normal. This helps because each normal value can be considered as a draw of the standard normal distribution, and then a linear transformation of it. In fact, here, for ϕ_i, which is the problematic part, it suffices to assume a normal distribution. This choice also helps in drawing this value in the simulation part because the standard normal distribution parameter has no unknown parameter.

With the help of the relation $\phi_i=\mu_x+k_x\omega_i$ in which ω_i is of the standard normal distribution, I rewrite the expression:

$$\sigma(s,\phi_i)_{\mathcal{X}}\begin{pmatrix}1 & \omega_i & is\_cable\end{pmatrix}\cdot\begin{bmatrix}\mu_x\\ k_x\\ y_{IC}\end{bmatrix}$$

The part that is determined solely on the basis of variables is $W(s,\sigma,\varepsilon_{it})$, therefore:

$$
\begin{aligned}
W(s,\sigma,\varepsilon_{it})\cdot\theta = \\
&\begin{pmatrix} m_p & is\_cable & is\_fast \end{pmatrix}\cdot\gamma + \left(\#(is\_cable : is\_fast)\right)\cdot\alpha - \\
&\sigma(s,\phi_i)_{\mathcal{I}}\begin{pmatrix} 1 & is\_cable \end{pmatrix}\cdot\begin{bmatrix} \bar{y} & y_{CI} \end{bmatrix}^T + \\
&\sigma(s,\phi_i)_{\mathcal{X}}\begin{pmatrix} 1 & \omega_i & is\_cable \end{pmatrix}\cdot\begin{bmatrix} \mu_x & k_x & y_{IC} \end{bmatrix}^T
\end{aligned}
\tag{5.1}
$$

Now the expression of the value function is based on W:

$$
V_i(s;\sigma,\theta) = \theta\cdot\mathrm{E}\left[\sum_{t=0}^{\infty}\beta^t W(s,\sigma,\varepsilon_{it})\big|s\right] = W_i(s,\sigma)\cdot\theta
$$

And the task is simplified to the calculation of the mathematical expectation term.

For the firm that is entrant, there are also structural parameters. Essentially, these two categories of the structural parameters of the firms are estimated separately, because in the condition of Markov equilibrium as well as the simulation of the value function, the firm that has been operating since $t = 0$ is considered. If we estimate the entry decision from the data, we do not need any other information about the firm that is entrant to perform the simulation. But after this estimate is made, the values of the value functions are obtained numerically (because θ is calculated), the entrant also considers only its entry cost, and the value of the incumbent in the next period, which are now available to us. Thus the structural parameters for the entrant can also be estimated:

$$
\begin{aligned}
V_i^E(s) = & 0 + \max_{ne,es,ef}\Big\{0, (-\kappa_i - y_{EC}\, is\_cable) + EV^{slow}(s), \\
& (-\kappa_i - y_{EC}\, is\_cable) + \\
& -(\bar{y} + y_{CI}\, is\_cable) + EV^{fast}(s)\Big\}
\end{aligned}
$$

Therefore:

$$\Pr(entry|s) = \Pr(\kappa_i + y_{EC}\, is\_cable < \max\left\{EV^{slow}, -(\bar{y} + y_{CI}\, is\_cable) + EV^{fast}(s)\right\})$$

The expectation is now known or obtainable from estimates of parameters of incumbent firms. Therefore, in any given framework, by matching the probabilities obtained from the above expression for different values of the parameters with the probabilities observed in the data, the correct value for the parameter can be obtained.

By knowing the policy functions of the data, and by considering the discourse above, we can now proceed to simulation to find the values of the value function depending on parameters. Finding these values is needed so as to then obtain the values of the structural parameters by placing them in the Markov equilibrium condition, in which case the work of estimation would be done.

The simulation approach is forward simulation and according to what is stated in Bajari et al. 2007:

1. Starting with each state $s_0 = s$, we will draw private shock for each firm
2. We find the decisions of each firm according to the policy we have estimated from the data and calculate the profit
3. We advance the state with the help of transition probabilities to the next state
4. Repeat the first to third steps for T for a specified period or when all firms reach their final conditions (exit all) and compute the profits.

5.3 Equilibrium condition and estimates of the dynamic parameters

Markov equilibrium condition:

$$V_i\big(s, \sigma_i(s), \sigma_{-i}(s); \theta\big) \geq V_i\big(s, \tilde{\sigma}_i(s), \sigma_{-i}(s); \theta\big)$$

Also according to what was said in the simulation section:

$$V_i(s; \sigma, \theta) = W_i(s, \sigma) \cdot \theta$$

So the Markov equilibrium condition is:

$$\begin{aligned} g(\tilde{\sigma}_i; \theta) &= \big[W(s; \sigma_i, \sigma_{-i}) - W(s; \tilde{\sigma}_i, \sigma_{-i})\big] \cdot \theta \\ &\geq 0 \end{aligned} \tag{5.2}$$

To test this condition, one can basically use different alternative policy functions ($\tilde{\sigma}$). According to Bajari et al. 2007, this choice can affect the performance of the estimation. In either case, the work merely suggests perturbing the estimated policy functions of the data as one way. In the present work, the exit policy is perturbed by adding a value equal to two standard errors from the policy's estimated intercept.

And once again for this policy function the values of the value functions dependant on the parameters are computed.

One problem is that the above expression is an inequality and may point identification may not be possible, in which case we can only estimate the set of answers. In this situation only intervals for each of the parameters are obtained. Proving that point identification is possible is a difficult task itself. In any case the work of ibid. proves, that if point estimation is possible, the following estimator is a consistent one:

$$\min \frac{1}{n_l} \sum_{k=1}^{n_l} \Big(\min \big\{ g(\tilde{\sigma}_i; \theta), 0 \big\} \Big)^2 \tag{5.3}$$

The values of the parameters are obtained by calculating $g(...)$ and using the above estimator. In above, n_l are the number of moments we consider: it is not necessary to calculate for all possible states s, the term g, but a suitable subset is also sufficient.

The work of Bajari et al. 2007 suggests random selection of this subset but states that by knowing the moments (which are the same as states) and their possible influence on the estimation, as well as their influence on each other, this set can be chosen more intelligently. Of course, this also suggests that the choice of moments affects the performance of the estimator. In the present paper as well, moments are simply chosen at random.

5.4 Counter-factuals

For the generation of counter-factuals I adopt a simpler method than simulating the whole state and solving the Markov equilibrium based on the estimated parameter. In this method, only in the first round for each firm, any decision that could have been considered in the framework of a counter-factual is considered and then based on alternative parameters the amount of profit from that decision in this period is calculated. And for the remaining periods I follow the same simulation process as before with the same parameters as before. Then, at the end, when the value of each of these situations is calculated, I examine what the optimal decision for the firm would have been. After that, I do the simulation again, with the difference that in the first stage, I consider this optimal decision for the firm, and this is how I generate that counter-factual. This is similar to examining the deviation motivation in a subgame perfect equilibrium. This allows the analysis of the counter-factual without having to fully calculate the new equilibrium.

6 Results

6.1 Results of the first stage

In the first stage, we had to estimate the decision-making policies of the firms, which were derived directly from the data. The results are as follows:

policies.texpolicies.tex

	Dependent variable:			
	exited	upgrade	cbind(entry, nentry)	fastEntry
	probit	*logistic*	*probit*	*logistic*
	(1)	(2)	(3)	(4)
nCS1	0.179***	−0.535***	−0.044*	−0.086
	(0.053)	(0.051)	(0.025)	(0.215)
nCS>=2	0.279**	−1.437***	−0.177**	−3.034***
	(0.123)	(0.107)	(0.085)	(0.702)
nCF1	−0.136*	−1.014***	−0.205***	−0.436
	(0.070)	(0.057)	(0.043)	(0.342)
nCF>=2	−0.096	−1.648***	−0.248***	−1.047**
	(0.086)	(0.071)	(0.053)	(0.459)
nDS1	0.467**	−0.397***	−0.088	0.715
	(0.203)	(0.091)	(0.063)	(0.501)
nDS>=2	0.947***	0.546***	−0.069	1.420**
	(0.207)	(0.097)	(0.068)	(0.557)
nDF1	0.411***	−0.270***	−0.026	1.343***
	(0.052)	(0.046)	(0.035)	(0.298)
nDF>=2	0.613***	−0.908***	0.011	2.032**
	(0.120)	(0.172)	(0.121)	(0.803)
MktSize2	−0.039	0.122***	0.130***	0.030
	(0.043)	(0.029)	(0.020)	(0.184)
IsFast1	−0.362***			
	(0.055)			
IsCable1	0.115**	1.871***		4.886***
	(0.058)	(0.053)		(0.234)
initTypeD			−0.462***	
			(0.022)	
zC2	−0.177***	0.209***	−0.482***	0.209
	(0.053)	(0.036)	(0.025)	(0.244)
zD2	−0.105**	0.230***	−0.187***	−0.937***
	(0.052)	(0.036)	(0.024)	(0.240)
Constant	−2.948***	−0.975***	−1.483***	−2.799***
	(0.206)	(0.092)	(0.063)	(0.508)
Observations	43,960	36,988	45,684	1,543
Log Likelihood	−2,013.100	−15,978.640	−6,712.525	−471.908
Akaike Inf. Crit.	4,054.200	31,983.280	13,451.050	969.816
Note:			*p<0.1; **p<0.05; ***p<0.01	

Table 6.1: First-stage estimates for firm policy functions

First, an overview of the coefficients. Most coefficients of different policies are significant. In fact, we do not have an explanatory variable that has been reported insignificant in all three decisions, which indicates that it was necessary to consider these variables as part of the state. Of course, the comparison of the fits, because unlike linear regression, is done only relative to a model that has no variables, does not necessarily indicate that we have obtained fair results. But in any case, it shows that the differences among markets and firms (that is, the state) have been quite influential on various decisions, or to be more precise, at least have been related to these decisions. The individual interpretation of the estimated policies is as follows:

For exit policy, we see that the number of slow cable firms at level one increases the probability of exit relative to level zero. This probability varies even more for levels two or more (all of these interpretations, of course, can be accurately expressed only in the mean of the variables). This reflects what we also saw in the data: slow cable firms are few, so it was expected that a market with a large number of slow cable firms would move toward a market with fast cable firms, one mechanism of which is the exit of slow firms. But in the case of fast cable, the exact opposite is true still based on previous intuition. Regarding the levels of the number of DSL firms, for both types, positive and significant effects on the exit are observed, that can only be interpreted due to the more intense competition in terms of the greater number of active firms. For the number of fast cables, of course, the opposite was true, which probably indicates the greater value of being a fast cable than any type of dsl or cable. The size of the market at the significance level of 0.1 does not have a significant effect on the exit decision, and it seems that mostly the conditions of the competition with other firms are involved in this decision. But in general, this decision is less likely to be made for a firm that is fast, which is logical because it will have more to lose if it leaves, and for a slow cable firm, the opposite is true with similar intuition. Concerning the size of the pool of the entrants for both cable and DSL, the greater the value, the less likely that exit will be. One intuition is that such a market also has higher value, so exiting it also means losing a bigger opportunity and thus is less likely to happen.

For upgrade policy, we see that where slow cable companies are fewer, this is less likely because there is probably no reason or incentive to upgrade, and the market remains competitive as it is now, indicating a kind of inertia in market evolution. That is, firms do not feel the need to upgrade and are content with just their market share. Higher levels reduce the likelihood of upgrades for fast cable companies in the market. This may be due to the fact that the slow firm that decides to upgrade finds it more difficult to compete directly with faster firms and decides to simply offer inferior service, which is likely to have fewer providers. For the DSL firm, the results follow similar logic, except for the two and more levels for the DSL, which has a positive effect, which is probably because the firm in this case tends to differentiate itself from the large number of other DSL firms that exist, and offer different services. For market size in upgrade decisions, the fact that the firm is fast is directly related to the consumers of the market, and therefore the positive impact of a larger market size on this decision seems logical. For two levels of entrant firms, similar to the exit decision, it can indicate more developed market conditions and therefore the need for higher speeds and therefore a positive impact on the upgrade decision.

