Socio-economic Impact of Fiber to the Home in Sweden

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Degree project in
Communication Systems
Second level, 30.0 HEC
Stockholm, Sweden

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2013-02-26

Master's Thesis

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Abstract

Fiber-to-the-Home (FTTH) has been talked about since the introduction of fiber in the 1970s. It is nowadays shaping up to be the foundation of our new digital society, bringing economic prosperity and a multitude of business, social, and entertainment opportunities to its users. The increased consumer demand for high-speed network accessibility is being taken more and more seriously and a fiber-based network is able to cope with these growing demands due to its wide bandwidth and reliability. Today there is a practical need for quantitative analysis regarding the socio-economic impacts of fiber-based access networks. This analysis could be used as an indicator/reference for all the stakeholder entities as they consider future investments and developments. Sweden is a suitable target country for this analysis since it has adopted fiber for some years and the benefits that FTTH has brought seem to already be tangible.

The primary value of this thesis lies in investigation of its quantified evidence of the socio-economic impacts of FTTH deployment in Sweden. This has been achieved based on data from the Swedish Post and Telecommunications Authority (PTS), Statistics Sweden (SCB), previous related studies, and information collected on-line from operators involved in the fiber market, along with empirical analysis based on multivariate regression models.

The results of the study show that fiber penetration has had a significant impact on the population's evolution, specially the net amount of migration into a municipality, which indicates the attractiveness of municipalities per se. It is therefore reasonable to suggest that local government and local authorities take fiber deployment into consideration, if they want to attract people to stay for further local development. The study also analyzed the competition in fiber-based open networks and the prices of subscribing for 10/10 Mbps symmetrical Internet Service. Study findings revealed that networks with multiple competing service providers have a wider range of services and a lower price: the more ISPs competing in a fiber network, the lower consumer prices. Specifically, for each new service provider present in the network, there will be 5 SEK per month decrease of the average price of the Internet services, and an approximately 7 SEK per month reduction in the lowest price.

Nevertheless, a number of socio-economic impacts remain unquantifiable as of the current time and due to the limited available data. It is recommended to incorporate more socio-economic effects in future research in order to draw a more complete picture for all the interested sectors, and to supplement the data with recent figures for 2012 and 2013.

Key Words: Fiber-to-the-home, FTTH, Broadband Technologies, Open Access Fiber Network, Socio-economic impact, Population Evolution, Migration, ISP competition, Price of Internet Service, Municipalities, Sweden

Sammanfattning

Fiber till hemmet (Fiber-to-the-Home, FTTH) har talats om sedan fiber introducerades på 1970-talet. Det håller numera på att bli grunden för vårt nya digitala samhälle, och bidra till ekonomiskt välstånd och medföra en mängd affärsmässiga, sociala och underhållningsmässiga möjligheter till slutanvändare. Den ökade efterfrågan på höghastighetsnät tas mer och mer på allvar och ett fiberbaserat nät kan hantera dessa ökade krav på grund av dess breda bandbredd och tillförlitlighet. Idag finns ett praktiskt behov av kvantitativ analys av de socioekonomiska effekterna av fiberbaserade accessnät. Denna analys kan användas som en indikator och referens för alla intressenter när de överväger framtida investeringar. Sverige är ett lämpligt mållland för denna analys eftersom den har antagit fiber i några år och de fördelar som FTTH har fört verkar redan vara synliga.

Det huvudsakliga värdet av denna avhandling ligger i utredningen av kvantifierade bevis för de socioekonomiska effekterna av FTTH utbyggnad i Sverige. Detta har uppnåtts på grundval av uppgifter från den Post- och telestyrelsen (PTS), Statistiska centralbyrån (SCB), tidigare liknande studier och information som samlats in på nätet från aktörer inom fiber, tillsammans med empirisk analys baserad på multivariate regressionsmodeller.

Resultatet visat att fiber har haft en betydande inverkan på befolkningens utveckling, speciellt netto in- och utflyttning till en kommun, vilket indikerar attraktionskraft kommunerna i sig. Det är därför rimligt att föreslå att kommunerna och de lokala myndigheterna överväger fiber driftsättning på allvar om de vill locka invånare att stanna för ytterligare lokal utveckling. Studien analyserar också konkurrensen på fiberbaserade öppna nät och priserna på 10/10 Mbps symmetrisk Internet-tjänst. Resultaten visar att nätverk med flera konkurrerande tjänsteleverantörer har ett bredare utbud av tjänster och ett lägre pris: ju fler Internetleverantörer i ett fibernät, desto lägre konsumentpriser. Mer specifikt, för varje ny tjänsteleverantör som finns i nätverket, minskar det genomsnittliga priset med 5 kronor per månad, och det lägsta priset med cirka 7 kronor per månad.

Ändå förblir ett antal socioekonomiska effekter omätbara på grund av begränsade tillgängliga data. Rekommendationen är att införliva fler socioekonomiska effekter i framtida forskning för att dra en mer komplett bild för alla berörda sektorer, och att komplettera data med färska siffror för 2012 och 2013.

Nyckelord: Fiber-to-the-home, FTTH, Bredband, Öppet access fibernät, Socioekonomiska konsekvenser, Population Evolution, Migration, ISP konkurrens, Internettjänst Pris, Kommuner, Sverige

Acknowledgements

First and foremost, I would like to express my profound gratitude and deepest regards to my academic supervisor Prof. Gerald Q. Maguire Jr. (School of ICT, KTH), for his valuable time and exemplary guidance throughout the course of this thesis. I cannot be more grateful for his elaborate and insightful comments that inspired me in improving the work. His rigorous attitude in scientific research has enlightening me and shall continuously benefit me in my future work.

This project would have been impossible without the extremely valuable support and guidance from Dr. Marco Forzati, my industrial supervisor at Acreo. I would like to express my heartfelt gratitude, for giving me the opportunity to present my skills, and constantly supporting me, and sharing his knowledge throughout the whole project. I very much appreciate it, as I was enriched every day, from every single discussion with him, which was the most invaluable experience to me.

I would also like to show my sincere gratitude to Mr. L Christer Lie (School of CSC, KTH), who is the best mentor I have ever met. The blessing, help and guidance given by him time to time during my master's studies shall carry me a long way in my life.

Furthermore, I am obliged to Ms. May-Britt Eklund-Larsson for all her cordial help, and all the great teachers at KTH for equipping me with the latest knowledge in both technical and business fields. I also want to express my gratitude to Mr. Crister Mattson for confirming the value of my research, as well as Mr. Viktor Nordell, Mr. Walter Margulis, and all of the stuff at Acreo AB, I am highly grateful for all their invaluable supports and making me feel like at home.

Last but not least, I am especially grateful to my dear parents for their unconditional support, great understanding, constant encouragement and their infinite love. I would like to thank my special one, all my friends and everyone else who supported and inspired me during my life. I have been fortunate enough to have you by my side. Love you.

Ziyi Xiong

18th Feb 2013, Stockholm

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List of Acronyms and Abbreviations

ARPU	Average Revenue per User
CAPEX	Capital Expenditures
DSL	Digital Subscriber Line
FTTB	Fiber to the building
FTTC	Fiber to the curb
FTTH	Fiber to the home
FTTN	Fiber to the node
GDP	Gross Domestic Product
ICT	Information and Communication Technology
ISP	Internet Service Providers
LAN	Local Area Network
NP	Network Provider
OECD	Organization for Economic Co-operation and Development
OPEX	Operational Expense
P2P	Point to Point
PIP	Physical Infrastructure Provider
POP	Point of Presence
QoE	Quality of Experience
QoS	Quality of Service
SP	Service Provider
UE	User Experience

1 Introduction

This chapter introduces the problem area with a brief introduction, followed by a statement of the purpose of the research and the questions to be addressed. The thesis outline and necessary context are provided for readers who interested in this topic.

1.1 Project overview

The Internet has emerged as a critical component of society's communications infrastructure in the last two decades. Of the many advanced technologies that fall under the Information and Communication Technology (ICT) umbrella, broadband communications is perceived as the future of Internet and the availability of broadband access is continuously driving the evolution of advanced communication services and overall economic growth[1,2]. Given the increasing importance of ICT in the knowledge-based and communications-intensive economy, people have realized that those who adapted to the revolution are increasingly at a competitive advantage. In many countries, this awareness has matured as an important national agenda to promote nationwide deployment of broadband services, in particular of fiber-based access technologies.

Compared to the traditional broadband connections, fiber-based access networks (often referred as Fiber-to-the-Home, FTTH[*]) based upon its virtually unlimited capacity and future-proof nature, is considered to uncork the "last mile"[†] bottleneck in terms of Quality of Experience (QoE) and Quality of Service (QoS) that traditional broadband technologies have[3]. Yet there is still a debate among scholars and policy makers as to whether it is necessary to promote or invest in FTTH, as it is possible to deliver services over the existing copper-based broadband infrastructure or even broadband wireless access networks[4]. Therefore, there is a need to study what benefits FTTH has already brought. There have been some dedicated studies concerning the benefits of fiber-based access networks (see[5–7]), but there seems to have been almost no *quantitative* econometric study measuring the socio-economic impact of fiber-based access networks. This study aims to fill this information gap by quantifying the socio-economic effects of FTTH networks.

It is not surprising that there is little econometric analysis done on the impact of fiber-based access networks, due to the fact that relatively few fiber networks have been deployed and the data is scarce. Sweden has been a leading country in the adoption of FTTH over the past decade. According to Organization for Economic Co-operation and Development (OECD) statistics at the end of 2011, it is the OECD-EU country that has the highest proportion of fiber subscribers out of all fixed broadband subscribers[8,9]. Sweden is therefore considered as a good target for an analysis of the benefits of FTTH, because some of the social, economic, and environmental benefits that FTTH has brought are believed to already be tangible[10]. Looking at the effects at an inter-municipal level within the country will help us avoid variance due to cultural differences.

[*] Collectively named FTTx networks, where x refers to different cases, e.g. Cabinets (FTTC), Buildings (FTTB), and Homes (FTTH). All of these will be referred to as FTTH in this report, but we indicate which applies where it is relevant.
[†] The final stretch of connection that delivers voice, data and video to end users' homes and offices.

This Master's project[*] was carried out at Acreo AB, a Swedish research institute providing leading edge solutions within the field of electronics, fiber optics, and communication technology. This research institute is based in Kista, Stockholm. Acreo is currently very active in enhancing fiber optic technologies and evaluating the effects of Next Generation Access technologies on society and the economy in Sweden. Acreo has performed an early stage study on FTTH's impacts on population and employment[4].

The study reported in this thesis targets quantifying empirical evidence of the socio-economic impacts of FTTH deployment in the context of Sweden at a municipal level, with attempts to robustly extend the earlier research on population evolution and to look deeper into the market in terms of competition and the price of Internet service. On these networks, typically triple-play services are offered, which consist of Internet access, Television, and Telephony, and the service we are analyzing in the thesis is the Internet access[†] (specifically: 10/10Mbps symmetric Internet access speed). Because on one hand, Internet access is most commonly required and sold service; on the other hand, it is a well-specified commodity, which in principle has no service differentiation, meaning service value/quality (e.g., 10/10Mbps symmetric) is the same everywhere, hence the price differences are not due to the inherent value of the service, we can therefore analyze it on the equal term. These findings could serve as a reference to whoever is interested an in the future development of or making investments in fiber based access networks.

1.2 Thesis outline

The thesis starts with a theoretical framework for FTTH, to equip readers with the necessary background information. In Chapter two, the benefits of FTTH are illustrated from both technical and socio-economic perspectives in order to explain why it is worthwhile deploying FTTH and why consumers would like to pay for fiber-based Internet access. Chapter three introduces the methods utilized in the research, from data collection to processing and analysis. The calculations and findings are presented and discussed in detail in chapter four. Subsequently, the implications of this research, along with discussions of its constraints and possible directions for future work are provided in Chapter five.

1.3 Readers

This thesis should be easily understood by readers who are interested in the socio-economic impact of FTTH, with or without a prior background in ICT, networking, or economic issues related to FTTH. This thesis is specifically target for:

- Governments or municipalities,
- Telecommunication operators,
- Service providers,
- Residential associations,
- Venture capital investors, and
- Scholars who is interested in FTTH

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[*] Part of the European ICT-OASE project, which is financed by the European Commission's FP7 programme.