In terms of entrant firm, first there is the decision to enter: for each increase in the number of firms, we see a negative impact on this decision, which is logical: the market has no room for another firm, so entry is low. Of course, for the number of DSL firms, the effect is generally insignificant, which in a way indicates the greater importance of the cable relative to DSL. As for the market size, larger values make it more attractive thus making entry more likely. There are fewer entries for the DSL firm (i.e. type D), which in a way indicates the greater capabilities of the cable firm that we expected. As for the higher levels of entry-level pools, obviously when these levels are larger (i.e., we have more potential entrant firms), while the entry rates are generally lower as seen in the data, fewer firms will be able to enter than the total number of this larger level. And therefore the effect of the larger size of these levels on the entry decision is negative. The reason why the entry is low is also due to the difficult competition conditions after entering the market, which in itself has a good number of active firms.

The decision to enter as fast firm for firms that are entrant is interpreted in this way: We do not have a significant effect for level one of the slow cable firm, but for level two and above, it seems that the firm also prefers to operate in the same slow mode, which is similar to the inertia explanation mentioned above. Level one is still insignificant for the number of fast cable companies, but level two shows that the firm faces difficult conditions to compete with fast cable companies that are already incumbent and prefers to differentiate itself. For level one, slow DSL is still insignificant, but for level two, it shows that the firm has entered the market essentially to provide fast service along a number of slow DSL firms, from which it has distinguished itself. For fast levels, too, the overall effect is positive, one of the intuitions of which may be that competing with a fast firm is considered easy, and therefore takes direct competition instead of differentiating the firm. It seems that the decision to enter as a firm fast or slow does not depend on the size of the market and contrary to the situation between firms that are incumbent, this decision is made at the same stage of deciding to enter the market. Cable companies are generally appearing as fast providers, which shows their capabilities. The larger pool size of cable firms that are entrant has no effect, but the larger pool size of DSL firms has a negative effect, which probably suggests that other DSL firms that are entrant are generally expected to appear as slow providers and therefore inclination to enter as fast is reduced.

An examination of other aspects of these estimates is provided in Appendix B.1.

6.2 Results of the second stage

The result of estimating structural coefficients is according to the below table:

	MktSize	IsCable	IsFast	nCF	nCS	nDF	nDS	ymean	yIsCable	xmean	xdeviance	xIsCable
Coefficient	0.38	0.76	0.36	-0.01	0.01	-0.03	-0.06	-3.67	1.42	2.74	2.32	6.51
se	0.52	0.72	0.43	0.13	0.12	0.08	0.06	3.64	3.46	3.24	2.46	3.74

Table 6.2: The results of the second stage estimates. For standard errors computation, nboost = 1000.

Coefficients are as expected. Firstly, the larger the market, the higher the profit margin. Cable business is more profitable. A fast firm can expect more periodic profits. Increasing the number of fast cable companies and any type of DSL company reduces the profit of the period. Slow cable conditions seem to improve competition for the firm in general, and thus has a positive factor. The average upgrade cost is negative as expected. According to the fixed coefficient for cable, this cost is less than the DSL cost for the cable company. The benefit of exit is positive and in the magnitudes of the upgrade cost. Still, it is associated with a relatively large standard deviation. And finally, the exit benefit for the cable company, and in fact its value in the market, is more than that of the DSL firm.

6.3 Results of counter-factuals

The results of counter-factual can now also be obtained. The term fsfit is for predictions that was made only with first-stage estimates of the data. The terms cfact with the number in front of them indicate the situation with that percentage of subsidy on the upgrade cost.

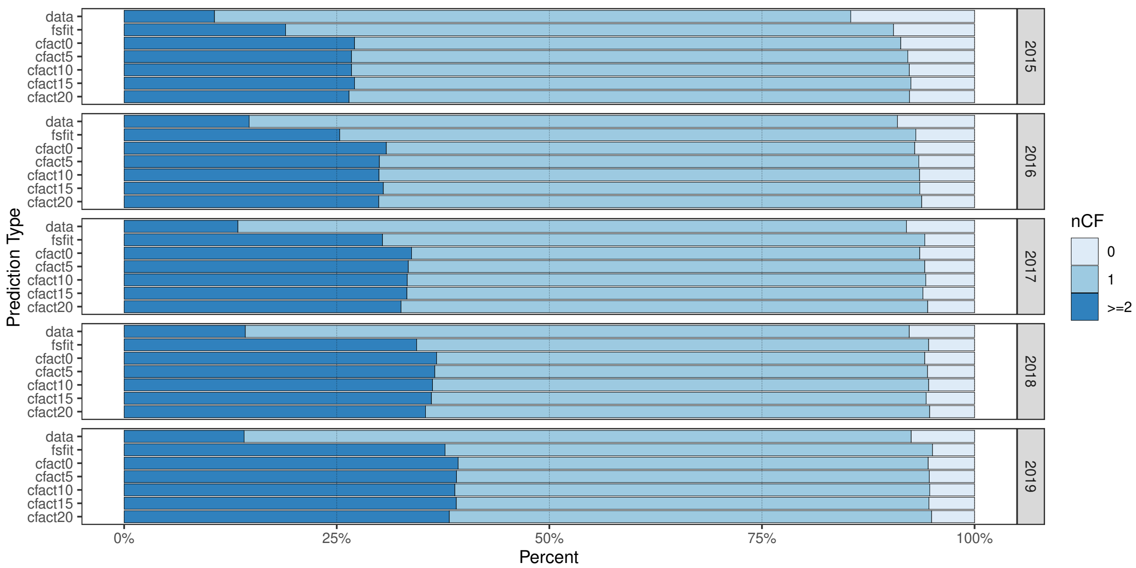

Figure 6.1: Prediction results for the number of fast cable companies

With subsidizing the upgrade cost, the status of fast cable companies does not change much, because in general we saw that cable companies are already mostly fast firms and that the cost of upgrading for cable is lower. The situations are quite the same except for the data. In the case of data, the monopoly prediction is again the same, only that the model predicts the presence of two or more firms more frequently.

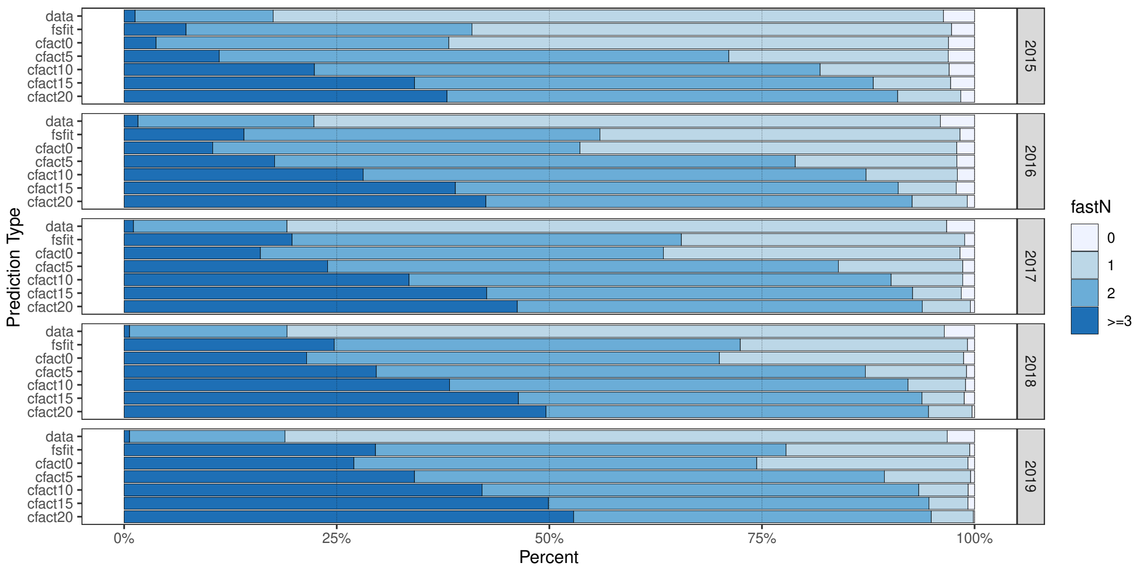

Figure 6.2: Prediction results for the number of fast firms of any type

Subsidizing is more specific in changing the general situation of the number of fast firms. We see that as the percentage of subsidies increases, the number of firms increases rapidly and monopolies decrease. Another point about the proximity of cfact0 and fsfit shows that the generation approach for counter-factuals has been correct. But still the modelling expects more optimistic outcomes, while in general we have an inertia for the presence of two or more firms in the data, In the modelling this is not the case and it is more closely related to the data only in the number of monopolies.

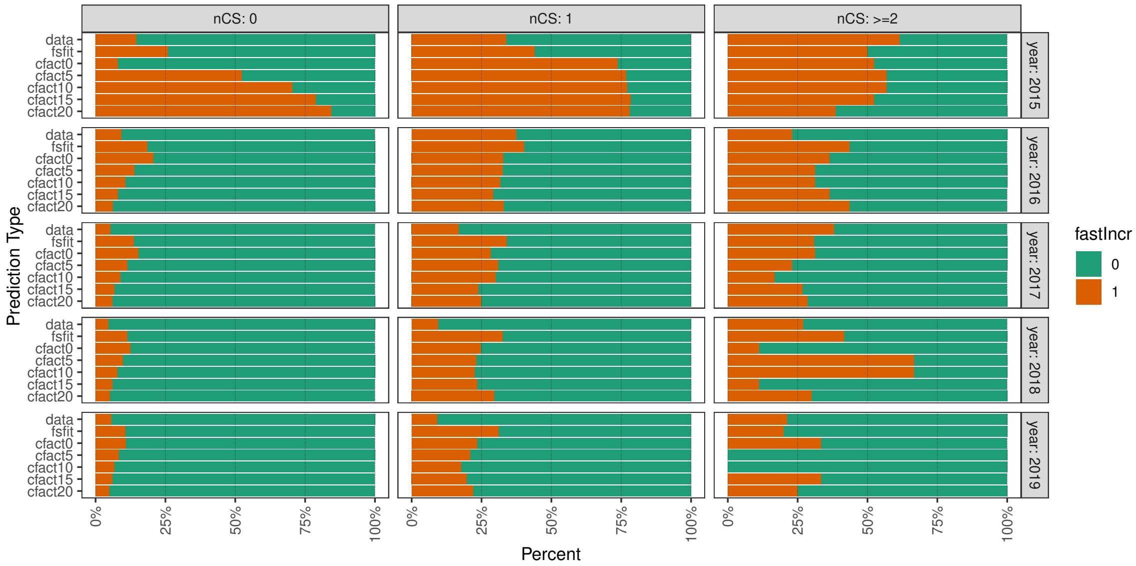

Figure 6.3: Increase in the number of fast firms per year at different levels of the market in terms of the number of slow cable firms

This figure shows the percentage of markets in which the number of fast firms has increased each year, compared to the previous year, which could be both due to the entry and upgrade of the firm. I have represented this figure separately for slow cable levels. In later years, the figures are almost the same, especially at levels 0 and 1. Only in the first year we have a significant difference. For markets with level 1 of the number of slow cable firms, subsidizing had no effect at all, but for level 0, where we did not have a slow cable firm, it seems that either the slow DSL firm could upgrade or entry of fast firm of any kind was made possible. The results are a bit odd for Level 2, but this is because the number of markets with level 2 number of slow cables was small in the first place, and the generation process for counter-factuals is a random process, so it does not reach the logical average in this small sample. Yet for the sake of completeness. this case is shown as well.