[†] VoIP and IPTV are not included in our analysis as the varied service differentiations (e.g., package definition, HD service) make it difficult to analyze on equal term.

2 Background

This chapter introduces the essential background information concerning FTTH. The aim is to explain why it FTTH is worth adopting by illustrating the benefits of FTTH from technical, socio-economic, and environmental perspectives.

2.1 What is FTTH?

The theoretical background of FTTH and its environmental context, as well as the difference between FTTH and other FTTx technologies are briefly introduced in this section.

2.1.1 FTTH Network Environment

Fiber-to-the-home (FTTH) is a network connection using optical fiber directly from the access network operator's network to the home. Conceptually, FTTH is an access network architecture using optical fiber to extend optical interconnection to reach the boundary of a living or working space. The characteristics of optical fiber technology not only provided greater bandwidth, but also enhanced network transparency in regards to data format, rate, wavelength and protocol; relaxing the demands on the links' environmental conditions and power supply; and simplifying maintenance and installation[11].

In a FTTH network, a central point, known as an access node or point of presence (POP), provides connectivity to the subscribers via one or more optical fibers. Each access node can connect to other access networks, for instance, wireless local area networks and mobile wide area networks. A FTTH network can be built as a part of wide area access networks. Depending upon the specific country's policies & regulations and the geographic location of the subscribers, FTTH networks are normally deployed in different sites, such as cities, residential areas, rural areas, and for single family and multi-family dwellings[12]. These different types of FTTH sites are shown in Figure 2-1. Regardless of the FTTH site locations, the fiber optic communication signals are generally terminated at the subscriber's endpoint.

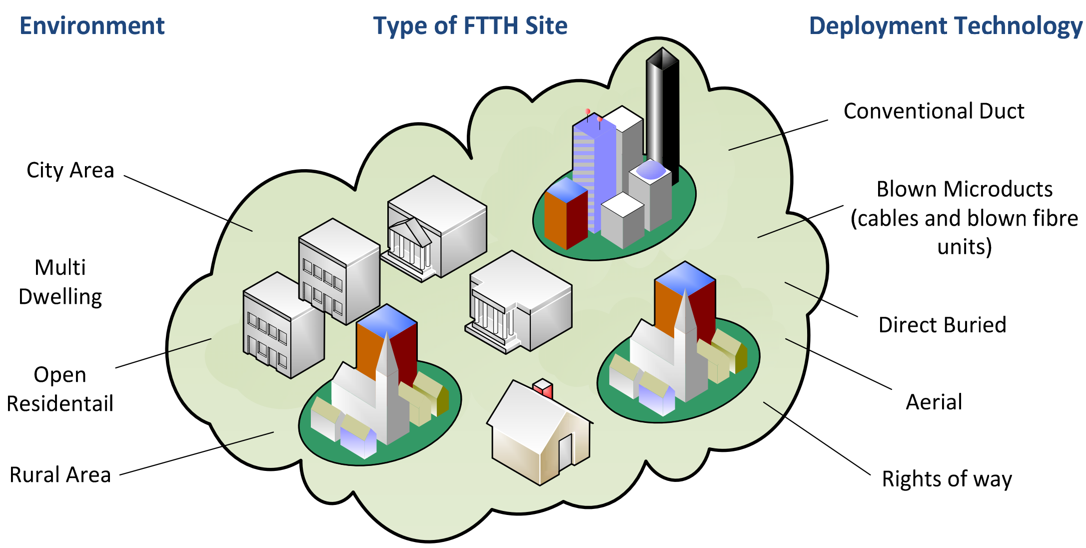

Figure 2-1: Types of FTTH sites

2.1.2 Fiber-based Access Network Architectures

In fiber-based access networks, depending upon the distance between the optical line terminal and the optical network units or optical network terminal, the fiber optic technologies can normally be classified into four types: FTTN, FTTC, FTTB, and FTTH (see Table 2-1). These are sometimes referred to collectively as FTTx networks, where x indicates how close the fiber endpoint is to the actual user, as illustrated in

Figure 2-2[13]. This study will mainly concentrate on FTTH, since in the long term this is considered as key target architecture due to its virtually unlimited scalability[12].

Table 2-1: FTTx variants

Fiber to the node (FTTN)	Fiber is terminated in a street, which is several kilometers away from the end users, with the final connection being copper. Fiber-to-the-node can be considered as an interim step towards full FTTH.
Fiber to the curb (FTTC)	Fiber reaches a street cabinet, similar to FTTN but the street is closer to the users, typically within 300m, within the range for copper technologies with high-bandwidth, such as wired Ethernet and IEEE P1901 power line networking, and wireless technology (e.g., Wi-Fi).
Fiber to the building (FTTB)	Fiber to the premises, for instance, reaches the basement in a multi-dwelling unit, with the final connection to the individual living space being made via alternative means, similar to the curb/pole technologies, but also possibly shorter-range technology like Thunderbolt.
Fiber to the home (FTTH)	Fiber reaches the boundary of the living or working space, such as a box on the outside wall of a home. Subscribers are connected then by a dedicated fiber to a port on the equipment in the POP.

We will analyze FTTH in this thesis, because we believe it is the ultimate solution as it can cope with growing consumer demands in terms of bandwidth, it can offer symmetric bandwidths with "future-proof" unlimited capacity, and because it will eventually make a difference in the way we live and work.

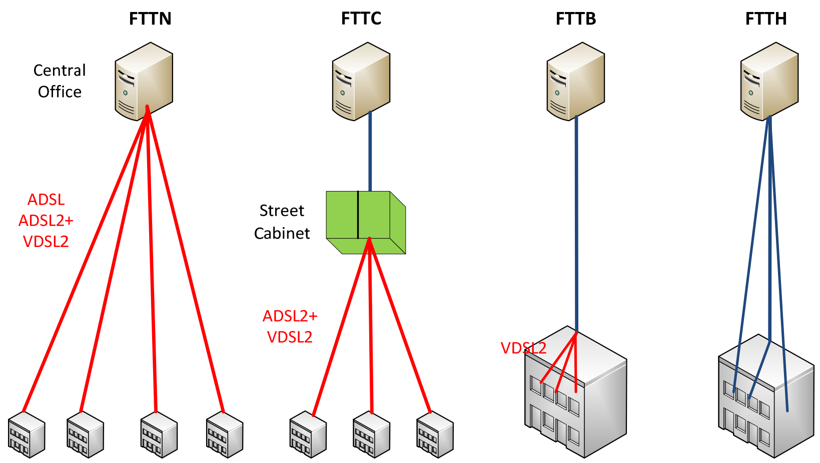

Figure 2-2: Different types of FTTx networks

2.1.3 FTTH Topologies

Two topologies are widely used in FTTH networks: point-to-point (P2P) topology (which normally uses Ethernet transmission technologies) and point-to-multipoint) topology (which is frequently combined with passive optical network (PON) technology). See Figure 2-3.

In P2P topologies each subscriber has a direct, uninterrupted connection to the access point or central office via a dedicated fiber (or fiber pair). Most P2P FTTH networks use Ethernet transmission technologies, since Ethernet is easier to configure and operate than other transmission technologies, especially for business applications. PON technology can also use a P2P topology by placing a passive optical splitter at the access point.

In point-to-multipoint topologies routing is accomplished optically using passive optical splitters with standardized PON technologies*. Only one fiber is needed in the shared feeder part in this architecture and time-sharing protocols are used to control the access of multiple subscribers[11]. In such a point-to-multipoint topology Active Ethernet technology can also be used to control subscriber by deploying Ethernet switches in the field.

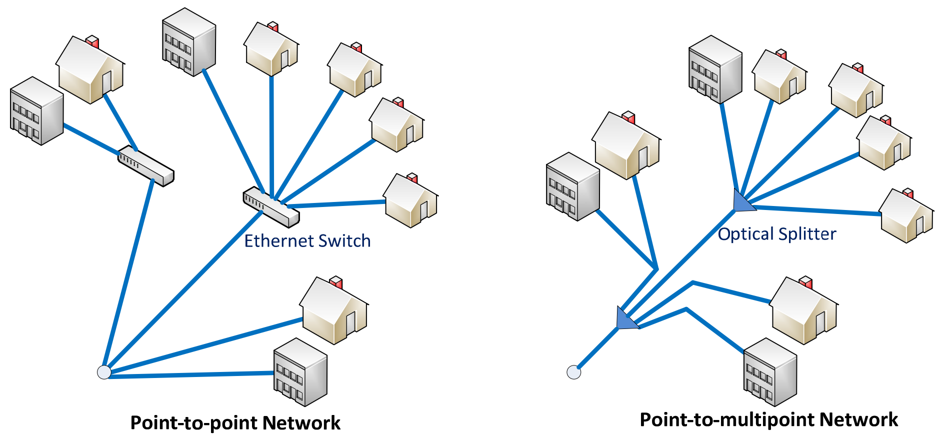

Figure 2-3: Point-to-point network and Point-to-multipoint network[12]

2.2 Why deploy Fiber-to-the-Home?

The world has witnessed the rapid development of the ICT sector and its impact on society. It is doubtless that improvements due to the use of ICT technologies will stimulate economic growth (e.g. in terms of increased gross domestic product (GDP), increased employee productivity, etc.) at a certain level according to [14–16]. Among various technologies, the enhancement of the telecommunication infrastructure has been vital to both technical and economic changes[17]. Since late 1990s, broadband deployments sparked scholars' interests into research on the potential economic impact of broadband access networks. Many of these researchers have highlighted the positive impact on the wider economy, such as [2,18]. Recent studies also indicates broadband is a driving factor that accelerates economic growth in terms of GDP, but the degree to which it does varies with the ICT maturity of the country[19–28]. The results of previous research on the economic impact of traditional broadband are summarized in Table 2-2.

* GPON is today's frontrunner standard in Europe, while EPON is most popular in Asia[12].

Table 2-2: Previous Research on Economic Impact of Traditional Broadband

Source	Covered Scope	Key Findings & Major Conclusions
[19]	Input-output calculation on impacts of investments in broadband in the German economy	To achieve 75% household broadband penetration of at least 50Mb/s access speed by 2014, 407,000 new jobs will be created. A 10 year investment in broadband (2010-2020) would lead to 0.6% increase in annual GDP growth.
[20]	Econometric investigation on productivity growth in 15 OECD nations (14 European nations, and USA)	Sweden has experienced the 2nd highest growth in broadband penetration among the target countries during 1998-2007. The economic impact of adding a broadband connection is greater in countries that have a good ICT environment and faster broadband diffusion. A 1% increase in broadband penetration results in a positive impact on GDP ranging from \$160 million/year in Finland to \$12 billion/year in USA.
[21]	Cross-sectional model covers data of 120 countries	Broadband has a significant impact on economic growth and the significance is greater in developed countries than in developing countries, due to a longer track record of broadband diffusion.
[22]	Effects of broadband penetration on Output and Employment: Cross-sectional data covers 2003-2005 period in 48 states of USA	Employment and Output in both manufacturing and services industries (especially finance, education, and health care) is positively correlated with broadband penetration. A 1% increase in broadband penetration is associated with an increase of ~300,000 jobs in the entire USA.
[23]	Instrument Variable (IV) regression approach on 20 OECD countries panel data covering 1996-2007 period	Positive impact on GDP per capita: an increase of 10% in broadband penetration would stimulate GDP per capita growth by 0.9% – 1.5% in subsequent years.
[24]	15 European Union countries' data between 2003-2006	There are increasing returns on broadband telecommunication investments, especially in Scandinavia countries.
[25]	Cross-sectional data of communities in USA, covers 1998-2002 period	Broadband enhances economic activities (e.g., establishment and economic growth in IT intensive sectors, job positions, residential property values etc.)
[26]	Econometric model on GDP per household for a developed country sample with panel data from 2005-2009	Positive direct effect on country GDP per household, especially in the high income samples. Significant effect on decreasing inefficiency.
[27]	From a technological and political perspective analysis on the impact of increasing broadband penetration on trade in Sweden, by means of regression analysis	High broadband penetration is highly correlated with a high level of international trade in the context of broadband access in Sweden, which leads to the conclusion that high-speed Internet access has a positive impact on the economy in terms of increased international trade.

One may argue why we still need fiber, as we already have traditional broadband access networks, which already have had a positive impact on economic growth, i.e., the benefits of fiber-based access networks seems could also be attained by traditional broadband technologies (e.g. Cable*, DSL†, Wi-Fi/WiMax, and 3G/4G) over the existing infrastructure. This question will be answered from several different perspectives, in the following subsections.

2.2.1 From a Technical Perspective

FTTH possesses the greatest capacity (due to its bandwidth) in comparison with the traditional broadband technologies (see Figure 2-4). The virtually unlimited capacity of FTTH and the characteristics of optical fibers enable the user's maximum data rate to **not decrease** with the distance between the access node and the end-user. Similarly the number of users who share the network does not have a large effect upon each of the user's individual maximum data rates. The guaranteed bandwidth and unprecedented reliability are far beyond what traditional broadband access networks can offer.

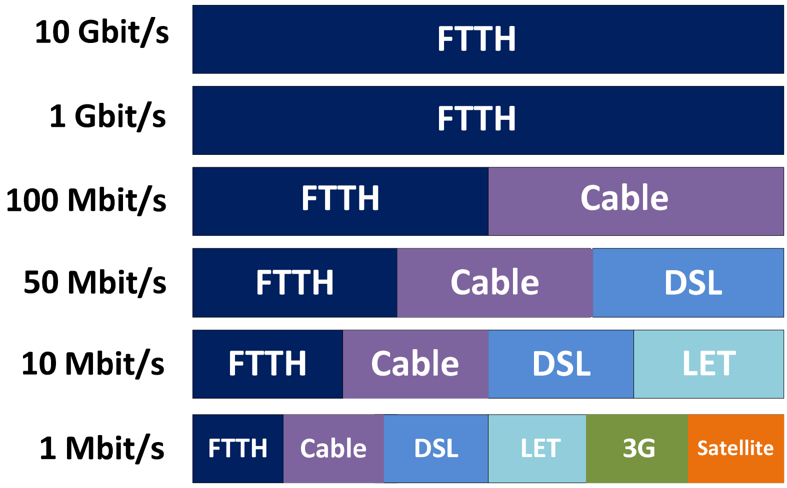

Figure 2-4: Various Broadband Technologies and Their Maximum Data Rates[28]

People have grown dependent upon digital resources, with enriched experience due to increasingly unlimited storage and bandwidth; hence the "future proof" FTTH is perfectly aligned to meet these demands. A study regarding the potential economic benefit of widespread diffusion of high-speed access broadband indicates that both consumers and operators can benefit substantially from broadband access networks. These result suggests the annual consumer benefits can eventually reach $300 billion and the operators could easily earn another $100 billion per year from increased demand for services via broadband access networks[2]. Compared with traditional broadband access networks, FTTH's superiority is expected to bring even greater benefits. The following paragraphs described some of these expected benefits for consumers and for operators.

* DOCSIS technology, which uses coaxial cable to carry both television and data signals connecting home users to the Internet[29].

† Often known as xDSL, which existing telephone lines (twisted pair wiring) are used[29], [30].

2.2.1.1 Benefits for Consumers

As to the user experience (UE), nothing could better fulfill consumers' demands than good reliability and high capacity. Fiber has proven to possess highest bandwidth and unprecedented reliability among all of the broadband technologies. As a result:

- Users with a 100 Mbps FTTH connection can download content over 10 times faster than users with a typical 8 Mbps ADSL connection.
- With higher bandwidth in the uplink **and** downlink directions, multitasking, passive-networking (multiple on-line applications running passively in the background) demands can be fully met.
- The higher reliability ensures a more personalized touch, as well as greater privacy and security per service and user.
- Multiple choices of fast Ethernet access speed, limited only by the speed provided by the ISPs.
- QoS and QoE are assured within the access network, enabling high quality reception of the content that previously would have been carried by broadcast radio and TV signals.
- Adaption to standard radio and TV equipment, subscribers can use set-top boxes or another type of converter for additional services.

Moreover, the stability of FTTH means that users suffering less downtime, thus FTTH users show the highest satisfaction level with their internet service than users of other access methods according to a study carried by Troulos[31]. This study reported that the percentage of satisfied users of FTTH was 85%, whereas cable users had a 75% satisfaction rate and DSL users only 60%.

The Next Generation Access service portfolio study[10] showed that higher bandwidth leads consumers to spend more time using existing Internet services, as well as giving them the ability to use new services. This study found that FTTH subscribers are net contributors to the Internet, uploading more material than they download, while utilizing 3~5 times more bandwidth than ADSL users. It also suggests that with increasing bandwidth, there will be greater demands for new services and the consumer will spend more time using existing services, thus driving consumer adoption of new services and potentially leading to new usage patterns of value added services, such as e-learning, distance working, high quality and reliable e-health services, simpler and more transparent interaction with public services (e-government), etc.

2.2.1.2 Benefits for Operators

In the massive and over-crowded telecommunications market, FTTH can be considered as a perfect Blue Ocean Strategy[32] for operators who can gain a strong competitive advantage, by providing better technical performance, more economic solutions in terms of low Capital Expenditures (CAPEX) and Operational Expense (OPEX), and a strategically superior platform that can offer differentiated services at a lower cost[33].

As a future-proof infrastructure, FTTH offers:

- Longer life-time

  Fiber itself is made of plastic or glass. The resulting fiber (and jacket) is robust and degrades extremely slowly, thus optic fiber and optic fiber cables can last in excess of 25 years (the uncertainty in this lifetime prediction is small[34] and is further supported by the fiber deployments that have already been in place for more than this period of time). When a bandwidth upgrade is needed, all one needs is to change the equipment on the ends of the fiber when the active equipment reaches the end of its lifespan, typically seven years (the same period as any other broadband technology). In contrast, alternative technologies (e.g. VDSL) have a limited operating life making payback challenging for the operator. No operators want to invest in repeated upgrades with a very short timeframe. As bandwidth demands increase rapidly with technological advances, fiber give service providers a future-proof network infrastructure with guarantees on bandwidth, versatility, and optimization that are needed for the future.

- Lower CAPEX and OPEX

  A FTTH network has significantly lower operating costs than existing copper or coaxial cable networks. Fiber is considered **the** medium for long distance communication, because the cost of transmitting a single phone conversation over fiber optics is only about 1% the cost of transmitting the same call of over a copper wire. Great bandwidths combined with lower operating cost bring long distance communication in line with network operators' large-scale using patterns. Additionally, fiber links are capable of supporting multiple protocols flexibly. The FTTH network consumes 20 times less electricity than a VDSL access network with the same number of subscribers. Fiber reduces the network operations and maintenance costs by simplifying control and troubleshooting, which leads to lowering the cost of hiring maintenance professionals since the process can be fully automated and software controlled.

- High competence on offering new services

  Communication over fiber gives service providers future-proof network infrastructure guarantees. With FTTH, richer services can be delivered to the subscribers in a multi-room and multi-screen approach, which will increase the demand for service assurance and remote management solutions for in-home services. The ability to offer new services is a strong competence requirement for service providers (SPs) to stay ahead in a highly dynamic and competitive market, and can eventually attract and retain consumers with faster access data rates and enriched QoE.

- Capacity to meet future demands

  Flexible network architecture design, excellent scalability, and relatively mature functionality (e.g. for P2P) allow fiber-based access networks to easily support future upgrades and expansion. Utilizing a passive optical network maximizes the capacity availability for future service demands, by directing connecting each end user to the operator's active equipment. The tradeoff between technical and economic demands facing network owners and operators can be met with FTTH.

2.2.2 From a Socio-economic Perspective

FTTH has been an important ingredient in telecommunication operators overall investments, but there is a lag in turning these investments into tangible returns. Previous studies examining the benefits of fiber were mainly done as a cost benefit analysis, which usually compares initial investments and OPEX to consumers' willingness-to-pay for certain services from traditional telecom perspective [6,28,35,36]. However, such a qualitative calculation of benefits may result in an *underestimation* of potential benefits, because it neglects some factors that may be beneficial for improving social welfare, these factors are referred to as un-captured values[37].

From Table 2-2 we can conclude that broadband has strongly contributed to people's well-being in many ways. However, even from the limited number of previous qualitative/quantitative studies we can see that fiber access networks have contributed even more, both socially and economically, to many dimensions of life, for instance, the population's evolution, education, health, distance working, employment, etc., as summarized in

2.2.2.1 Benefits for Companies in General

As mentioned in section 2.2.1.2, the stakeholders in a FTTH network can benefit from lower CAPEX and OPEX. Besides lower telecommunication costs, the adoption of an open access business model for fiber network results in greater competition among network providers (NPs) and SPs (depending on the level of openness), which brings greater benefits to the consumers in the form of multiple choices and higher QoS at lower prices, while increasing the provider's average revenue per user (ARPU).

Companies that adopted fiber have more competitive advantages as comparing to non-adopters. FTTH enables innovation and new business opportunities in the knowledge economy, driving enterprises and organizations to adopt new business models and marketing strategies. More on-demand enterprises, such as virtual companies emerge, creating more job opportunities and introducing new ways of working. For employees FTTH saves a lot time and cost for travel between the home and workplace(s), hence employees can better manage their time and increasingly work from home (e.g. two or more days per month[40]), contributing to higher productivity for the companies. Companies' competitiveness is enhanced, while reducing a lot of costs (such as for rental of physical office space).

For housing companies, competitiveness improves as well with FTTH. The presence of FTTH increases the value of a property, therefore attracting more people to move in.

Table 2-3.

According to these earlier studies, the resulting indirect and induced benefits of increasing FTTH penetration can be categorized in detail from different social beneficiaries' perspectives. These are described in the following subsections.

2.2.2.2 Benefits for Companies in General

As mentioned in section 2.2.1.2, the stakeholders in a FTTH network can benefit from lower CAPEX and OPEX. Besides lower telecommunication costs, the adoption of an open access business model for fiber network results in greater competition among network providers (NPs) and SPs (depending on the level of openness), which brings greater benefits to the consumers in the form of multiple choices and higher QoS at lower prices, while increasing the provider's average revenue per user (ARPU).

Companies that adopted fiber have more competitive advantages as comparing to non-adopters. FTTH enables innovation and new business opportunities in the knowledge economy, driving enterprises and organizations to adopt new business models and marketing strategies. More on-demand enterprises, such as virtual companies emerge, creating more job opportunities and introducing new ways of working. For employees FTTH saves a lot time and cost for travel between the home and workplace(s), hence employees can better manage their time and increasingly work from home (e.g. two or more days per month[40]), contributing to higher productivity for the companies. Companies' competitiveness is enhanced, while reducing a lot of costs (such as for rental of physical office space).

For housing companies, competitiveness improves as well with FTTH. The presence of FTTH increases the value of a property, therefore attracting more people to move in.

Table 2-3: Previous Research on Socio-economic Benefits of FTTH

Source	Covered Scope	Key Findings & Major Conclusions
[4] [28]	Multivariate regression analysis on effect of FTTH/FTTx in Sweden on employment and population evolution, based on data from 290 municipalities between 2007-2010	Fiber networks are showing statistically significant socio-economic impact with a lag of three years. A 10% increase in population living within 353 meters of a fiber-connected area has a 0.25% positive change in population after three years, and a 0% – 0.2% positive change in employment after two and a half years. Cost benefit analysis suggests that a total of 56 billion SEK invested on FTTH (with 30% fiber penetration) in Sweden will lead to an increase in GDP of up to 52 billion SEK.
[5]	Qualitative studies based on interviews (2009) in Sweden and an analysis of the Eindhoven study	Fiber deployment brings distinct economic and social benefits to health, education, and other public services; it stimulates new ways of working and leads to GDP growth.
[7] [31]	Qualitative assessment based on surveys (2009 and 2010 respectively) in Bulgaria	FTTH users in 2009 had an average of 10% additional benefit compared to non-adopters. FTTH/FTTB users have the highest satisfaction level of all broadband users. FTTH/FTTB encourages distance working (tele-working). In 2010, 66% of Bulgarians agreed that availability of high-speed broadband connectivity affects their selection of a residence.
[38]	Quantitative cross-sectional analysis for 16 experimental communities and 16 matched control cities in USA, between 1998-2002	Potential economic improvement (e.g. annual employment rate, mean annual household income, and educational attainment) could arise if FTTH is present in a community. Indicators, such as annual employment rate, mean annual household income, and educational attainment, are significantly higher in cities that have adopted FTTH than in cities that did not adopt FTTH.
[39]	Cross-sectional data covers 25 countries over the period of 1999-2009	FTTx broadband has a positive impact on economy growth.