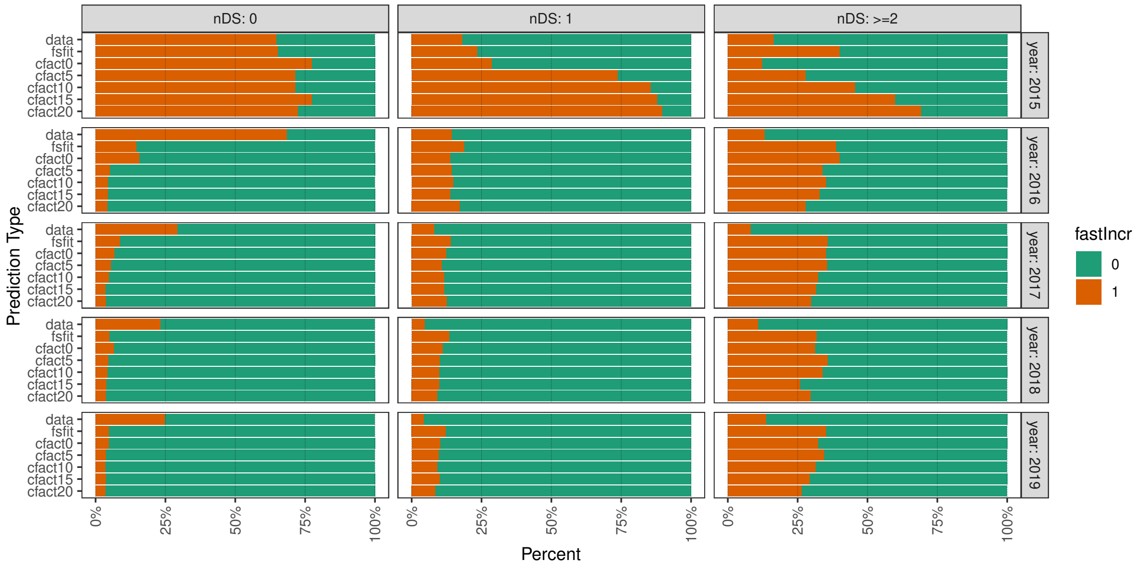

Figure 6.4: Increase in the number of fast firms per year at different levels of the market by slow DSL firm

We have the following interpretations for the differences between the levels of DSL firms present. First, subsidies at level 0 did not work at all, because we generally expected subsidies to be useful for slow firms. Again, for the following years, the results of increasing the number of fast firms have been almost the same, which means that subsidies have been effective only in the first year. But in the case of levels 1 and 2, subsidies acted as expected, and with larger amounts of subsidies, we see more markets to which a fast firm has been added.

Figure 6.5: Increase in the number of fast firms per year at different levels of the market based on a combination of the number of cable and DSL firms

We can also see the addition of a fast firm according to this composition in a comparison between the levels of the number of slow cable and DSL firms. For data, fsfit, and cfact0 the results are very similar. The results are almost the same for other years as well. But in the year of subsidies, we see that for all percentages of subsidies, most of the increase in the number of fast firms is in markets with one slow DSL firm and no slow cable firm. After that, it has been in the case of 1 slow dsl and 1 slow cable and also 2 or more DSL and no cable company.

monopoly predictions.texmonopoly predictions.tex

	year														
	2015			2016			2017			2018			2019		
	incN			incN			incN			incN			incN		
prediction type	1	2	>=3	1	2	>=3	1	2	>=3	1	2	>=3	1	2	>=3
cfact20	3.6	43.0	53.4	3.5	40.6	55.8	3.2	39.1	57.7	3.1	37.1	59.8	3.0	35.0	62.0
cfact15	3.7	42.5	53.8	3.4	40.3	56.2	3.3	38.5	58.3	3.1	36.4	60.5	2.9	34.3	62.7
cfact10	3.7	42.4	53.9	3.6	40.7	55.7	3.3	38.4	58.3	3.1	36.4	60.5	2.9	34.8	62.3
cfact5	3.8	42.3	53.8	3.7	40.6	55.6	3.5	38.5	58.0	3.1	37.0	59.9	3.0	35.3	61.7
cfact0	3.9	42.3	53.8	3.6	40.2	56.2	3.4	38.0	58.6	3.3	36.3	60.5	3.0	34.8	62.3
fsfit	3.6	42.3	54.1	3.4	40.5	56.1	3.3	38.4	58.4	3.1	36.5	60.5	2.9	35.1	62.0
data	3.3	44.6	52.1	2.9	39.2	57.9	2.2	43.7	54.0	2.4	42.0	55.6	2.4	44.5	53.1

Table 6.3: Prediction of the existence of monopolies in different conditions over the years as a percentage of markets with the specific number of incumbent (incN) firms

Numerically, we can see the change in the conditions of monopoly and duopoly and other competition paradigms in the table above. Perfect monopoly is already low in data such that we would have only one active firm. But in any case, this subsidy does not seem to have changed much in terms of monopoly, duopoly or oligopoly, and its composition for different percentages of subsidy is almost the same as the data, and in particular very similar to the predictions of the first stage.

fast firm predictions.texfast firm predictions.tex

	year																			
	2015				2016				2017				2018				2019			
	fastN				fastN				fastN				fastN				fastN			
prediction type	0	1	2	>=3	0	1	2	>=3	0	1	2	>=3	0	1	2	>=3	0	1	2	>=3
cfact20	1.62	7.43	52.99	37.96	0.86	6.49	50.12	42.52	0.50	5.66	47.63	46.22	0.31	5.12	44.98	49.60	0.15	4.95	42.05	52.85
cfact15	2.83	9.09	53.94	34.14	2.16	6.82	52.08	38.93	1.57	5.73	50.08	42.62	1.22	4.97	47.46	46.35	0.78	4.59	44.74	49.89
cfact10	3.00	15.17	59.47	22.36	2.03	10.74	59.13	28.10	1.40	8.43	56.68	33.49	1.07	6.77	53.90	38.26	0.76	5.81	51.34	42.09
cfact5	3.10	25.81	59.92	11.18	2.08	19.01	61.21	17.70	1.39	14.62	60.06	23.93	0.96	11.89	57.52	29.64	0.48	10.13	55.26	34.13
cfact0	3.08	58.76	34.42	3.74	2.10	44.31	43.18	10.41	1.72	34.87	47.40	16.01	1.30	28.72	48.53	21.46	0.78	24.84	47.37	27.00
fsfit	2.72	56.39	33.63	7.27	1.72	42.33	41.87	14.08	1.17	33.32	45.77	19.74	0.84	26.72	47.74	24.69	0.57	21.60	48.28	29.54
data	3.66	78.81	16.24	1.28	4.02	73.67	20.69	1.62	3.29	77.57	18.05	1.09	3.56	77.29	18.52	0.63	3.22	77.88	18.28	0.63

Table 6.4: Prediction for the number of firms with fast services in different conditions over the years as percentage of markets with the specific number of fast firms (fastN)

But we certainly expect from this subsidy that, although it does not disrupt the composition of the number of firms, it will certainly bring about fundamental changes in the number of fast firms present. Again, the results of our first stage are optimistic, but in any case, more subsidies have changed the composition to more fast firms in each market, and the cfact0 and fsfit results are similar. Subsidizing has been particularly effective at levels 2 and 3 and above, while markets as a whole have already had one fast service provider, according to the data.

7 Conclusion

The present work's model has demonstrated competition between Internet service providers in the United States, in which cable and DSL companies compete for markets defined by the census tracts in Texas. The state of competition in this situation, unlike most of the literature around it, is at least duopolistic and essentially oligopolistic. Also, contrary to the problems where we could consider the situation as full competition with free entry, here, due to this oligopolistic nature, it is no longer possible to consider the firm separately, only maximizes its profit in each situation. In such a case, we have to deal with the game between firms and the competition that prevails in each market, which, given the complexity of the behaviors that players can exhibit in each dynamic game, and the many strategic behaviors that can lead to simply a Nash equilibrium, we had to limit the analysis to Markov equilibrium and therefore the strategies to Markovian strategies whose behavior is determined solely by the state.

The present data indicates distinctive features for cable and DSL that our estimates were consistent with for most of these observations. In the next step, I generated the situation of counter-factuals in which the counter-factual of interest was to provide general subsidies for upgrading to all firms and markets, so that the cost of upgrading services would be reduced by a percentage. The results of this practice were as expected: Based on the distinctions observable in the data, the cable company is generally a fast provider, and it is estimated that the cost of upgrading for it is lower. Therefore, subsidies really help the DSL company in upgrade its services. Another observation is that higher amounts of subsidies, as expected, increase the number of fast firms in all circumstances. Nevertheless, the observation on the competitive paradigm is that this subsidy does not change the composition of the market in terms of monopolies and duopolies and the like, but instead it does so in terms of the number of firms with fast services, moving the state to markets with more firms of this type, which is again, the expected result.

Policies that can be suggested to the market regulator in this case, first of all is the general importance of subsidies in upgrading quality of services, even if paid in a one-time period as we have adopted here. Even small subsidies such as 5% according to its respective counter-factual made a significant difference. Because a regulator such as the FCC basically defines access on the basis of speed rather than just firm presence, this means that the FCC can provide wider access to consumers simply by subsidizing firms and without pursuing a complex policy favoring specific situations. Another is that this payment, according to our simulation, does not seem to have any other harmful aspect, except that the main beneficiary is the firm with DSL technology, which can be considered as an inferior technology. But in any case, the issue of facilities-based competition between cable and DSL is a prominent issue in the literature that shows the need for the presence of DSL. Of course, this analysis is limited in that it is done in partial equilibrium and that the generation of the counter-factuals is more restricted. More complex situations may include other aspects of such a decision in general.

Here only the counter-factual of subsidies for upgrades were considered, which was more important. Yet, basically, based on the modelling presented in this work, other situations such as subsidies for entry and subsidies for different market characteristics can be analyzed with a few extra steps.

This will determine to what extent and to which markets the network of better firm services will expand. But what is not conclusively estimated is general and definite welfare changes. Because the demand side is not estimated, the amount of welfare created for subscribers can not be definitively calculated. Of course, higher quality services are desirable for the subscriber. But how the social benefit will change in the face of the firm's own costs and the cost of subsidizing the firm is not something that the current framework can address, and it requires adding the demand side to the modeling of the problem, and using more sophisticated estimation methods.

Other aspects that can be added to the present work and seem important are the addition of the above demand side, and a more generall modelling of the static part of the competition. Also, the firm's decision to choose the speed can be considered in the general context of quality level selection, which has been done in a lot of previous works though mostly only in theoretical modelling. Adapting them for this purpose should not be too difficult. Another is that the first-stage estimates seemed to differ significantly from the data, thus the use of other statistical methods or the addition of other aspects of the data, such as other features that can be considered for each firm and market, may improve these estimates, although the size of the state In such cases would increase significantly due to the curse of dimensionality.

Finally, the issue of improving Internet services is an issue that seems to be of increasing importance. In such circumstances, the question of how subsidizing different firms and markets would change the situation, given the current market conditions and structure, required a serious answer that was found to be of contradictory results in the literature. The reason for this is that the answer to such a question is better not understood from contradictory theoretical methods as in the present literature, but from estimating the structure and conditions of the market with specific data. Estimates of the present work, using the available data in a structural framework, are able to provide insights into the changes that would result from subsidies, and thus provide evidence for the improvement of fixed broadband Internet services, empirically. The simplifications of modeling the problem in this situation were such that it could include the status and decision of firms to upgrade in order to answer the question posed at the beginning of this writing.