2.2.2.3 Benefits for Municipalities, Public Bodies, and Communities

The participation of public authorities in FTTH deployment will positively contribute to the social cohesion, and the promotion of FTTH would boost the degree of urbanization of a municipality, thereby enhancing its local competitiveness and attractiveness.

At a local level, efficient governance can be achieved with the adoption of FTTH. Public utilities can improve their intelligent power grids, while efficient public transportation control can reduce traffic congestion and cost of infrastructure maintenance. Public services can be delivered in an intelligent and efficient way that reduces (at least some) administration costs.

Closer collaboration in building up/sharing fiber networks (e.g. *Stadsnät*[*]) among municipalities, communities, and other public sectors, can consolidate social and business relationships, while providing a cooperation platform for new business opportunities and networked public services. This is especially good for rural areas, which could benefit to a greater extent from newly established business and investment, bring increased economic attractiveness in terms of increased job opportunities, increased immigration, and increased tax revenues while reducing welfare expenditures.

2.2.2.4 Benefits for Society at Large

FTTH is a key economic driver that indirectly generates an overall annual increase in GDP of a country, through various enhanced and newly attracted business - as well as through new investment. FTTH is cost-efficient in delivering public services, and can already save up to 1.5% of costs in the four main public economic sectors – Electricity, Transportation, Education, and Health, besides the direct benefits to the telecommunication industry[40].

High-speed network access and increased ICT maturity improve the way people live and work. An e-learning services pool of educational resources benefits knowledge seekers without limitations in time or space. E-health supports remote diagnostics, improving healthcare services with higher efficiency in information sharing and treatment. E-governance brings transparency of authorities. Distance working reduces physical transportation, resulting in reduced traffic congestion. People’s safety in traffic is enhanced while contributing to GDP with high productivity, and the increase in job opportunities leads to higher regional attractiveness in terms of increased immigration, especially of skilled labor. E-entertainment and social networking changes the way people entertain and communicate, while broadening their social groups, enrich their cultural and social experiences. All these effects have directly and indirectly improved people’s wellbeing in terms of their quality of life leading to a higher degree of satisfaction, while stimulating further innovation in public services. Together these effects produce visible economic growth and ultimately drive positive societal development.

2.2.3 From Environmental Perspective

Fiber is a green technology that supports the transportation of data over one cable and one network, ecologically eliminating the waste of raw materials, unnecessary parallel infrastructures, and extra power provisioning, which would be needed for other communication infrastructures. Unlike others, its future-proof characteristics minimize the environmental damage of future upgrades. Therefore the ecological contribution of FTTH is considered as a vital sustainable utility driver for low carbon economic development, as every one million users connected to FTTH save at least one million tons of CO_2 [40], thus utilization of FTTH can save equivalent CO_2 emission of 4,600 km car driving per year per household[41]. Furthermore, the FTTH induced effects of reduced commuting and reduced public traffic congestion as well as lower power utilization; positively contribute to a large extent to sustainable environmental development.

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[*] Indicates the municipality fiber networks. We will use this term - *stadsnät* - throughout the thesis.

2.3 Current Status of Fiber Penetration

According to OECD statistics, fixed broadband subscriptions reached 314 million in the OECD area by the end of 2011. The overall share of DSL subscriptions continued to decrease to 55.8% with coaxial cable having a penetration rate of 30%, while FTTH subscriptions represent 13.7% of the total number of fixed broadband subscriptions[8]. A FTTH/B panorama across 35 countries in Europe, shows an increased average fiber take up rate of 18.4%, indicating FTTH/B is expanding its coverage with a 28% positive growth in FTTH/B subscribers and rollout progressed at an annual rate of 41% in 2011[9,42].

Specifically within Sweden, broadband subscriptions reached 8.2 million out of 8.4 million total subscriptions for Internet services at the end of 2011[43]. A total of 39.54% of all households and 34.81% of workplaces had access to fiber by October 2011, corresponding to a increase of 6.50% and 7.62% (respectively) in comparison to October 2010[44], making Sweden the OECD-EU country with the highest proportion of fiber and fiber LAN subscribers out of all fixed broadband subscribers[9,45], as shown in Figure 2-5.

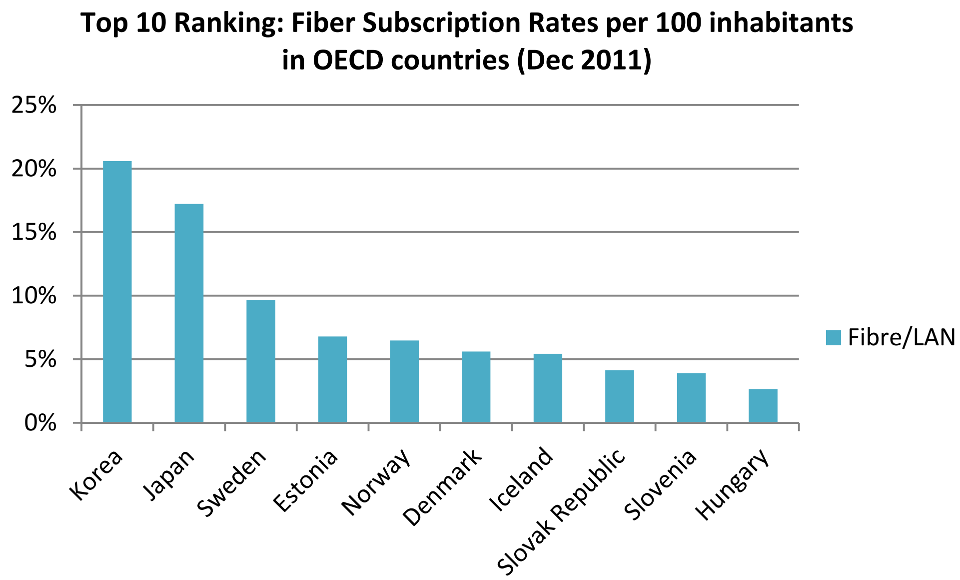

Figure 2-5: Fiber Subscriptions per 100 Inhabitants in OECD Countries (as of December 2011) [46]

Moreover, one can see from Figure 2-6 that in Sweden the number of DSL subscriptions is decreasing, while fiber subscriptions constantly increased, especially in the last three years. This phenomenon follows the broadband development trend, that copper-based access networks are on the way out, while fiber is continue its rolling out as the most important alternative fixed platform[47]. This is due to fiber's ability to cope with the increased demands of consumers over time.

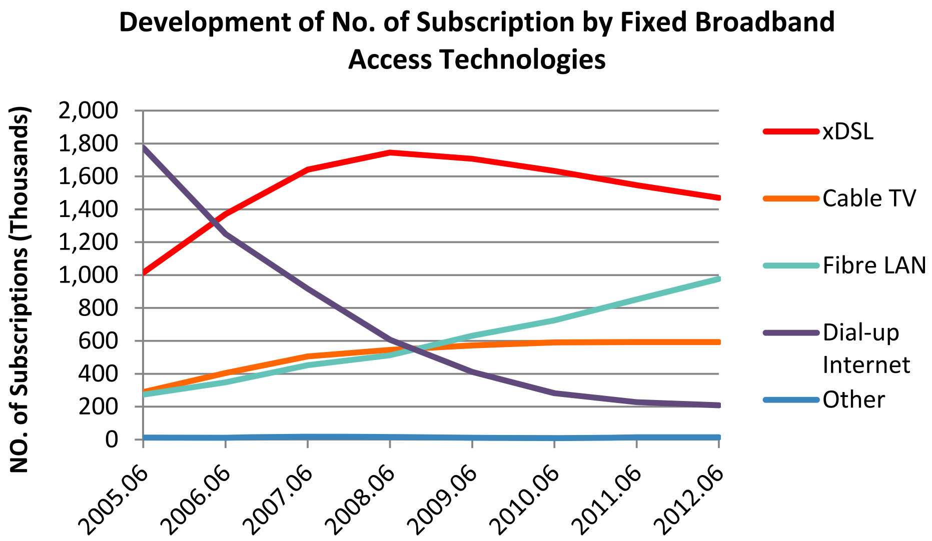

Figure 2-6: Development of Number of Subscriptions to Fixed Broadband* by Access Technologies in Sweden [48]

Figure 2-7 vividly illustrated the fiber penetration at county (Län) level in Sweden. In Figure 2-7(a) the green areas indicate existing fiber connectivity, while the blue areas indicate newly connected areas (between October 2010 and October 2011) with coverage at workplaces and households. It can be noticed that fiber deployment has a large geographical variation in densely populated areas and sparsely populated areas. Most newly fiber-connected areas are found on the west coast, in the southern part of *Värmland County*, and in *Stockholm County*. More specifically, ***Sundbyberg*** municipality (Kommun) in Stockholm County possess the highest penetration of fiber accessibility in workplaces and households among all 290 municipalities in Sweden, while there is only one municipality that seems to completely lack fiber access[44].

Figure 2-7(b) illustrates fiber penetration in terms of access availability. Most regions are having at least 10%~40% of availability to access fiber as the orange areas have the largest proportion. This is in line with the general access performance of fixed broadband in Sweden, with a grown availability (accounting for 52.4% of all subscribers) of 10+ Mbps connectivity[47]. Based on the current fiber deployment trends, Sweden is forecasted to reach fiber maturity by 2014[42, 49], accompanied with a strong political interest in FTTH networks, as the increased broadband penetration is favorable for social and economic development. This interest has directly or indirectly translated into government engagement in the deployment of open access fiber networks in municipalities over the past 10 to 15 years.

* Fiber here includes fiber to the building + LAN within the building.

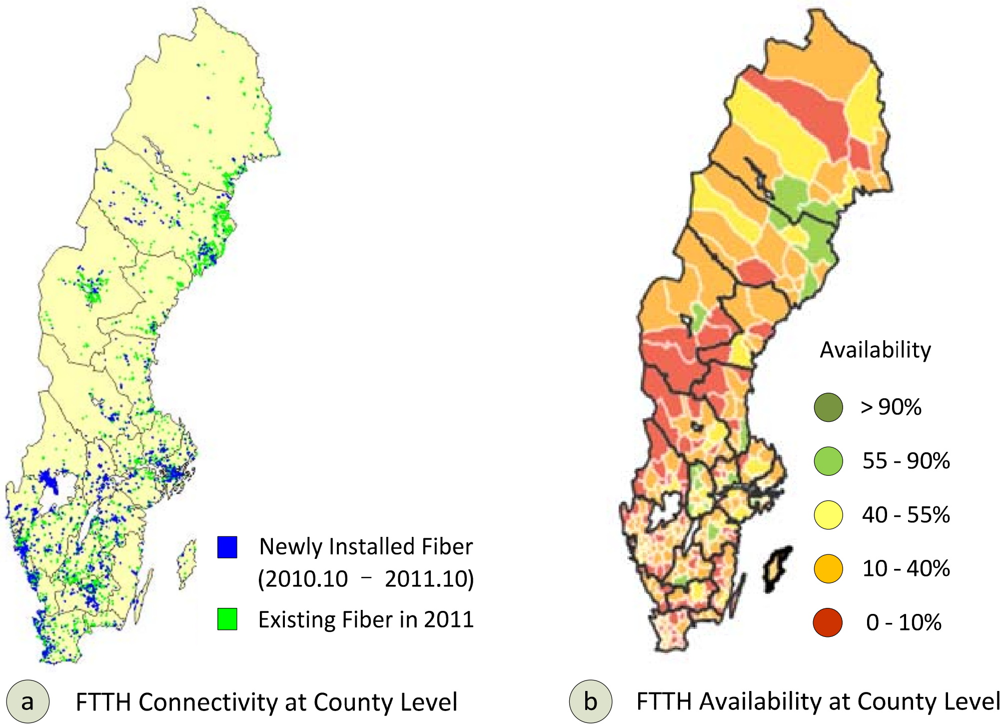

Figure 2-7: Fiber Penetration at the County Level in Sweden (publicly available at PTS website [44], [50])

2.3.1 Determinants of Fiber Penetration

The deployment of fiber in a country is determined by various factors, such as:

- Industry factors

  In the highly competitive telecommunication industry, access technologies with better performance but lower cost would always be the best option from both supply and demand perspectives. Thus *technological competition* and *low cost of deploying infrastructure*[51] would be the key factors influencing the adoption of high-speed broadband access networks, such as FTTH. Combined with high *access data rates*, low *price* is also an important factor contributing to the high level of broadband penetration as studied in [52–54]. The price may strongly affect consumers' decisions of which access technology to adopt.