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Appendices

A Data Appendix

A.1 Types of Internet services in data

year	IsDsl	IsCable	IsCoppOther	IsFTH	IsSatellite	IsTerr	IsPLine	IsOther
2014	7555	6514	186	2168	10596	8034	0	1
2015	7618	6709	403	2985	10519	7727	0	0
2016	8107	7057	295	4411	15784	10051	0	1
2017	7289	7567	215	5105	15784	9493	0	45
2018	7186	7598	178	5960	15785	8003	0	13
2019	7018	7527	220	6466	15782	9599	0	2

Table A.1: Data count based on technology number in FCC main data

year	IsDsl	IsCable	IsFTH	DslCable	DslCableFTH	FTHDsl	FTHCable	JustFTH
2014	7555	6514	2168	71	32	1368	615	217
2015	7618	6709	2985	125	78	1827	833	403
2016	8107	7057	4411	215	173	3006	976	602
2017	7289	7567	5105	191	163	3593	1062	613
2018	7186	7598	5960	94	79	4028	1265	746
2019	7018	7527	6466	91	82	4390	1348	810

Table A.2: Number of FTH servers compared to other types

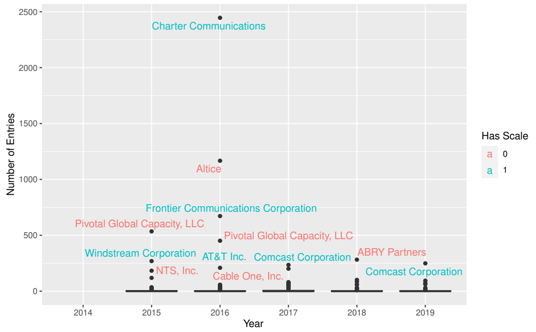
A.2 Checking entries exits out of the market definition

year	HocoFinal	entrant	IsDsl	IsCable	scaleUS	Yentries	YentryMean	YentryMedian	YentriesShare
2019	Comcast Corporation	249	0	1	TRUE	670	8.481013	0	0.3716418
	GCTR	94	0	1	FALSE	670	8.481013	0	0.1402985
	Cable One, Inc.	74	0	1	FALSE	670	8.481013	0	0.1104478
2018	ABRY Partners	282	1	1	FALSE	772	9.530864	0	0.3652850
	Comcast Corporation	101	0	1	TRUE	772	9.530864	0	0.1308290
	Windstream Corporation	84	1	1	TRUE	772	9.530864	0	0.1088083
2017	Comcast Corporation	235	0	1	TRUE	1063	13.805195	0	0.2210724
	Cable One, Inc.	201	0	1	FALSE	1063	13.805195	0	0.1890875
	Dell Telephone Cooperative, Inc.	81	1	0	FALSE	1063	13.805195	0	0.0761994
2016	Charter Communications	2446	0	1	TRUE	5289	69.592105	0	0.4624693
	Altice	1167	0	1	FALSE	5289	69.592105	0	0.2206466
	Frontier Communications Corporation	672	1	0	TRUE	5289	69.592105	0	0.1270562
2015	Pivotal Global Capacity, LLC	535	1	0	FALSE	1415	17.469136	0	0.3780919
	Windstream Corporation	269	1	1	TRUE	1415	17.469136	0	0.1901060
	NTS, Inc.	183	1	1	FALSE	1415	17.469136	0	0.1293286

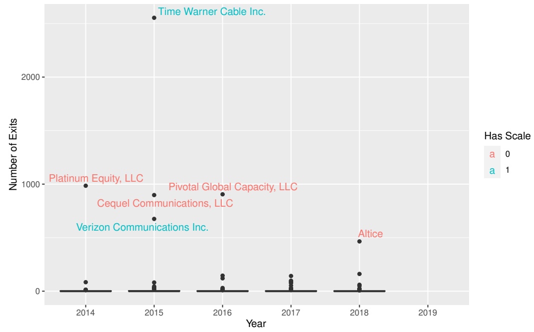
Table A.3: High entries per year

year	HocoFinal	exit	IsDsl	IsCable	scaleUS	Yexits	YexitMean	YexitMedian	YexitsShare
2018	Altice	465	0	1	FALSE	906	11.185185	0	0.5132450
	Huntleigh Telecommunications Group, Inc.	161	1	0	FALSE	906	11.185185	0	0.1777042
	GTCR	60	0	1	FALSE	906	11.185185	0	0.0662252
2017	Reach Broadband	142	0	1	FALSE	747	9.701299	0	0.1900937
	USConnect Holdings, Inc.	98	1	1	FALSE	747	9.701299	0	0.1311914
	Comcast Corporation	92	0	1	TRUE	747	9.701299	0	0.1231593
2016	Pivotal Global Capacity, LLC	905	1	0	FALSE	1347	17.723684	0	0.6718634
	Windstream Corporation	145	1	1	TRUE	1347	17.723684	0	0.1076466
	Telecommunications Management LLC	120	0	1	FALSE	1347	17.723684	0	0.0890869
2015	Time Warner Cable Inc.	2554	0	1	TRUE	4542	56.074074	0	0.5623074
	Cequel Communications, LLC	898	0	1	FALSE	4542	56.074074	0	0.1977103
	Verizon Communications Inc.	675	1	0	TRUE	4542	56.074074	0	0.1486129
2014	Platinum Equity, LLC	985	1	0	FALSE	1211	15.137500	0	0.8133774
	CenturyLink, Inc.	84	1	0	TRUE	1211	15.137500	0	0.0693642
	Cequel Communications, LLC	14	0	1	FALSE	1211	15.137500	0	0.0115607

Table A.4: High exits per year

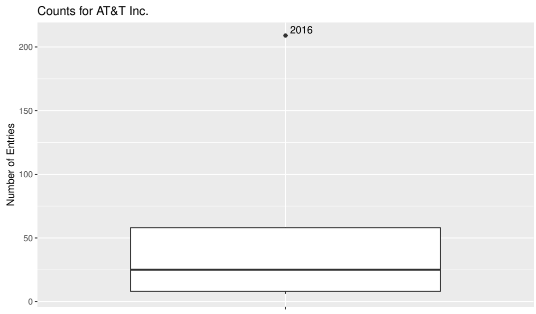


(a) Boxplot of outlier entries each year

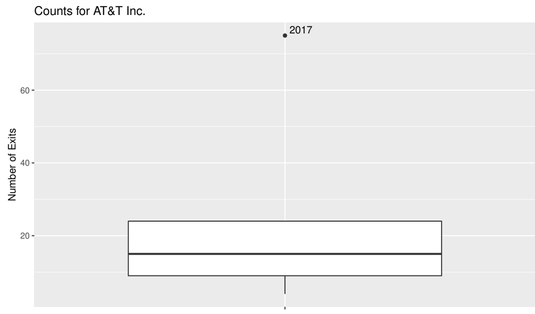


(b) Boxplot of outlier exits each year

caption Outlier diagrams by scale advantage



(a) entry



(b) exit

Figure A.2: Entry-exit outliers for AT&T

A.3 Other Data Plots

stats.texstats.tex

	MaxAdDown	Population	MedDownSp	nCS	nCF	nDS	nDF	exitCount	entryCount
min	0.004	0	0.752	0.0000	0.000	0.000	0.0000	0.0000	0.0000
1st Qu	24.000	3168	45.000	0.0000	1.000	1.000	0.0000	0.0000	0.0000
median	100.000	4452	100.000	0.0000	1.000	1.000	0.0000	0.0000	0.0000
mean	268.972	4789	232.313	0.3336	1.032	1.287	0.1356	0.3338	0.3509
3st Qu	300.000	5976	479.000	1.0000	1.000	2.000	0.0000	1.0000	1.0000
max	1000.000	33201	1000.000	4.0000	4.000	4.000	3.0000	4.0000	5.0000

Table A.5: FCC Statistical Summary for broadband fixed

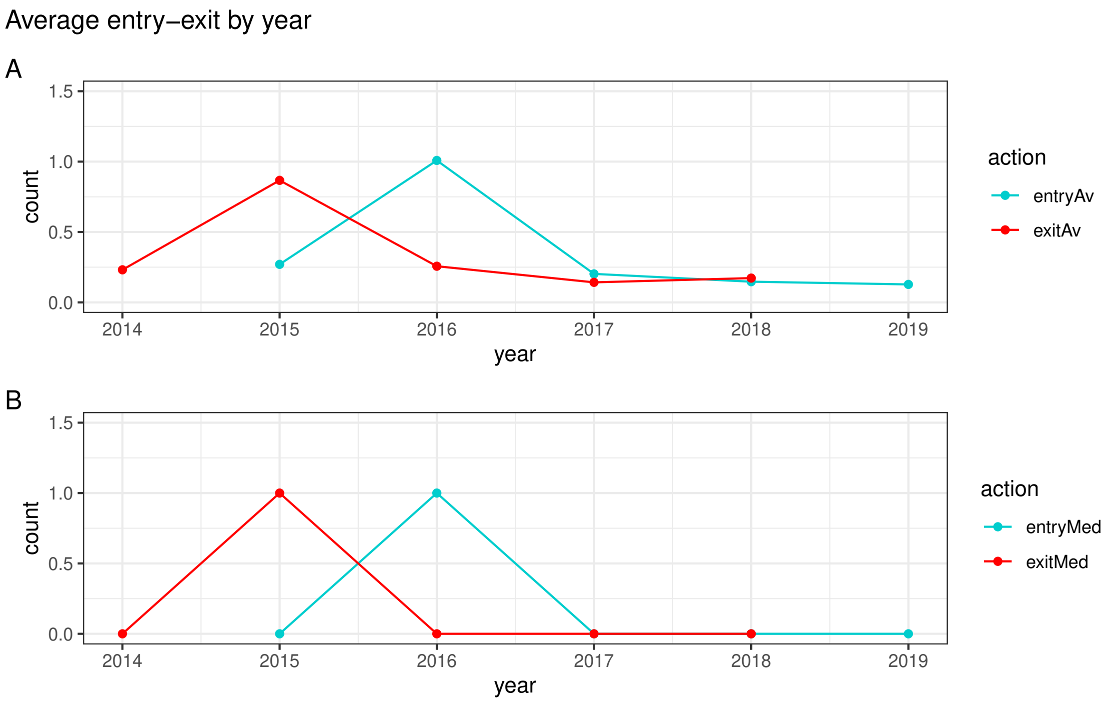


Figure A.3: Market entry and exit trends for average (A) and mean(B)

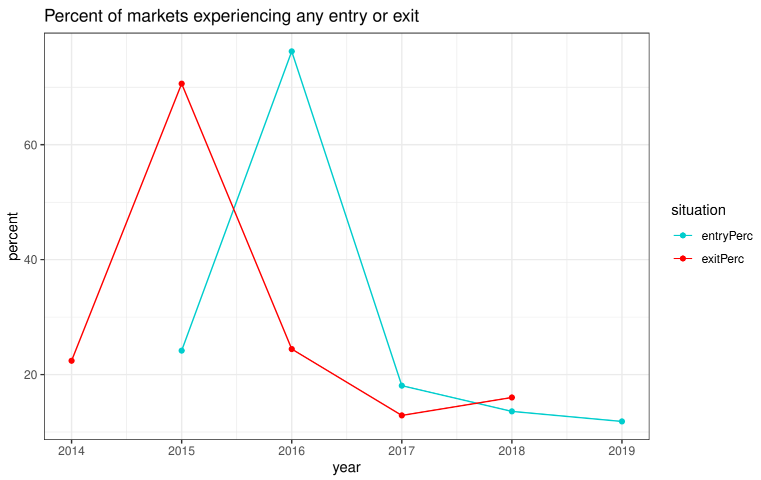


Figure A.4: Percentage of markets that have experienced entry and exit each year across market size.texacross market across market size.texacross market

size.tex

	Entry Counts		
Market Size	Mean	Median	sd
1	0.3260	0	0.5855
2	0.3793	0	0.6404
All	0.3509	0	0.6123

(a) Number of entries in different market sizes

size.tex

	Exit Counts		
Market Size	Mean	Median	sd
1	0.3120	0	0.5383
2	0.3585	0	0.5761
All	0.3338	0	0.5568

(b) Number of exits in different market sizes

Table A.6: Number of entries and exits in different market sizes

	Incumbents					
	nDsl		nCable		Median Speed	
Market Size	mean	median	mean	median	mean	median
1	1.400	1	1.213	1	228.7	100.0
2	1.448	1	1.538	1	236.4	107.5
All	1.422	1	1.365	1	232.3	100.0

Table A.8: General market characteristics for each market size level

numbers.texnumbers.tex

	Number by Types							
	Slow Cable		Fast Cable		Slow DSL		Fast DSL	
Market Size	mean	median	mean	median	mean	median	mean	median
1	0.2742	0	0.9389	1	1.246	1	0.1537	0
2	0.4011	0	1.1371	1	1.333	1	0.1151	0
All	0.3336	0	1.0316	1	1.287	1	0.1356	0

Table A.9: Number of incumbent firms of any type in the market depending on market size