  The lower cost of deploying infrastructure would be an advantage to attract greater *investment* in network deployment from both private and public sectors. Sweden has employed infrastructure investments from both private and public sectors as its national broadband deployment strategy[55, 56].

- Socio-demographic factors

  Several studies has shown that *population density*[57], younger *age*[52, 53], *urbanization*[58], and the *presence of children*[59] are influential factors driving the penetration of high-speed broadband access.

In addition, households with higher *income* and higher *educational level* prefer to have higher speed access technologies[60, 61]. These factors are therefore believed that would influence the adoption decision of FTTH at a certain degree.

- Policy factors

  The Swedish broadband market is regulated subject to the supervision of the Swedish *National Regulatory Authorities (NRA)* – Post och Telestyrelsen (PTS)[47].

  The *involvement of local government* has been an increasingly important factor in the evolution of the "last-mile" infrastructure[1]. Many municipalities in Sweden have adopted policies to promote FTTH. Their initiatives to deploy municipal FTTH networks have brought tangible economic benefits back to them and made Sweden successful in overall rate of fiber penetration.

  The Local Loop Unbundling[*] (LLU) policy has influenced fix-broadband deployment according to a regression analysis on OECD data[63]. This may bring consumer benefits through open access to competitors in a relatively short term[64].

- Other factors

  There are many other factors that may also have impact FTTH penetration, such as *user behaviors* (e.g. PC, Internet, … usage), *network size*, *service level, available content,* etc. These factors also influence the fiber penetration rates.

Note that while these factors influence the rate of fiber adoption, they may also interact intimately in a complex way.

2.3.2 Open Access Network

To date it is estimated that 95% of the municipal fiber networks in Sweden are operating with an open access model[65]. The traditional telecommunication model is vertically integrated with a single entity that delivers a service, operates the network, and owns a network infrastructure that is dedicated to specific (telephony, radio, and television) services. Considering the specific geographical conditions of Sweden (i.e., that is large in area with 85% of population densely live in urban areas, while 15% live in more sparsely populated areas[45]), it is highly inefficient and unprofitable for traditional large operators to provide broadband access at sustainable prices in remote areas. However, the need for broadband access is as great in these rural areas as in other areas of the country. Therefore a large number of rural municipalities have deployed open access fiber networks, because the open access model is *sufficient* to meet their specific demands. Some of these municipal networks have formed regional associations to connect to different networks, in order to facilitate access by their users to various service providers and wholesale market actors.

Unlike the traditional telecommunications business model, the open access model maximizes the consumer's benefits in terms of freedom of choice and presents the highest degree of competition on equal terms in order to avoid monopoly behaviors, by separating the roles of service provider and the infrastructure & network

[*] Includes all types of LLU: full unbundling, line sharing, and bit stream access[62].

provider[66]. Due to different nature (both technical and economic) of the different parts of the network, the open access model also optimizes resource allocation for a passive infrastructure and active equipment by further separating the roles of physical infrastructure provider (PIP) and network provider (NP). The PIP (e.g. municipalities or utilities) typically owns a passive infrastructure and takes care of its physical maintenance, as the PIP is normally highly local. A passive infrastructure requires high initial CAPEX, low OPEX, and is hard to duplicate and inherently subject to regulation[65]. The NP (e.g. incumbent operators and broadband companies), on the other hand, usually operates nationally with large economies of scale; hence they can afford the high OPEX of running the active equipment.

Figure 2-8[65] exhibits a typical value chain of the open access model. The PIP builds up the physical infrastructure of the network, lays cables to the premises of end users and charges a monthly connection fee to the NP for providing network access to the NP. In some cases end users pay a one-off connection fee of ~15–20 thousand SEK to the PIP in order to get their single home (i.e. a villa) connected; whereas in case of multi-dwelling units, especially if it is a public housing company, the end users pay ~47 SEK per month to their landlords for the FTTH connection[28]. The NP in the value chain provides users with access, ensures correct network operation, and receives revenue by allowing different SPs to offer services to end users via their (logical) network. In reality, the network is open at different levels depending on which roles different market actors take, and different business models will arise, as illustrated in Figure 2-9.

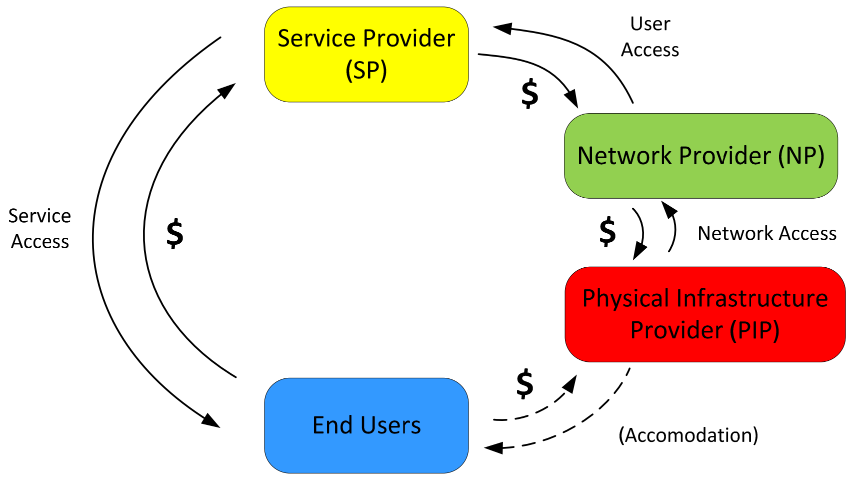

Figure 2-8: Typical Open Access Value Chain

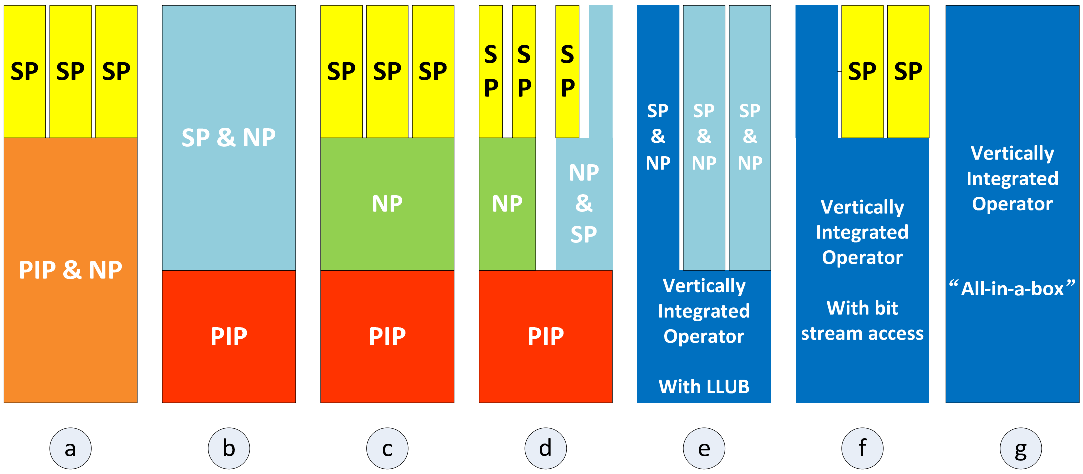

Figure 2-9: Different Open Access Network Models[65]

Swedish fiber-based access networks have matured considerably and have progressively changed from vertical integrated model towards open access models over the years. For example, TeliaSonera is the biggest incumbent with the highest market share in the Swedish telecommunications market. It originally operated as a typical vertically integrated operator (as do most incumbents worldwide) and controlled the whole value chain from fiber infrastructure to network services (as in Figure 2-9(g)). However, today TeliaSonera also finds it profitable to utilize the open access model in different ways. For example, it opens its network at service level, e.g. ***Telia Öppen Fiber***, to allow other SPs to provide attractive services and contents as in Figure 2-9(a), while Telia also offers its own services over the open fiber network, as in Figure 2-9(f). Telia's LLUB allows multiple actors to work as combined NP and SP (for bundled services, e.g. Triple play), then the model becomes the one shown in Figure 2-9(e). To compete with other NPs, TeliaSonera operates ***Stadsnät*** as well, in which by collaborating with municipalities (PIP) who owns a network, Telia acts as NP and takes care of handling the SPs' (e.g., attracting SPs), thereby openness at the infrastructure level is achieved as the roles of PIP and NP are separated, see Figure 2-9(c, d). If the NP acts as a SP as shown in Figure 2-9(b), the network is not really considered open as there is no competition at either the infrastructure or service levels, and thus the end users have no choice but to subscribe to this single operator. However, on the other hand it is still open because similarly to Figure 2-9(c), the PIP can decide which NP & SP they want to cooperate with for a fixed period of time, when this contract ends the PIP may choose another NP & SP to work with – although the active equipment may need to be replaced.

The Swedish fiber network market is not fully mature yet, but many municipalities have realized that they should focus on providing infrastructure rather than competing with commercial telecommunication companies, thus they have downwards in the value chain. Note that the definition of "open" is flexible and may vary to allow more subdivided roles with different network actors each operating in their own level of the network.

3 Methodology

Unsurprising there is little econometric analysis done regarding the impact of fiber penetration, given the fact that relatively few fiber-based access networks have been deployed and methodological limitations pertaining to data availability, measurement, and time lag issue exist. However, Sweden has deployed many fiber-based access networks during recent years. For this reason, if there are any effects they should already have produced some tangible socio-economic effects that can be quantified with a large number of indicators. Therefore we collected data at a municipality level (specifically, for the 290 municipalities in Sweden) to obtain a large enough set of observations for a high quality multiple regression statistical analysis of selected effects.

3.1 Selection of Parameters

The deployment of FTTH may bring a number of benefits, directly or indirectly impacting various aspects that in turn would induce additional positive effects on society and the economy as a whole, as illustrated in Figure 3-1.

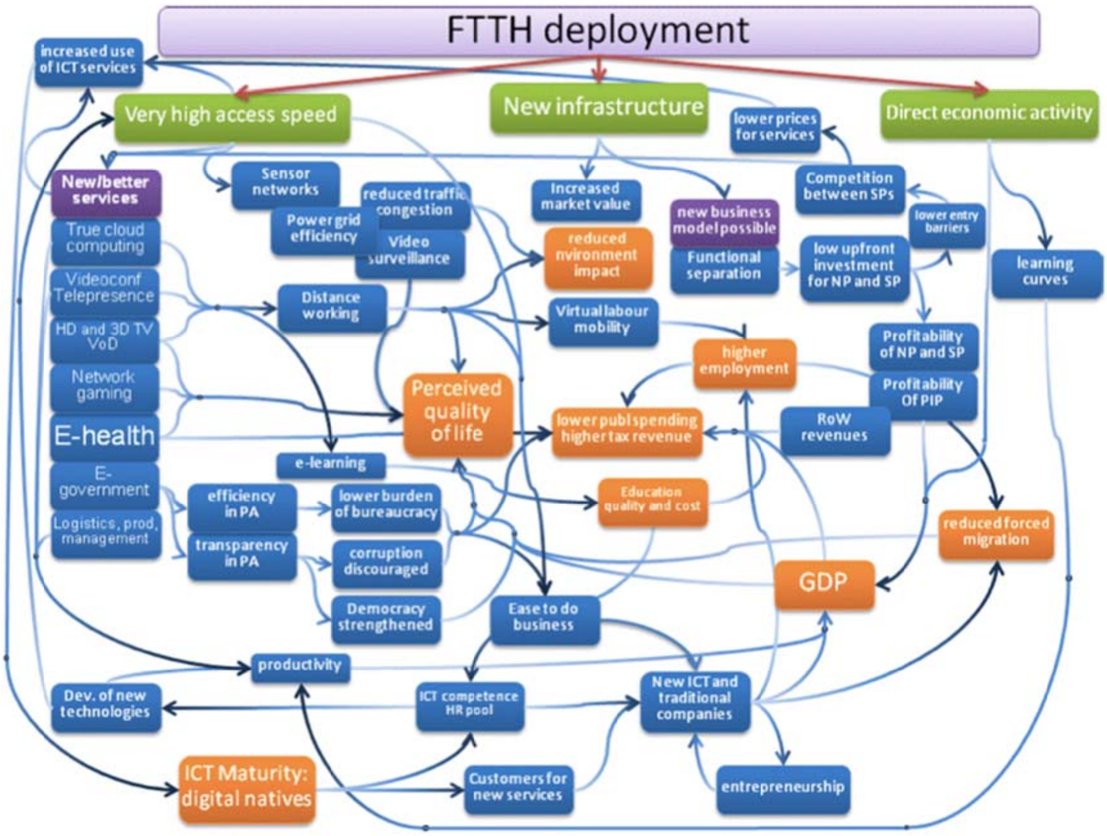

Figure 3-1: Effects of FTTH Deployment [28]

Figure 3-1 shows the complex interaction of the various effects of fiber deployment, which effects are basically categorized to three types: high access speed, new infrastructure and direct economic activity. Note that there may be time lag for some of the effects (especially for the indirect and induced effects) to be tangible with respect to technological innovations, and there is no theoretical evidence can aid in determining the precise time lag. To ensure the hypothesis is testable with available data and in light of issue of time lag, a number of quantifiable effects were selected as the focus in this study, including:

- Population evolution
  In addition to the original population trend, we consider that the utilization of FTTH may increase the attractiveness of a municipality, attracting people to move to the municipality instead of moving out. The effect on population change is not instantaneous and may show up with a delay. We have to carefully avoid the potential problem of backward causality. The population evolution is subdivided into *excess of migration* and *birth rates*, as these are the two the main components of population change.
- Competition and price of Internet services: savings/added value for individuals
  Considering that the open access model of FTTH network has led to a functional separation of SP, NP, and PIP roles, the highly competitive open environment may benefit consumers in the short terms with better services at lower prices. In this study the price is computed as the number of SPs offering 10/10Mbps access services that compete in the same fiber network.

3.2 Econometric Methodology

The classical methodology in economics[67] was adopted for this empirical research. We stated an initial hypothesis, specified the mathematical model and extended this model to an econometric model, then we obtained the data, estimated the parameters of the model to test the hypothesis. Following this we were able to make a prediction based upon the current trend and thereby drew a conclusion.

As to the statistical analysis, a large amount of relevant data for the 290 municipalities of Sweden was collected. We related fiber penetration to our selected socio-economic indicators in order to find out how things have changed over time in these municipalities. In addition to fiber deployment, the socio-economic development of a municipality also depends on many other variables. Therefore a reliable analysis on the impact of fiber penetration must be based on a model that takes as many relevant factors into account, and for that reason multiple regress analysis* [67] is used. The regression model is described as a function shown below:

$$\boldsymbol{Y = f(X_1, X_2, X_3, \ldots, X_N)}$$

Equation 3.1

Y is a dependent variable that denotes a function of the explanatory variables X_n. In our study, Y is assumed to be a linear function of X_n. The X_n are the various factors that we believe have an impact on the socio-economic indicator (Y) that we want to explain.

Such a model must be evaluated in terms of how well it reflects reality through observations of the measurement collected from these municipalities. Given the probabilistic nature of these factors (e.g. there is an inexact relationship between the economic variables), the difference between Y and $f(X_1, X_2, X_3, \ldots, X_N)$ gives a disturbance term: μ, which represents all those factors that affect Y but were **not** explicitly taken into account due to some limitation of the model or possible measurement errors[67].

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* Also known as Multivariate regression analysis.

In our study *Equation 3.1* is written as a multivariate linear function of parameters over which we want to optimize, generally by means of Ordinary Least Squares (OLS). In this way the sum of the square of μ for all observations is minimized. *Equation 3.1* will be presented in exact form in Chapter 4, where the analysis of the effect of fiber deployment and some other influential socio-economic factors is performed.

3.3 Data Processing

As a large dataset was essential for this research approach we needed to collect a suitable amount of data. Due to limited data availability the data was hard to collect, hence data had to be collected through multiple channels. The collected data was processed and stored in a database for stability and security purposes. This data was employed in the regression analyses.

3.3.1 Data Collection

Data used in the analysis was mainly collected through four ways:

- Online database of Statistics Sweden (Statistiska Centralbyrån - SCB)

  Socio-economic and demographic data (e.g., *degree of urbanization, population, regionalism, etc.)* was obtained from SCB's annual reports and their statistical database[68].

- Online database of Swedish Post and Telecommunications Authority (PTS[*])

  The data for the telecommunication industry (i.e., *fiber penetration*) was collected from PTS's online database[44], where fiber penetration in each municipality of Sweden in 2007, 2008, 2009, 2010, and 2011 is provided. However, the data for fiber penetration is only available from 2007 (i.e., no earlier data available), and is defined differently by PTS as *percentage of population living in or within 353 meters from a fiber-connected premise*[†] prior to the year 2010 (i.e., 2007-2009). Since then (i.e., 2010 and 2011) fiber penetration is measured based upon the *percentage of population with effective access to broadband via fiber or fiber LAN* [‡], typically fiber connected to the households (FTTH) or terminated in the basement while households are connected with dedicated CAT 5 Ethernet cables within the building (i.e., a point-to-point network) in a FTTB deployment.

- Data collected manually from SPs, NPs, and Municipalities' websites

  Information concerning the main business sectors in the FTTH market (e.g., *number of SPs, prices of subscribing to fiber-based Internet services, various fiber networks*) is scarce, vague, and decentralized, and no integrated source was readily available. To ensure the accuracy and reliability of the data to be analyzed, the relevant data at a municipal level was manually collected using a joint search method, which was extensive, complex, and exceptionally time-consuming, but was carefully crafted to enable a more precise determination of the impact of fiber deployment.

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[*] PTS – Post- och Telestyrelsen

[†] In Swedish: "Andel i eller inom 353 meter av en fiberansluten fastighet ".

[‡] In Swedish: "Andel med faktiskt tillgång till bredband via fiber eller fiber-LAN".

Different fiber networks operated by different NPs have different competition and different numbers of SPs. Initially we identified different fiber networks (mainly *Öppna Stadsnäts*) operated by various NPs in each municipality, as well as a number of the main competitors offering equal services (specifically focusing on 10/10 Mbps symmetric broadband access via fiber, since this access speed is available in most areas in Sweden) in the same fiber networks. Then we collected the service details (e.g. *service price, binding period, notice period,* etc.) of each SP for different fiber networks via the NPs' websites. We compared the service details in each municipality with the information that was provided at each SP's own website. Specifically, the service price was collected and calculated depending on what business model each NP was following. Two major models were identified. For model 1 the NP charges a network connection fee to SPs, which of course is passed on to the end users; hence the service prices found on the SPs' websites were considered. Whereas for model 2, the NP directly charges end users a network connection fee, hence the final price is the sum of the service fee available on SPs' websites plus the connection fee found on NPs' websites. Nevertheless, the substance does not really change. Moreover, campaign prices were not considered in either case. Instead, the original price for subscribing for the same service was used in order to treat each SP equally. Afterwards for unmatched or unclear information, we double-checked via the municipal websites (including municipal owned utilities) and contacts, to verify the information. All the details collected were the latest information for the second half year of 2012.

- Other data sources

  To clear up some of the contradictions in the price details and to ensure the information we collected is correct, we verified it through contacts with key players from *stadsnät*, NPs and SPs, municipalities and power utilities, as well as with the PTS.

3.3.2 Applied Tools

This subsection describes the details of the tools used for storing the data and for the data analysis.

3.3.2.1 Tools for data storage

The collected data was originally stored in Excel sheets until it was realized that this method would not be sufficient stable and secure enough for large-scale storage or future updates to this collection of data. For this reason a database was established and stored on a local server with a suitable configuration. The collected data was saved as a .csv formated file and imported into a MySQL™ open source database with Python™ scripts. The application phpMyAdmin was used for administration of the database. Figure 3-2 illustrates the phpMyAdmin web interface to our database.

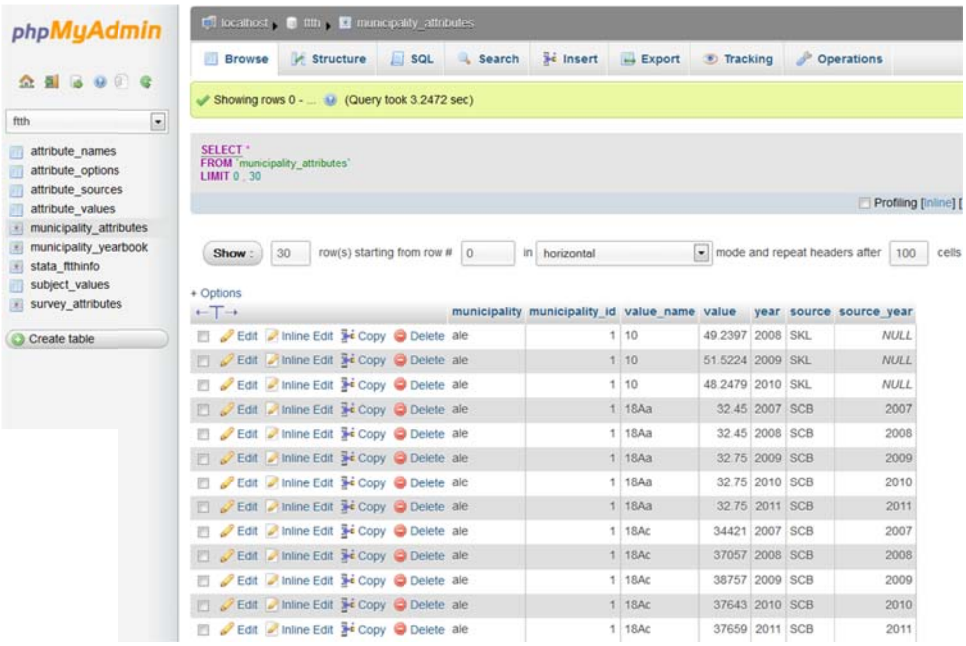

Figure 3-2: Screenshot of the phpMyAdmin GUI to our database

3.3.2.2 Tools for data analysis

There are a number of programs available for statistical analysis. Stata® was selected as the main tool in this study, due to its strong capabilities for data management, and compatibility with ODBC* and SQL†. It provides the necessary statistical analysis, and offers a user-friendly interface. However, it cannot import data from multiple sheets (without starting with a clear dataset) and bcause a large dataset containing all the needed variables from our different sources is essential, Python™ scripts were written to load the desired set of data from our MySQL™ database and merge it in to a dataset (even in the existing work set) in Stata®, along with detailed information about the attributes. Matlab® was also used as an auxiliary tool for benchmarking.

* ODBC – Open Database Connectivity [69]

† SQL – Structured Query Language [70]

4 Analysis and Results

Given the expected extensive benefits of FTTH deployment, this chapter relates the theoretical framework to the empirical data for the analysis of the indirect socio-economic benefit of FTTH penetration, with respect of population evolution and network service price, by means of econometric models.

Extending the logical boundaries of an overall positive impact of broadband development on various dimensions of the society and economy, it is rational to propose the hypotheses that: *The promotion and utilization of FTTH infrastructure would enhance the attractiveness of a municipality, particularly in terms of increased population change; and an FTTH network open to several market players leads to reduced Internet service prices*. The hypotheses are tested in the following sections.

4.1 Population Evolution

The trend of population evolution is affected by various factors, which may influence the attractiveness of a municipality. One of these factors could be the availability of fiber infrastructure – as we argued in section 2.2, that more fiber can lead to more job opportunities and better social welfare, which are important to attract people to move into a municipality and to discourage people from moving out. The hypotheses to be tested are formally stated as:

H_0 **:** FTTH penetration does **not** contribute to the population evolution in Sweden.

H_1 **:** FTTH penetration does contribute to the population evolution in Sweden.

The evolution of population size is considered to have a tendency to continue in a trend, unless something else happens[71] , i.e.:

$$\frac{\boldsymbol{P_t}}{\boldsymbol{P_{t_0}}} = \left[\frac{\boldsymbol{P_{t_0}}}{\boldsymbol{P_{t_0-T}}}\right]^{\boldsymbol{\kappa_P}}$$

Equation 4.1

Where κ_P is a factor defining the linear trend, and tends to be $\boldsymbol{(t - t_0)/T}$.