B Results Appendix

B.1 Checking the first stage regressions

B.1.1 Exit Policy

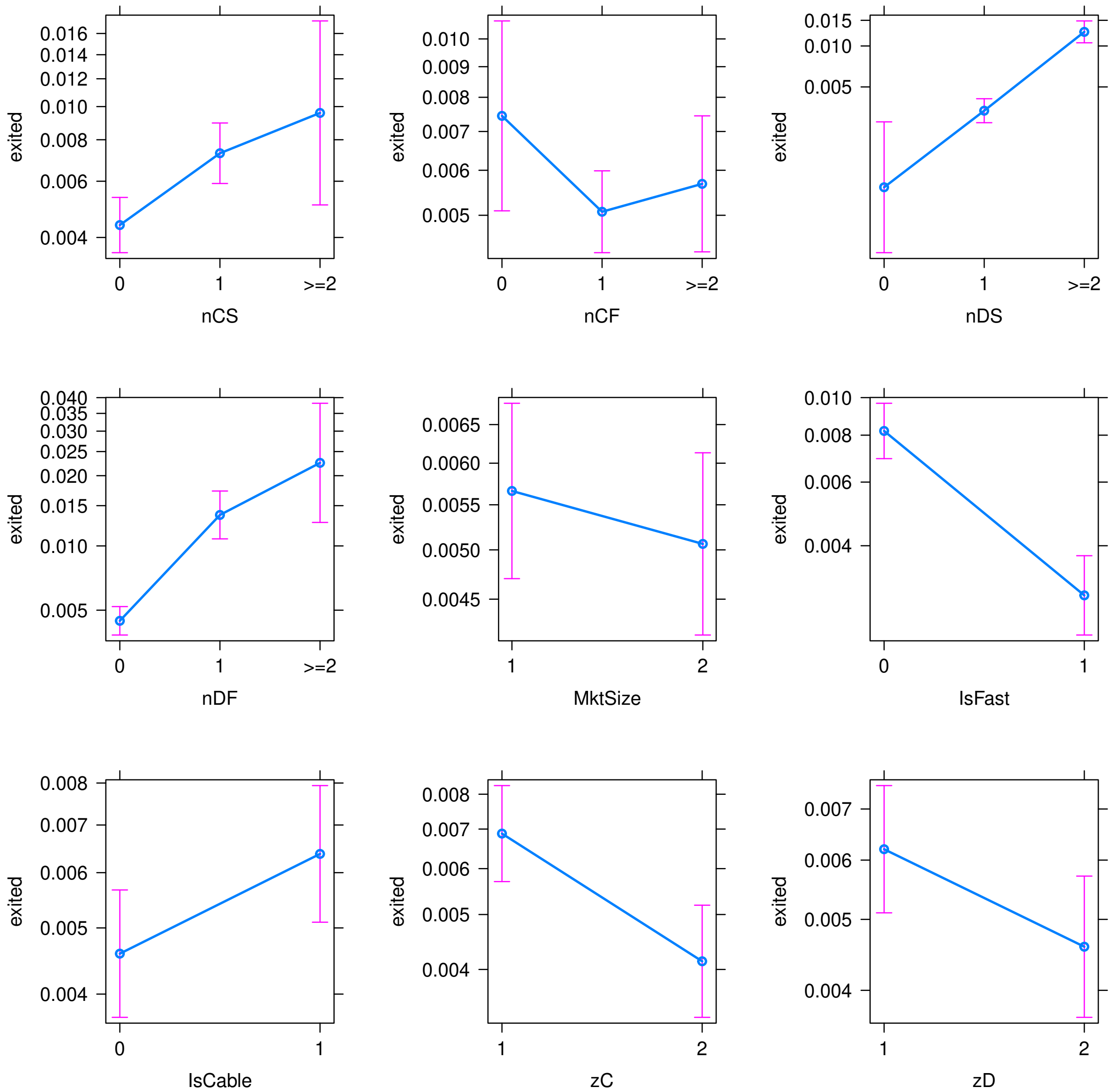


Figure B.1: Effects of variables on exit policy

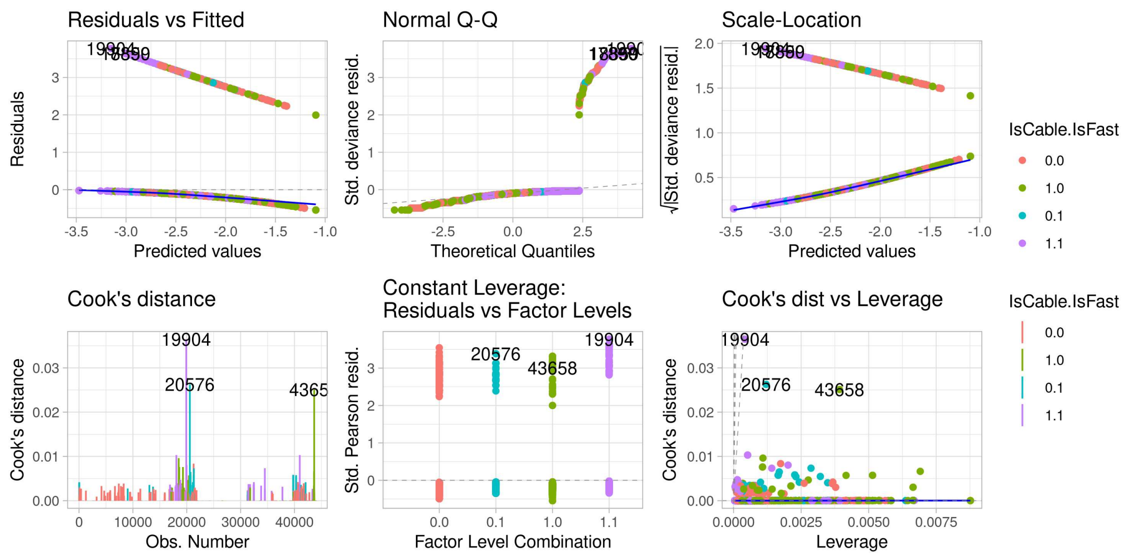


Figure B.2: Exit policy regression quality check charts

anova.texanova.tex

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL			43959	4452.51	
nCS	2	5.36	43957	4447.15	0.0686
nCF	2	41.99	43955	4405.16	0.0000
nDS	2	221.48	43953	4183.68	0.0000
nDF	2	68.66	43951	4115.02	0.0000
MktSize	1	1.16	43950	4113.85	0.2805
IsFast	1	56.16	43949	4057.69	0.0000
IsCable	1	2.38	43948	4055.31	0.1229
zC	1	25.14	43947	4030.17	0.0000
zD	1	3.97	43946	4026.20	0.0462

Table B.1: anova exams for exit policy

anova.texanova.tex

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL			43959	4452.51	
nCS	2	5.36	43957	4447.15	0.0686
nCF	2	41.99	43955	4405.16	0.0000
nDS	2	221.48	43953	4183.68	0.0000
nDF	2	68.66	43951	4115.02	0.0000
MktSize	1	1.16	43950	4113.85	0.2805
IsFast	1	56.16	43949	4057.69	0.0000
IsCable	1	2.38	43948	4055.31	0.1229
zC	1	25.14	43947	4030.17	0.0000
zD	1	3.97	43946	4026.20	0.0462

Table B.2: VIF test for exit policy

B.1.2 Entry Policy

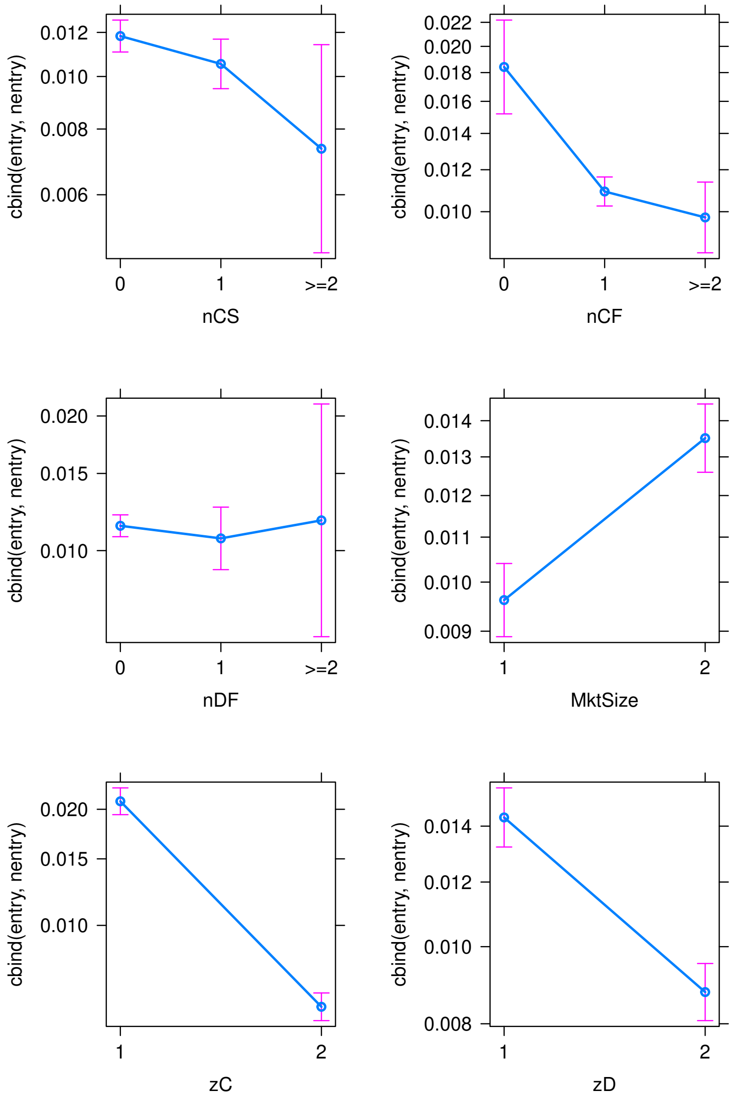


Figure B.3: Effects of variables on entry policy

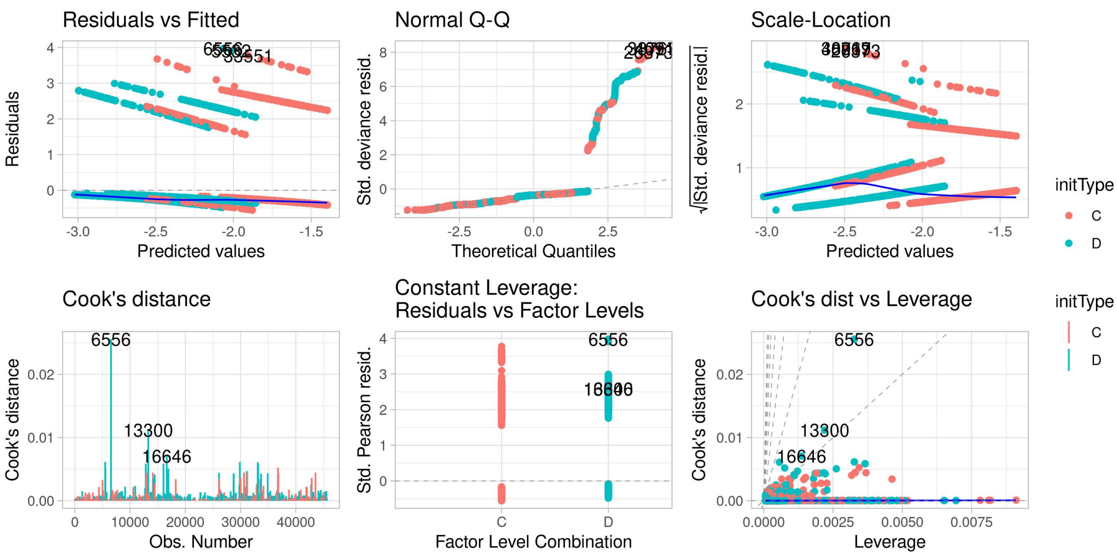


Figure B.4: Entry policy regression quality check charts

anova.texanova.tex

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL			45683	13000.84	
nCS	2	1.19	45681	12999.65	0.5528
nCF	2	160.29	45679	12839.36	0.0000
nDS	2	24.04	45677	12815.32	0.0000
nDF	2	4.32	45675	12811.00	0.1153
MktSize	1	38.49	45674	12772.51	0.0000
initType	1	346.02	45673	12426.50	0.0000
zC	1	732.23	45672	11694.26	0.0000
zD	1	58.48	45671	11635.78	0.0000