This trend may be influenced by various factors, such as tax rate, economic situation in the region, etc. The effect of these factors can be considered as contributing to the increase or decrease of the population, which therefore would be translated into an exponential term in our equation:

$$\frac{\boldsymbol{P_t}}{\boldsymbol{P_{t_0}}} = \left[\frac{\boldsymbol{P_{t_0}}}{\boldsymbol{P_{t_0-T}}}\right]^{\boldsymbol{\kappa_P}} \boldsymbol{exp\{\kappa_1 X_1 + \kappa_2 X_2 + \cdots + \kappa_n X_n\}}$$

Equation 4.2

By taking the logarithm on both sides of the equation, a simplified model is obtained:

$$\boldsymbol{\Delta P_{i,(t-t_0)} = \log P_t - \log P_{t_0} = \kappa_P \Delta P_{i,(t_0-T)} + \kappa_1 X_1 + \kappa_2 X_2 + \cdots + \kappa_n X_n + \varepsilon_t}$$

Equation 4.3

Where $\boldsymbol{i}$ is the municipality id and equals *1, 2, 3, ... 290*

$t = 2010, t_0 = 2007, T = 10$

$\Delta P_{i,(\mathrm{t}-t_0)}$	is the population change between year 2007-2010 in municipality i.
$\Delta P_{i,(t_0-\mathrm{T})}$	is the population change in the past 10 years, from year 1998 to 2007 in municipality i.
ε_t	is an error term, which is the sum of all possible unknown factors that were not taking into account in this model.
X_n	are other various (influential) factors that have an impact on the indicator
κ_P	are the parameters (to be optimized by the OLS) which quantify the impact of the respective factors X_n.

As population size has a tendency to continue its trend as per *Equation 4.1*, a regression was obtained from the simplified *Equation 4.3* using only the regressor $\Delta P_{i,(t_0-\mathrm{T})}$. We have population change over the past 10 years (T = 10, which is the data that only available) as a measure of a relatively medium-long term trend, to predate the trend of population evolution that a municipality is have at this moment, which is beyond the short-term shocks/advances that may have impact on that. The results are shown in Table 4-1.

Table 4-1: Regression: Population Change 2007-2010 vs. Population Change 1998-2007

Source	SS	df	MS
Model	.154215468	1	.154215468
Residual	.056073887	288	.000194701
Total	.210289355	289	.000727645

Number of obs	290
F(1, 288)	792.06
Prob > F	0.0000
R-squared	0.7333
Adj R-squared	0.7324
Root MSE	.01395

log_popchange_07to10	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Delta_pop_1998to2007	.290094	.0103076	28.14	0.000	.2698062	.3103818
_cons	.0058642	.0008241	7.12	0.000	.0042422	.0074863

Where:

SS	Sum of Squares
df	degrees of freedom
MS	Mean of Sum of Squares (RMS)
Root MSE	Root Mean Squared Error
R-squared	The amount of variance of Y explained by X
t stat	Significance level, greater than 1.96 (95% confidence)
p-value	Two-tailed probability, lower than 0.05 (coefficient is not 0)
Log_popchange_07to10	$\Delta P_{i,(t-t_0)}$
Delta_pop_1998to2007	$\Delta P_{i,(t_0-T)}$
_cons	Intercept, a constant value

As can be seen from Table 4-1, those municipalities which saw a growth in population between 1998 to 2007 have a tendency to remain in that positive trend: specifically, a 10% population increase over the 10 years between 1998 and 2007 (Delta_pop_1998to2007) is correlated with 2.9% (= coef. $0.29 \times 10\%$) positive growth in the population between 2007 and 2010 (Log_popchange_07to10), which both represent a roughly 0.97% increase per year. If things do not change, then the population change is expected to follow this trend, but as we mentioned before, there are disruptive factors which may change that trend. These factors, among all those possible, chosen to be included in the model are determined by a compromise between accuracy of the model, and the availability, reliability and accuracy of factor measurements. Since we want to see the population change between $\boldsymbol{t}$ and $\boldsymbol{t_0}$, only time-varying factors are relevant to be included: specifically, factors that are changing between $(t_0 - D)$ and $(t - D)$, where $\boldsymbol{D}$ is the delay for the effects to show up*. We believe that one of these factors is fiber penetration, as given by the *Equation 4.4*.

$$\boldsymbol{\Delta P_{i,(t-t_0)} = \log P_t - \log P_{t_0} = \kappa_P \cdot \Delta P_{i,(t_0-T)} + \kappa_F \cdot F_{i,t_0} + \kappa_2 X_2 + \cdots + \kappa_n X_n + \varepsilon_t}$$

Equation 4.4

Where F_{i,t_0} is the fiber penetration in the municipality i in year $t_0 = 2007$.

* Although it is not necessarily the best guide for the selection of the factors to include, it nonetheless reduces the risk of leaving out significant factors.

Ideally, we should include a changing fiber here between $(t_0 - D)$ and $(t - D)$, which is 2004-2007. However, as data for fiber penetration is only available starting from 2007 and is differently defined after 2009 (as mentioned in Chapter 3.3.1), the amount of fiber penetration is assumed in the model to be a new development in 2007 and the effects of fiber is about to show up in the next 3 years; however, this does not say that fiber had not been deployed earlier than 2007. It is a rough approximation that is not too unreasonable, because in fact fiber has been only recently deployed on a large scale. Nonetheless, even if there was some fiber three years prior to 2007, the fiber potential is more heavily exploited in 2007 than 2004, and as ICT services are involving more rapidly later, we can expect that there were more services and applications that took advantage of fiber than they were in 2004.

In the following subsection we examine what the effect of fiber penetration is on population evolution. We will separately measure the impact of FTTH on workplaces and residential units (as we have available data for both), and the coefficient of variables κ_x will be given respectively as α_x for variable x at workplaces and β_x for variable x at residential places.

4.1.1 Workplaces

We hypothesize a high fiber penetration among workplaces will lead to a higher productivity and more jobs being available, which naturally would attract people to move to this municipality.

We say that $\Delta P_{i,(t_0 - \mathrm{T})}$ is a proxy variable that indicates how attractive a municipality has been up until now. From Table 4-2 we can see the statistical significance of $\Delta P_{i,(t_0 - \mathrm{T})}$'s ability to predict population evolution between 2007 and 2010 increases when fiber penetration at workplaces is included as an explanatory variable. Secondly, we observe that F_{i,t_0} has a positive impact, specifically a 10% higher fiber penetration in workplaces in 2007 (FN_workplace_2007) leads - all other things being equal - to a 0.26% (= coef. $0.0256 \times 10\%$) improved population evolution (Log_popchange_07to10), with a 95% confidence interval (0.17% and 0.34% as shown in the table). Also observed that the coefficient of determination R^2 (R-squared in the table), which as a measure of the degree of variance[67] explained by the model *Equation 4.3* is ***0.76***.

Table 4-2: Regressing Results: Population Evolution 2007-2010 vs. FTTH Penetration 2007 at Workplaces and Population Change 1998-2007

Source	SS	df	MS
Model	.160346579	2	.08017329
Residual	.049942776	287	.000174017
Total	.210289355	289	.000727645

Number of obs =	290
F(2, 287) =	460.72
Prob > F =	0.0000
R-squared =	0.7625
Adj R-squared =	0.7608
Root MSE =	.01319

log_popchange_07to10	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
FN_workplace_2007	.0256067	.004314	5.94	0.000	.0171156	.0340977
Delta_pop_1998to2007	.2851444	.0097804	29.15	0.000	.2658941	.3043947
_cons	.0015536	.0010651	1.46	0.146	-.0005428	.00365

When considering which other specific factors can explain why and in which way the municipality is attractive, in order to complete the model and to increase the value of R^2, the degree of Urbanization and the share of people commuting into a municipality in 2007 are taken into account. The equation now becomes:

$$\Delta \boldsymbol{P}_{i,(t-t_0)} = \log \boldsymbol{P}_t - \log \boldsymbol{P}_{t_0} = \boldsymbol{\alpha}_P \cdot \Delta \boldsymbol{P}_{i,(t_0-T)} + \boldsymbol{\alpha}_F \cdot \boldsymbol{F'}_{i,t_0} + \boldsymbol{\alpha}_U \cdot \boldsymbol{U}_{i,t_0} + \boldsymbol{\alpha}_{IC} \cdot \boldsymbol{IC}_{i,t_0} + \boldsymbol{\varepsilon}_t$$

Equation 4.5

Where:

$t_0 = 2007$

F'_{i,t_0} is the fiber penetration at workplaces in the municipality i in year t_0.

U_{i,t_0} is the Urbanization degree of municipality i in the year t_0.

IC_{i,t_0} is the number of people commuting into the municipality i in the year t_0.

From Table 4-3, it is clear that fiber penetration at workplaces is statistically significant with a *t-stat* of 4.05, which together with other factors, show that nearly ***80%*** degree of variation (R^2) in population change from year 2007 to 2010 is explained by the explanatory variables in the model. The estimated parameters are given below along with their ***95%*** confidence intervals.

$$\boldsymbol{\alpha_P} = \mathbf{0.245} \pm \mathbf{0.021}$$
$$\boldsymbol{\alpha_F} = \mathbf{0.017} \pm \mathbf{0.008}$$
$$\boldsymbol{\alpha_U} = \mathbf{0.025} \pm \mathbf{0.012}$$
$$\boldsymbol{\alpha_{IC}} = \mathbf{0.045} \pm \mathbf{0.02}$$
$$\boldsymbol{\alpha_0} = -\mathbf{0.021} \pm \mathbf{0.008}$$

Table 4-3: Regressing Results: Population Evolution 2007-2010 on FTTH Penetration 2007 at Workplaces and 3 other factors

Source	SS	df	MS
Model	.168009464	4	.042002366
Residual	.042279891	285	.00014835
Total	.210289355	289	.000727645

Number of obs	= 290
F(4, 285)	= 283.13
Prob > F	= 0.0000
R-squared	= 0.7989
Adj R-squared	= 0.7961
Root MSE	= .01218

log_popchange_07to10	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
FN_workplace_2007	.0170292	.0042019	4.05	0.000	.0087585	.0253
Delta_pop_1998to2007	.2452571	.0106774	22.97	0.000	.2242405	.2662737
Urbanization	.0253748	.006091	4.17	0.000	.0133856	.0373639
Incommuting_shar~2007	.0452686	.0099777	4.54	0.000	.0256293	.064908
_cons	-.0212095	.0042756	-4.96	0.000	-.0296253	-.0127937

It can be noticed in Table 4-3 that when the two new variables (Urbanization, Incommuting_share_2007) were added to the regression the R^2 value increases to ***0.80;*** while the addition of the other two variables contributed a small change in the R^2 value. To figure out why and to verify the independence of the variables utilized in the regression, a Pearson correlation is tested in Table 4-4. In this table one can see that all correlations are within acceptance range, although the correlations between Urbanization and the other three other variables are relatively higher than the dependence among all others, which means the latter two additional variables are somewhat effected by the other two. This is understandable since an urbanized area would naturally attract additional people to move in. For those not living in the same municipality, the more an area is urbanized, the more people who would tend to commute into the area because companies tend to be in urbanized areas, e.g. cities. The degree of Urbanization itself has a direct effect on population change, and it also impacts the population indirectly through FTTH, because a more urbanized area would tend to have more advanced technologies deployed. Therefore, such a municipality, which was successful, continues to be successful in attracting people to it.