Table B.3: anova exams for entry policy

anova.texanova.tex

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL			45683	13000.84	
nCS	2	1.19	45681	12999.65	0.5528
nCF	2	160.29	45679	12839.36	0.0000
nDS	2	24.04	45677	12815.32	0.0000
nDF	2	4.32	45675	12811.00	0.1153
MktSize	1	38.49	45674	12772.51	0.0000
initType	1	346.02	45673	12426.50	0.0000
zC	1	732.23	45672	11694.26	0.0000
zD	1	58.48	45671	11635.78	0.0000

Table B.4: VIF test for entry policy

B.1.3 Upgrade Policy

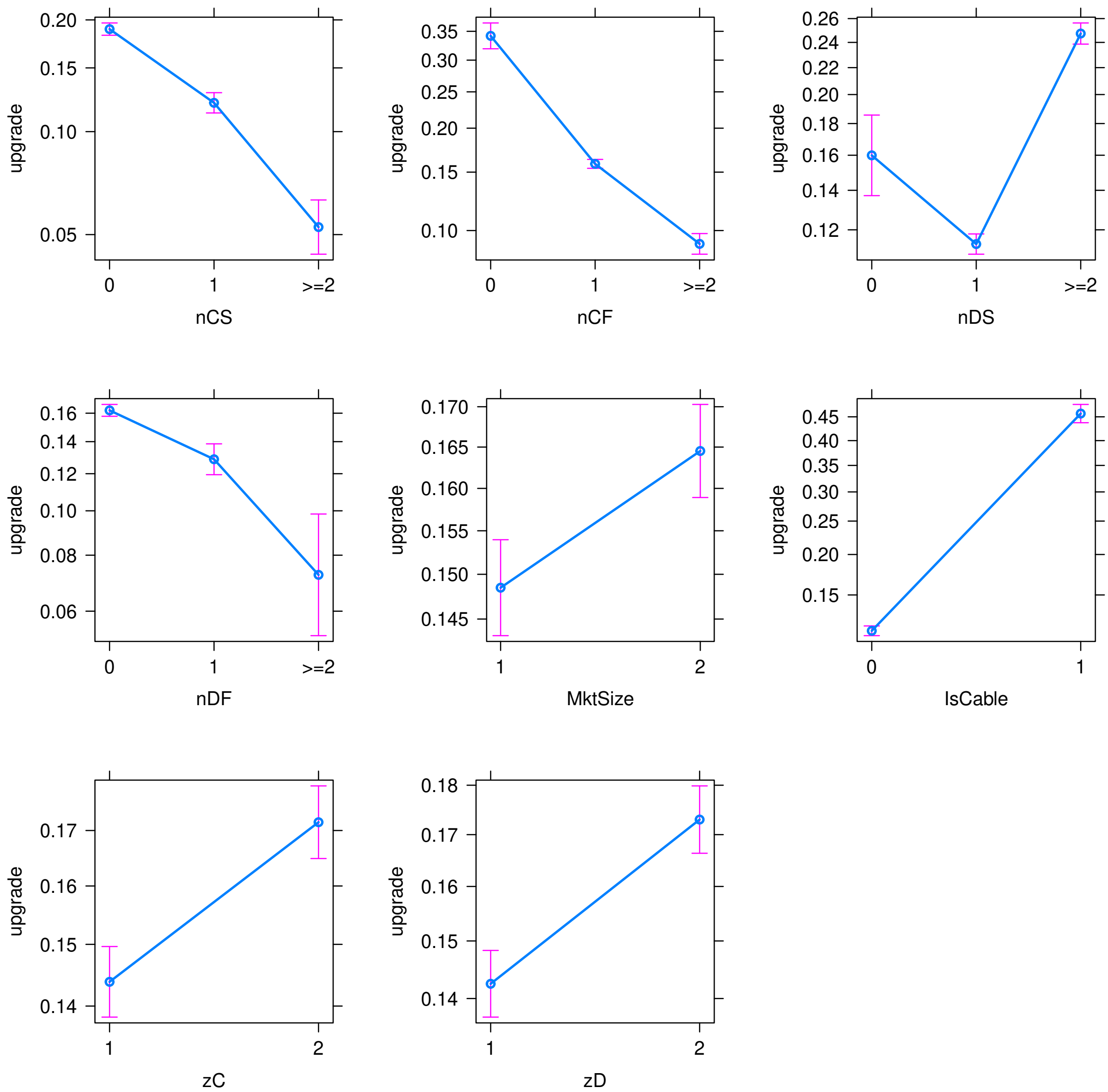


Figure B.5: Effects of variables on upgrade policy

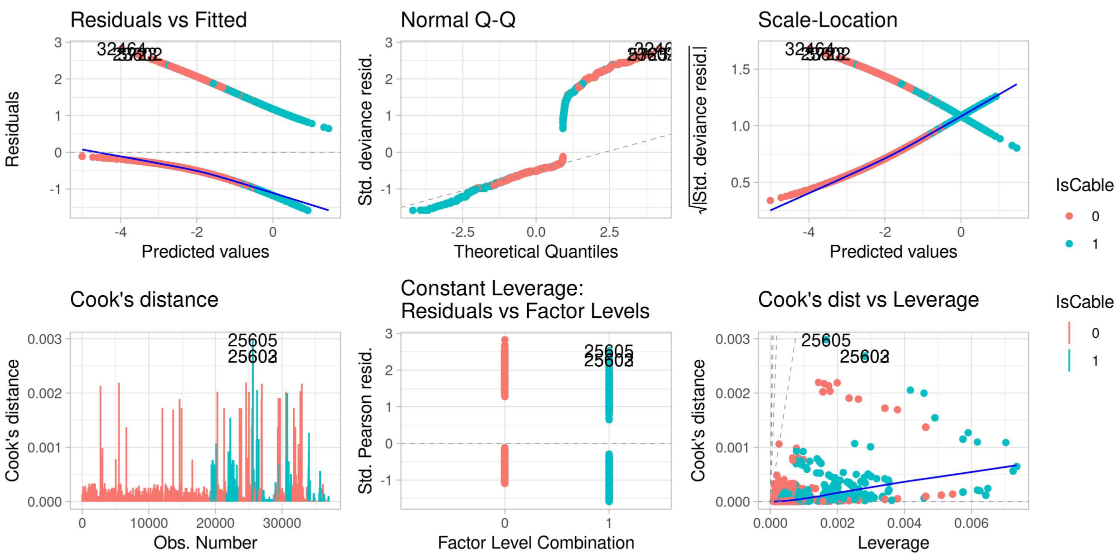


Figure B.6: Upgrade policy regression quality check charts

anova.texanova.tex

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL			36987	34908.66	
nCS	2	105.72	36985	34802.93	0.0000
nCF	2	438.99	36983	34363.95	0.0000
nDS	2	629.81	36981	33734.14	0.0000
nDF	2	88.42	36979	33645.72	0.0000
MktSize	1	17.13	36978	33628.59	0.0000
IsCable	1	1503.61	36977	32124.97	0.0000
zC	1	127.54	36976	31997.44	0.0000
zD	1	40.15	36975	31957.28	0.0000

Table B.5: anova exams for upgrade policy

anova.texanova.tex

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL			36987	34908.66	
nCS	2	105.72	36985	34802.93	0.0000
nCF	2	438.99	36983	34363.95	0.0000
nDS	2	629.81	36981	33734.14	0.0000
nDF	2	88.42	36979	33645.72	0.0000
MktSize	1	17.13	36978	33628.59	0.0000
IsCable	1	1503.61	36977	32124.97	0.0000
zC	1	127.54	36976	31997.44	0.0000
zD	1	40.15	36975	31957.28	0.0000

Table B.6: VIF test for upgrade policy

B.1.4 Fast Entry Policy

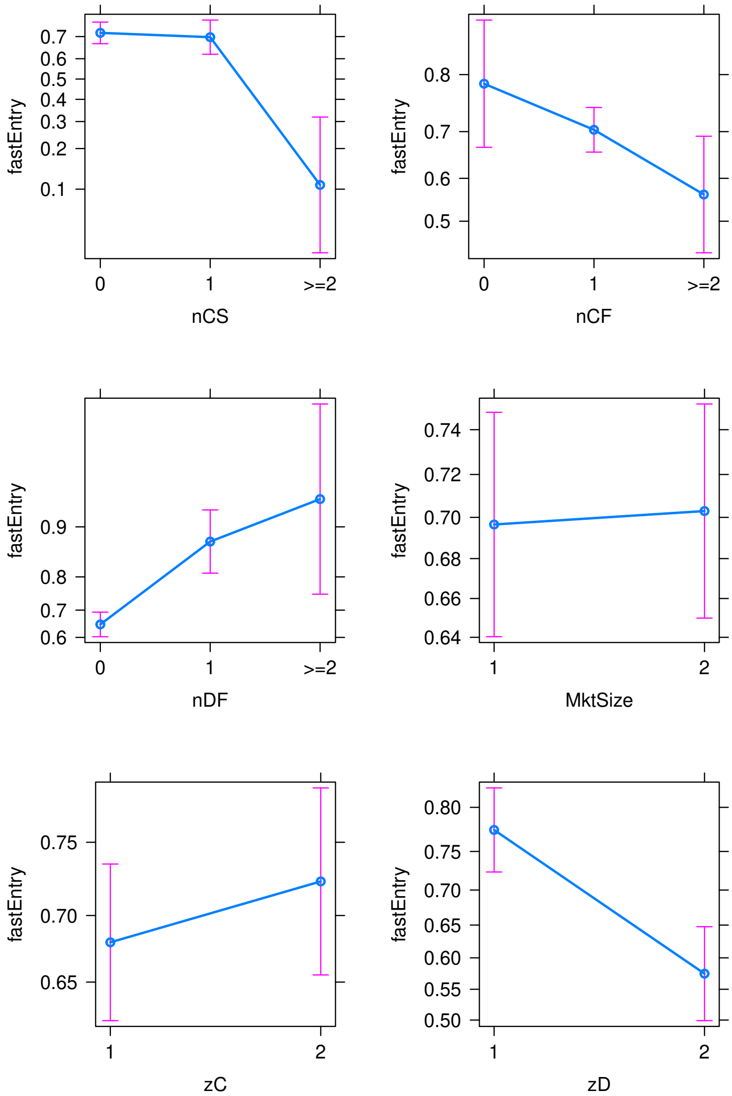


Figure B.7: Effects of variables on fast entry policy

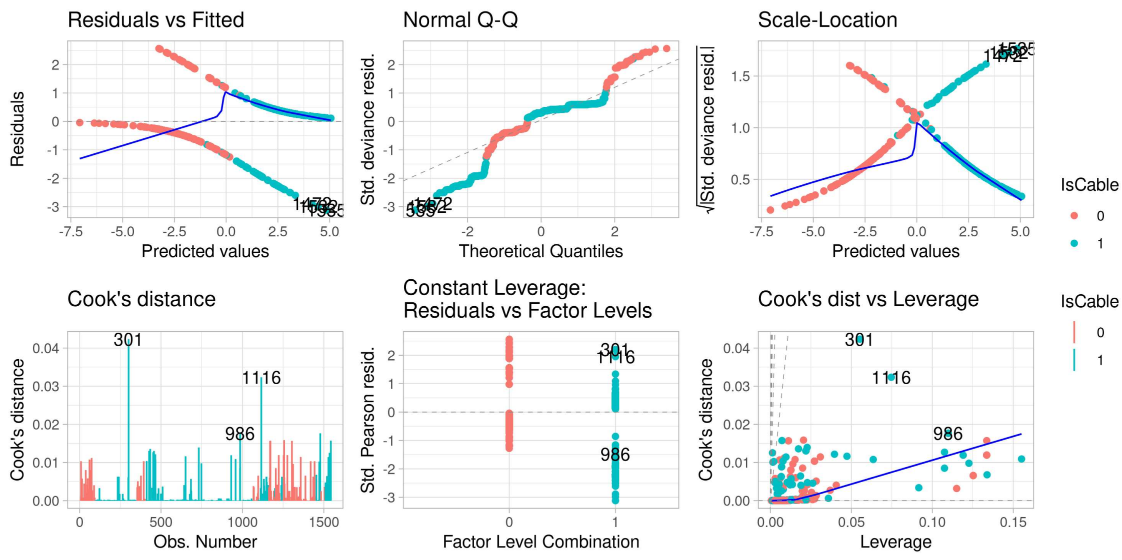


Figure B.8: Fast entry policy regression quality check charts

anova.texanova.tex

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL			1542	2007.68	
nCS	2	28.21	1540	1979.47	0.0000
nCF	2	1.61	1538	1977.86	0.4460
nDS	2	6.95	1536	1970.90	0.0309
nDF	2	5.87	1534	1965.03	0.0531
MktSize	1	1.36	1533	1963.67	0.2428
IsCable	1	1000.09	1532	963.57	0.0000
zC	1	3.52	1531	960.06	0.0608
zD	1	16.24	1530	943.82	0.0001

Table B.7: anova exams for fast entry policy

anova.texanova.tex

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL			1542	2007.68	
nCS	2	28.21	1540	1979.47	0.0000
nCF	2	1.61	1538	1977.86	0.4460
nDS	2	6.95	1536	1970.90	0.0309
nDF	2	5.87	1534	1965.03	0.0531
MktSize	1	1.36	1533	1963.67	0.2428
IsCable	1	1000.09	1532	963.57	0.0000
zC	1	3.52	1531	960.06	0.0608
zD	1	16.24	1530	943.82	0.0001

Table B.8: VIF test for fast entry policy

B.2 Other

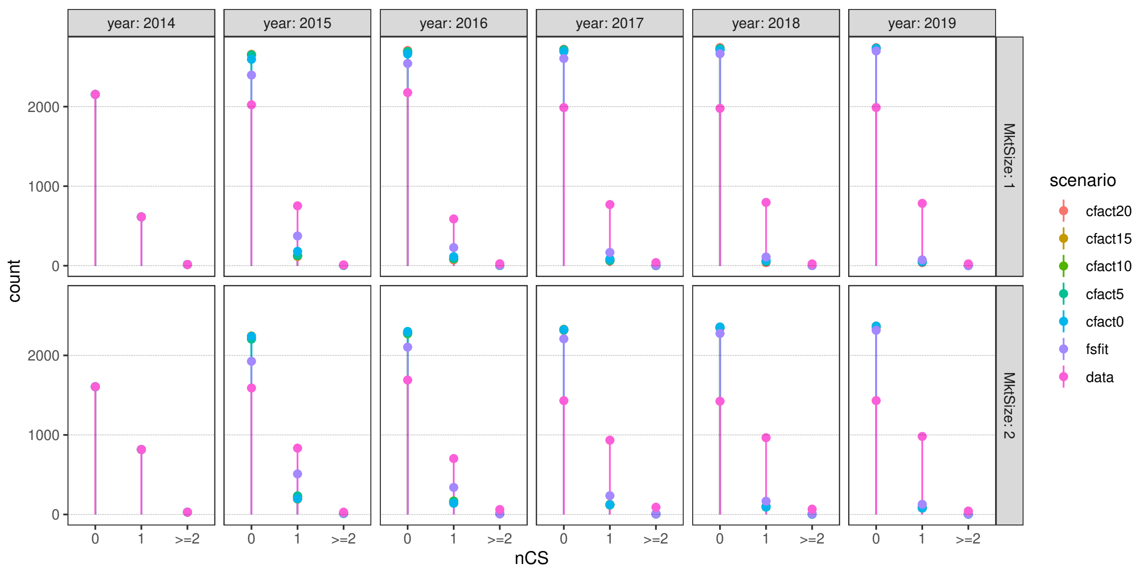


Figure B.9: Discrete Distribution of Number of Slow Cables

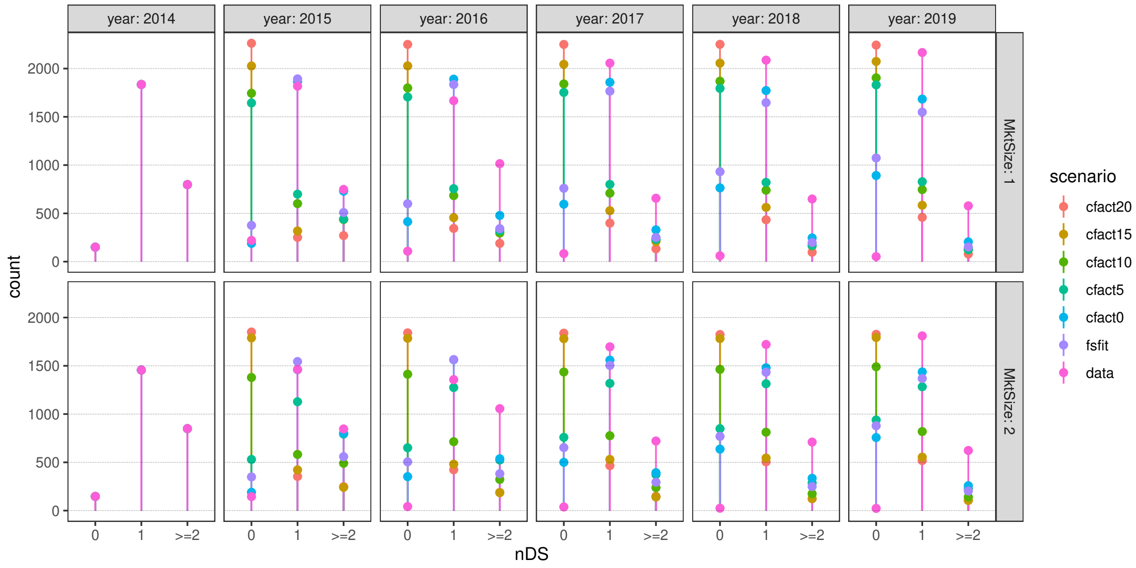


Figure B.10: Discrete the number of DSL distributions

C Logs

Thesis Logs

Mohamad Ali Mohamadi

May 18th, 2021

Contents

1 Project Inception

1.i Industrial Organization Proposal

- **5e3086e** **first commit** [*1 year, 10 months ago*]
- **de8263f** **add until economics of broadband** [*1 year, 10 months ago*]
- **fb7d33f** **add until last paper 2015** [*1 year, 10 months ago*]
- **502b40a** **add until review whole** [*1 year, 10 months ago*]
- **8bd4c90** **fix until spelling fix** [*1 year, 10 months ago*]
- **81788ef** **fix spelling first round** [*1 year, 10 months ago*]
- **da27119** **mend** [*1 year, 10 months ago*]

1.ii Literature Review Work

- **47fcf44** **inital commit** [*1 year, 6 months ago*]
- **e8aeb50** **put pdf list under watch (using a hook I wrote)** [*1 year, 6 months ago*]
- **4008a7e** **remove trailing space** [*1 year, 6 months ago*]
- **85ef8c5** **initial commit for notes on Unbundling the Incumbent** [*1 year, 5 months ago*]
- **159dbd5** **initial commit for notes on Broadband Investment and Regulation** [*1 year, 5 months ago*]
- **058c2f7** **add until empirical access regulation** [*1 year, 5 months ago*]
- **713501b** **add until conclusion** [*1 year, 5 months ago*]
- **b975fe4** **finish cambini slides** [*1 year, 5 months ago*]
- **330247c** **add until section 3 to Unbundling_notes** [*1 year, 5 months ago*]
- **5cfa04b** **add Bresnahan 94 paper** [*1 year, 5 months ago*]
- **3883757** **add until results of entry model** [*1 year, 5 months ago*]
- **771d046** **move images to img folder** [*1 year, 5 months ago*]
- **45b86dc** **add until penetration discussion** [*1 year, 5 months ago*]
- **b9ee49a** **finish Unbundling_notes** [*1 year, 5 months ago*]
- **f503207** **fix minor errors in Unboundling.md** [*1 year, 3 months ago*]
- **5ae2a77** **fix preamable to preamble** [*1 year, 2 months ago*]
- **33d2abd** **add fighting brands paper** [*1 year, 2 months ago*]
- **bb1ea94** **fix text not fitting** [*1 year, 2 months ago*]
- **231fdda** **add until supply model** [*1 year, 2 months ago*]
- **0e22010** **add until welfare** [*1 year, 2 months ago*]
- **9e4a2e3** **add household demand paper** [*1 year, 2 months ago*]
- **4f702e5** **add network papers** [*1 year, 2 months ago*]
- **95cc4bc** **finish railroads** [*1 year, 2 months ago*]
- **ff28531** **add until lessons for energy** [*1 year, 2 months ago*]
- **d374f7a** **finish network industries review** [*1 year, 2 months ago*]
- **a8b5c42** **write various notes excluding hazlett** [*1 year, 2 months ago*]
- **d9ba375** **add until measuring market power** [*1 year, 2 months ago*]
- **8e84b0a** **add until section 3** [*1 year, 2 months ago*]
- **bcf5ddd** **finish various papers** [*1 year, 2 months ago*]
- **ad27c95** **finish demand notes** [*1 year, 2 months ago*]
- **4df6b14** **fix various notes for beamer** [*1 year, 2 months ago*]
- **ae662dc** **fix network industries for beamer** [*1 year, 2 months ago*]
- **bd04acf** **add subsidy notes until counterfactuals** [*1 year, 1 month ago*]
- **280bf20** **finish telecom subs except model** [*1 year, 1 month ago*]
- **f277ffd** **finish subs until model** [*1 year, 1 month ago*]
- **4df3655** **add model except small part from xiao** [*1 year, 1 month ago*]
- **0e9fac2** **finish subsidies papers** [*1 year, 1 month ago*]
- **89d3af8** **fix subsidies for beamer** [*1 year, 1 month ago*]

1.iii Mini-Proposal

- **f16b52d** **Initial commit** [*11 months ago*]
- **ca6933b** **add most of the literature** [*11 months ago*]
- **466ba0b** **Add mostly all literature** [*11 months ago*]
- **784697a** **tidy up until literature** [*11 months ago*]
- **2a23ba2** **add tikz picture** [*11 months ago*]
- **ff1f550** **add some literature overview and all lit. strands** [*11 months ago*]
- **1f644f7** **finish except model and data** [*11 months ago*]

2 Project Proposal, Iran Data

2.i Persian Proposal

See further down.

2.ii Proposal Slides (from mini-proposal)

- f16b52d **Initial commit** [*11 months ago*]
- ca6933b **add most of the literature** [*11 months ago*]
- 466ba0b **Add mostly all literature** [*11 months ago*]
- 784697a **tidy up until literature** [*11 months ago*]
- 2a23ba2 **add tikz picture** [*11 months ago*]
- ff1f550 **add some literature overview and all lit. strands** [*11 months ago*]
- 1f644f7 **finish except model and data** [*11 months ago*]
- 6841797 **add model** [*10 months ago*]
- a200300 **fix note on other industries** [*10 months ago*]
- 7cd1e4d **add more on model, data, and small fixes** [*8 months ago*]
- ae55f46 **add comprehensive model section, reorder structure a bit** [*8 months ago*]

3 Switching Data and Model to US

4 Writing New Model from Scratch

- 5c325f6 **initial commit** [*7 months ago*]
- d09dbf1 **add except simulation explanation** [*6 months ago*]
- 77de4c3 **finish all of what I think was needed for estimation** [*6 months ago*]
- 2ed908a **add pandoc yaml** [*6 months ago*]
- f4cd09a **complete doc, add counterfactual generation explanation** [*5 weeks ago*]

5 US Data Cleaning and Exploration

- c8cbed0 **initial commit** [*12 months ago*]
- 3a996f2 **add elementry steps towards collapsing into blocks** [*12 months ago*]
- cf8ae30 **show ATAT data only** [*9 months ago*]
- 45fbe57 **add highspeed map derivation** [*8 months ago*]
- 977b95d **recomment and reorder code** [*8 months ago*]
- e3a8ff9 **write section to write summary to file** [*8 months ago*]
- 699d47d **use dtplyr from the getgo** [*8 months ago*]
- 0c7d5f3 **add aggregation capabilities** [*6 months ago*]
- dbfc29f **add market charactersitics on the incumbent's side** [*6 months ago*]
- 76a6169 **compute incumbents actions** [*6 months ago*]
- 946fc0b **prepare files to generate table-ready data** [*6 months ago*]
- ae969b8 **compute some of the summary tables** [*6 months ago*]
- 91f51d3 **add summary tables** [*6 months ago*]
- 2416cf1 **add some data consistency tests** [*6 months ago*]
- cf17b0d **minor fixes and notation changes** [*6 months ago*]
- 1dd2523 **add basic map visualization** [*5 months ago*]
- b713afa **fix tables: change rate, save to tex, add median and summary** [*5 months ago*]
- 7329078 **add further consistency checks, use data.table** [*5 months ago*]
- 54f1701 **add data plots (visualization.R), fix naming in visualizationMap** [*5 months ago*]
- 5a4b79b **change FRN to actual holding co. (HocoNum)** [*4 months ago*]
- d699fe6 **change market with firms to market only** [*4 months ago*]
- 1df5d2f **improve visualizating figures** [*4 months ago*]
- da192c7 **add utility functions useful in simulation** [*4 months ago*]
- ce0d759 **check and rule out firms entering state instead of state region.** [*4 months ago*]
- 0f0d0e8 **add meta-inspection of present firm types** [*4 months ago*]
- b49d9d1 **add fpredict, the fast predict func** [*4 months ago*]
- 58a602f **add further utility functions** [*4 months ago*]
- a26413f **add crucial fix to fpredict the issue was that I had not sorted the data's columns according to model coefs first.** [*4 months ago*]
- c8cc3d8 **remove making factors of ns, using characters only instead WARNING this is potentially dangerous, presently, I don't know why lm models interpret characters as factors on their own.** [*4 months ago*]
- a90326f **add potential entrants computations** [*4 months ago*]

- 390f1fe **fix bug in nvec with two-digit strings** [*4 months ago*]
- 8baaa20 **replace visualization script with a rmarkdown one** [*4 months ago*]
- 79892d4 **refactor outlier identification, add outlier inspection notes** [*4 months ago*]
- 6b6a2a2 **finalize outlier analysis, some tidying up** [*34 minutes ago*]

6 Slides on new Model and Data

- aac6fa3 **add slides for initial presentation** [*5 months ago*]
- 23db442 **fix some issues, reorganize model section** [*4 months ago*]
- 4c58142 **add slides on outliers discussion** [*4 months ago*]
- d2a8b8d **fix notes from previous session** [*3 months ago*]
- 4db04d0 **restructure folder** [*3 weeks ago*]
- 3108045 **add preamble, literature tree** [*26 minutes ago*]

7 Model Implementation and Simulation

- 7757776 **add initial steps for computing W** [*5 months ago*]
- 33a19f8 **add w preparation** [*5 months ago*]
- 26983aa **prepare the data structures for building and storing Ws** [*4 months ago*]
- 08989a4 **add w comp with exit only** [*4 months ago*]
- 18810e8 **create data ready for computing cable or dsl entry** [*4 months ago*]
- 7bb0c6f **add entry probit, with later upgrade decision to follow** [*4 months ago*]
- c5da81b **add basic exit policy estimation** [*4 months ago*]
- d3b1852 **add entry, entrant upgrade, and incumbent upgrade policy estimations** [*4 months ago*]
- f89d1d2 **separate functions and main script for W computations** [*4 months ago*]
- b4a4e0e **organize functions in a more hierarchial way** [*4 months ago*]
- 8f4c1e9 **start migrating code to efficient data.table ways** [*4 months ago*]
- f68928d **rewrite state to statefirms more efficiently** [*4 months ago*]
- 9a392d1 **initial rewrite of move_state** [*4 months ago*]
- 1715390 **fully simulate entry-exit with upgrade rather efficiently** [*4 months ago*]
- 43882c9 **use set to avoid [data.table overhead** [*4 months ago*]
- 00d0197 **further add set alternatives etc.** [*4 months ago*]
- 33c748b **optimize profit_comp along with other parts** [*4 months ago*]
- 5f263ef **first refactor of entry policy estimation** [*4 months ago*]
- 78ea42c **refactor all policies and main script (first round)** [*4 months ago*]
- 4fe2eda **add policies estimates examinations** [*4 months ago*]
- 260f734 **replace with inner join and fix incorrect firms list generation** [*4 months ago*]
- b2e3314 **use data.table transport and optimize fastE** [*4 months ago*]
- a7cf609 **minor fixes, parallel script, and gitignore** [*3 months ago*]
- 797a2b1 **delete kept alternative lines as version advances** [*3 months ago*]
- 2ab668f **add upgrade part of profit computation** [*3 months ago*]
- 46c35a0 **alter result structure for repeating computations** [*7 weeks ago*]
- 21c24dc **add initial post processing for W results** [*7 weeks ago*]
- 39af27e **add column names and averaging to postprocessing** [*7 weeks ago*]
- 9ca7d1c **fix exit mean and policy perturbation** [*6 weeks ago*]
- 775f195 **add W2 computations including final optimization** [*6 weeks ago*]
- ea20268 **factor state firms initialization in prep for cf_comp** [*6 weeks ago*]
- b6531df **add initial fit results** [*6 weeks ago*]
- d1082c7 **add model fit along with basic analysis** [*6 weeks ago*]
- 0e05399 **add initial counterfactual simulation** [*5 weeks ago*]
- 668f56a **add comparison report between cfact, fit, and data** [*5 weeks ago*]
- fd35ef7 **add initial cfactW data preparation** [*5 weeks ago*]
- 55cd921 **add initial cfactW computation** [*5 weeks ago*]
- e262222 **add counterfactual estimation through simulation** [*5 weeks ago*]
- ac8a554 **refactor cfact analysis to work with both latex and interactive** [*5 weeks ago*]
- 5e70963 **restructure project directory** [*4 weeks ago*]
- c433050 **fix profitTheta_comp for speed and explicit theta use** [*4 weeks ago*]
- dec3b69 **remove redundant and likely wrong cfact_comp and its script** [*4 weeks ago*]
- 3efa06d **reorder funcs, remove old unnecess. comment lines** [*4 weeks ago*]

- **a4bbad0 shorten data tidying for use in counterfactuals estimation** [*4 weeks ago*]
- **d7fd6ca change cfactW names to just cfact** [*4 weeks ago*]
- **9e5036f minor fixes of three script files** [*4 weeks ago*]
- **0db97a9 add initial steps towards factoring out data IO** [*4 weeks ago*]
- **b2b8fb8 refactor counterfactual decisions computation** [*4 weeks ago*]
- **5c2f7b4 fix wrong year moving, dependent on data** [*4 weeks ago*]
- **d63a6eb reposition year col and add lengthening function** [*4 weeks ago*]
- **1570356 return only state-years instead of whole firms** [*4 weeks ago*]
- **e8b047d refactor cfact simulation process** [*4 weeks ago*]
- **4ef4a01 add market ids to cfactsim to track market evolutions** [*4 weeks ago*]
- **3cd5a2f initial step towards refactoring second-stage estim** [*4 weeks ago*]
- **863c71f fix same id in base and cfact, keep data mktid** [*4 weeks ago*]
- **ce1239b add intial results exploration** [*4 weeks ago*]
- **da38176 factor a bit, put present states plots** [*3 weeks ago*]
- **dd33255 add theta script for second-stage refactoring** [*3 weeks ago*]
- **8cce824 Merge branch 'parfact'** [*3 weeks ago*]
- **8ffa4be add setting seed and sane values to scripts** [*3 weeks ago*]
- **2185b61 remove redundant scripts** [*3 weeks ago*]
- **0b858f0 set seed to value giving sensible theta estimates** [*3 weeks ago*]
- **a24d60e adapt the shorter theta components naming** [*3 weeks ago*]
- **5c96919 add firststage fit to visualizations as well** [*3 weeks ago*]
- **742206b refactor policies examination** [*12 days ago*]
- **772f061 modify theta computation adding bootsrapping** [*55 minutes ago*]
- **9311595 add some extra vizualizations** [*24 minutes ago*]

8 Thesis Writing

- **aa969b7 Initial commit** [*10 months ago*]
- **7c02628 add initial files** [*10 months ago*]
- **32e13c7 add until literature review** [*10 months ago*]
- **e8ca610 fix some latex packages and ignore their auxilary files** [*10 months ago*]
- **a6738ee add appendix on Iran's background, status** [*10 months ago*]
- **1206736 finish section on literature minus strands.** [*10 months ago*]
- **822542f add literature strands discussion** [*10 months ago*]
- **710e354 add model section** [*9 months ago*]
- **4b535eb add various small fixes** [*9 months ago*]
- **3874741 add Wilson estimation notes** [*9 months ago*]
- **ea216ba fix minor text issues** [*9 months ago*]
- **8b082bb add small parts to project** [*9 months ago*]
- **545d362 add conclusion and more-model sections** [*9 months ago*]
- **a78d98d add and finish other-literature section** [*9 months ago*]
- **2e0fdaa complete introduction section** [*9 months ago*]
- **6e617e8 complete conclusion section** [*9 months ago*]
- **1e2c451 finish general model section** [*9 months ago*]
- **a5665ba finish section on deriving expressions** [*9 months ago*]
- **2c93cc1 finish section on data for now** [*9 months ago*]
- **14a628e finish estimation notes for now** [*9 months ago*]
- **f744104 minor fixes and translation choice changes** [*8 months ago*]
- **edfcf8f reorder and put in sections the literature strands** [*8 months ago*]
- **4c76ef5 add small notes and make small content reordering** [*8 months ago*]
- **6f18c53 add some mostly financial tables** [*8 months ago*]
- **0faae96 add general model notes until Hotz-Miller, POB specifics** [*8 months ago*]
- **87ca39e add old commit I had forgotten** [*3 weeks ago*]
- **f10702a use vazir font, tcolorbox** [*3 weeks ago*]
- **46dc232 add tcb commands including code env** [*3 weeks ago*]
- **9322140 add model until random utility** [*3 weeks ago*]
- **85b8e15 add until dynamic costs part** [*3 weeks ago*]
- **e4e2668 add until entry-exit costs** [*2 weeks ago*]
- **2c40c6d add until states and actions** [*2 weeks ago*]
- **86fc856 finish model section** [*2 weeks ago*]
- **c4ba2b4 add estimation until transition probs** [*2 weeks ago*]

- **aa79d7f** **add until simulation explanation** [*2 weeks ago*]
- **078c612** **add until markov condition explanation** [*2 weeks ago*]
- **f10604c** **finish estimation section** [*2 weeks ago*]
- **59f60f7** **move old model to appendix** [*2 weeks ago*]
- **78ddefc** **add most tables and plots to respective files** [*11 days ago*]
- **9d4488e** **add until industry background** [*10 days ago*]
- **2061c91** **finish introduction section** [*9 days ago*]
- **fd4b235** **join literature parts into one file, with minor fixes** [*9 days ago*]
- **5a8459e** **add all old sections as appendix** [*9 days ago*]
- **81b9cd2** **minor fixes to project setup** [*9 days ago*]
- **92221d9** **add writings to the data section** [*8 days ago*]
- **c4c1ae2** **add writings to results** [*16 hours ago*]
- **aa5f260** **rewrite conclusion section** [*2 hours ago*]
- **2121e33** **add bootstrap results** [*56 minutes ago*]
- **e85236e** **minor fixes** [*20 minutes ago*]

9 Thesis Logs

- **7168c38** **initial commit** [*4 months ago*]
- **f083818** **add until switching to US data** [*4 months ago*]
- **e81c11d** **add until TODO section** [*4 months ago*]
- **08b0bdd** **add project logs file** [*19 minutes ago*]