Table 4-4: Pearson Correlation of Population Evolution Regression Model

(obs=290)

	log_p~10	FN_wor~7	Del~2007	Urbani~n	Inc~2007
log_popch~10	1.0000				
FN_work~2007	0.2431	1.0000			
Delta_p~2007	0.8564	0.0853	1.0000		
Urbanization	0.5911	0.3124	0.4933	1.0000	
Incommu~2007	0.5024	0.1748	0.3933	0.4323	1.0000

Fiber penetration is not correlated with the other indicators as can be seen from Table 4-4. This proves that the effects we see are explained by fiber penetration, but not by chance because fiber penetration is correlated with something else, which in turn is the true cause of the socio-economic improvement. Figure 4-1 shows intuitively the relationship of FTTH and population evolution as a red fitted trend line. The x-coordinate is scaled by the FTTH penetration rate in 290 municipalities and y-coordinate represents the rate of the population change from year 2007 to 2010. The slope of the red fitted line is the coefficient of FTTH penetration (α_F), which shows a positive relationship

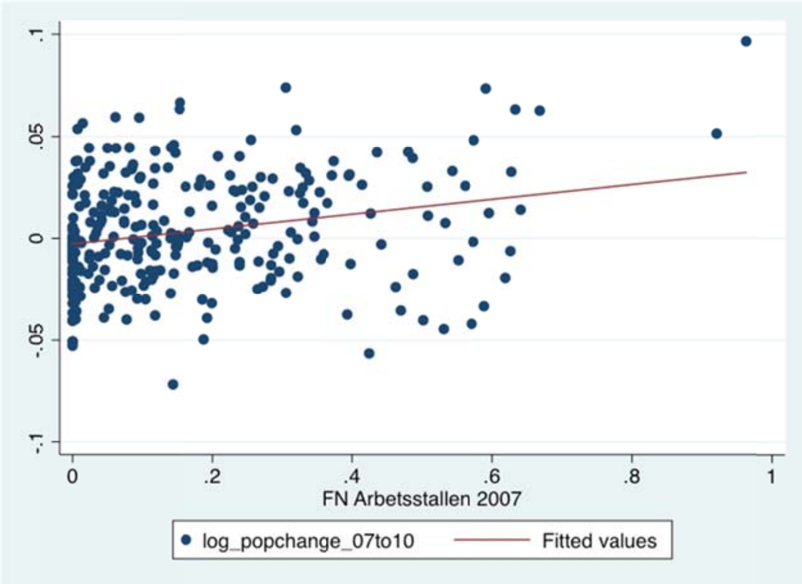

Figure 4-1: Linear Prediction of Population Evolution 2007-2010 on FTTH Penetration at Workplaces

4.1.2 Residential places

High-speed broadband connectivity at residential places is a great merit for individuals to consider when moving into a residential area. The previous analysis has shown that, municipalities with a 10% increase in fiber penetration at their workplaces have a tendency to have a population change three years later with 0.17% positive growth. We perform the same type of regression analysis in order to see if there are similar effects for residential places.

Based upon the simplified regression model given in *Equation 4.3*, we include fiber penetration at residential places in 2007 (i.e., F''_{i,t_0}), as shown in Table 4-5. It turns out that the fiber penetration at households also has a significant impact on the population change, with a 10% increase in FTTH penetration in residential places in year 2007 (FN_households_2007) leads to a 0.18% positive growth in population change in 2010, with a high coefficient of determination R^2 of 75%.

Table 4-5: Regressing Results: Population Evolution 2007-2010 vs. FTTH Penetration 2007 at Households and Population Change 1998-2007

Source	SS	df	MS
Model	.158673403	2	.079336701
Residual	.051615952	287	.000179847
Total	.210289355	289	.000727645

Number of obs	290
F(2, 287)	441.14
Prob > F	0.0000
R-squared	0.7545
Adj R-squared	0.7528
Root MSE	.01341

log_popchange_07to10	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
FN_households_2007	.0184859	.003713	4.98	0.000	.0111777	.0257941
Delta_pop_1998to2007	.2899913	.0099066	29.27	0.000	.2704924	.3094902
_cons	.0021387	.0010896	1.96	0.051	-5.97e-06	.0042834

As mentioned before, $\Delta P_{i,(t_0 - \mathrm{T})}$ is a casual variable that explains the attractivity of a municipality, it does not tell us **why** a municipality is attractive, but it simply tells us that it is attractive. When we include additional variables, for instance, the urbanization in addition to $\Delta P_{i,(t_0 - \mathrm{T})}$, one is able to see that a municipality that is more urbanized attracted more people. In Table 4-6 we regress with the degree of urbanization and the share of people commuting into a municipality in 2007, just as we did in the previous section. The equation becomes:

$$\boldsymbol{\Delta P_{i,(t-t_0)} = \log P_t - \log P_{t_0} = \beta_P \cdot \Delta P_{i,(t_0-T)} + \beta_F \cdot F''_{i,t_0} + \beta_U \cdot U_{i,t_0} + \beta_{IC} \cdot IC_{i,t_0} + \varepsilon_t}$$

Equation 4.6

Where F''_{i,t_0} is the fiber penetration at residential places in the municipality i in year $t_0 = 2007$.

Table 4-6: Regressing Results: Population Evolution 2007-2010 on FTTH Penetration 2007 at Households and 3 other factors

Source	SS	df	MS
Model	.167677787	4	.041919447
Residual	.042611567	285	.000149514
Total	.210289355	289	.000727645

Number of obs =	290
F(4, 285) =	280.37
Prob > F =	0.0000
R-squared =	0.7974
Adj R-squared =	0.7945
Root MSE =	.01223

log_popchange_07to10	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
FN_households_2007	.013105	.0034927	3.75	0.000	.0062302	.0199797
Delta_pop_1998to2007	.2459465	.0107477	22.88	0.000	.2247915	.2671015
Urbanization	.027058	.006033	4.49	0.000	.0151832	.0389329
Incommuting_share_2007	.0477124	.0099942	4.77	0.000	.0280407	.0673842
_cons	-.0225244	.0042568	-5.29	0.000	-.0309033	-.0141456

$$\boldsymbol{\beta_P = 0.246 \pm 0.021}$$
$$\boldsymbol{\beta_F = 0.013 \pm 0.007}$$
$$\boldsymbol{\beta_U = 0.027 \pm 0.012}$$
$$\boldsymbol{\beta_{IC} = 0.048 \pm 0.02}$$
$$\boldsymbol{\beta_0 = -0.022 \pm 0.008}$$

As one can see after including the latter two regressors, the coefficient of fiber penetration at households is 0.013, which is slightly lower (about 30%) than at workplaces where it was 0.017. Is it because the fiber penetration in residential areas is higher than in companies? Looking at the correlation between *FN workplaces* and *FN residential places*, we found the two are highly correlated (coef. = 0.9618), as can be seen in Figure 4-3, where the plot shows *FN residential places =1.3* × *FN workplaces*. The conclusion is identical to the hypothesis 1 (H_1) as FTTH does positively contribute to population evolution, hence the null Hypothesis (H_0) is rejected based on a low p-value (p = 0.000) for coefficients of fiber penetration (i.e., α_F and β_F) at both workplaces and residential places, and the only difference is simply the scaling factor.

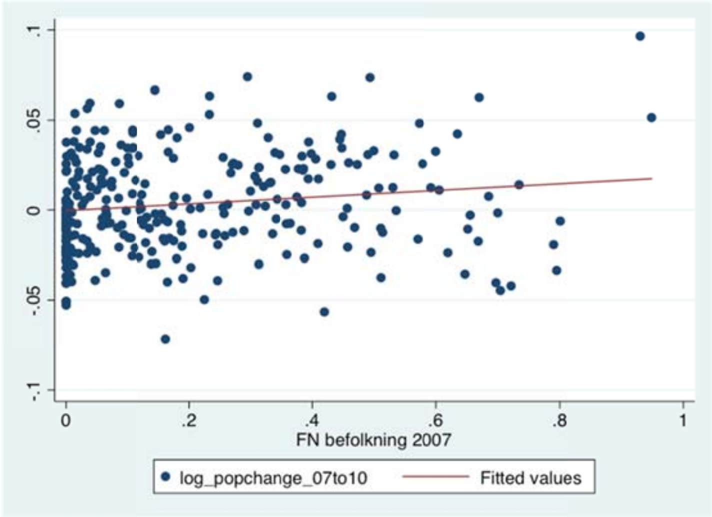

Figure 4-2: Linear Prediction of Population Evolution 2007-2010 on FTTH Penetration at Residential Places

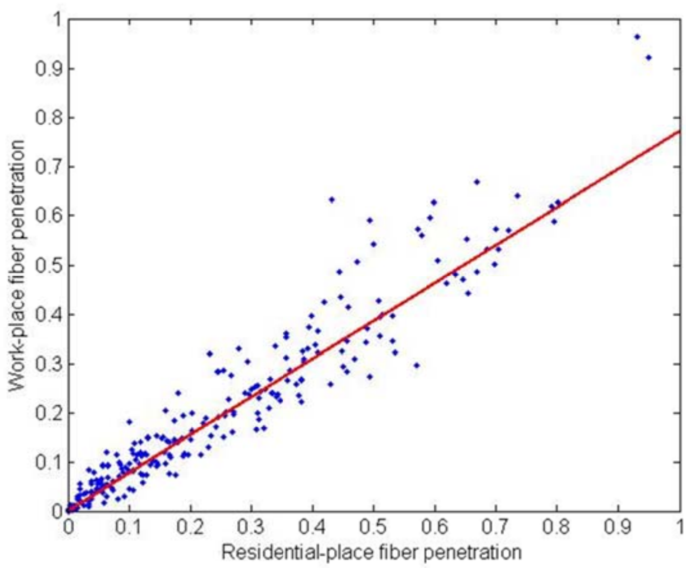

Figure 4-3: Plot of FN Residential Places vs. FN Workplaces

We observe that some municipalities have a more positive population growth trend than others. The cause for the population in a municipality to increase between 2007 and 2010 is the net amount of people migrating into municipality i ($EM_{i,(2008\sim2010)}$) and the number of new births ($B_{i,(2008\sim2010)}$), subtracting the total deaths ($D_{i,(2008\sim2010)}$) [72], as shown in *Equation 4.7*. We analyze these in detail.

$$\Delta \boldsymbol{P}_{\boldsymbol{i},(\boldsymbol{t}-\boldsymbol{t_0})} = \boldsymbol{EM}_{\boldsymbol{i},(\mathbf{2008\sim2010})} + \boldsymbol{B}_{\boldsymbol{i},(\mathbf{2008\sim2010})} - \boldsymbol{D}_{\boldsymbol{i},(\mathbf{2008\sim2010})}$$

Equation 4.7

Where:

$\Delta P_{i,(t-t_0)}$	is the population change of municipality i between 2007 and 2010.
$EM_{i,(2008\sim2010)}$	is the total excess of migration into municipality i in the years 2008, 2009, and 2010.
$B_{i,(2008\sim2010)}$	is the total births in municipality i in years 2008, 2009, and 2010.
$D_{i,(2008\sim2010)}$	is the total deaths in municipality i in years 2008, 2009, and 2010*.

4.1.3 Excess of Migration

According to Statistics Sweden, *Excess of migration*[74] is defined as the difference between immigration and emigration, i.e., the net number of people migrating into a municipality. This may explain the population change to a great extent. Taking the same indicators $\Delta P_{i,(t_0-\mathrm{T})}$, U_{i,t_0}, and IC_{i,t_0} in the regression, we have a similar model to that shown in Equation 4.8.

$$\boldsymbol{EM_{i,(2008\sim2010)} = \kappa_P \cdot \Delta P_{i,(t_0-T)} + \kappa_F \cdot F_{i,t_0} + \kappa_U \cdot U_{i,t_0} + \kappa_{IC} \cdot IC_{i,t_0} + \varepsilon_t}$$

Equation 4.8

The results of the regression are summarized in

* The death rate was not available at the time of performing the analysis. Besides, it is the 2nd lowest in the world[73] and is therefore not considered further in this analysis.

Table 4-7 and in Table 4-8 for fiber penetration at work places and residential places (respectively). We can see that the impact on excess migration is explained by the model with approximately 58% of variance. The estimated parameters are given below along with their 95% confidence interval, with α_x representing the coefficient of variable x at workplaces and β_x representing the coefficient of variable x at residential places.

$$\alpha_F = 0.012 \pm 0.007 \qquad \beta_F = 0.009 \pm 0.006$$

$$\alpha_P = 0.127 \pm 0.019 \qquad \beta_P = 0.128 \pm 0.019$$

$$\alpha_U = 0.013 \pm 0.011 \qquad \beta_U = 0.014 \pm 0.011$$

$$\alpha_{IC} = 0.026 \pm 0.018 \qquad \beta_{IC} = 0.027 \pm 0.018$$

$$\alpha_0 = -0.007 \pm 0.008 \qquad \beta_0 = -0.008 \pm 0.007$$

Table 4-7: Regressing Results: Excess of Migration 2008-2010 on FTTH Penetration 2007 at Workplaces and 3 other factors

Source	SS	df	MS
Model	.047093653	4	.011773413
Residual	.034062889	285	.000119519
Total	.081156542	289	.000280818

Number of obs	290
F(4, 285)	98.51
Prob > F	0.0000
R-squared	0.5803
Adj R-squared	0.5744
Root MSE	.01093

log_excess_share_08~10	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
FN_workplace_2007	.0124388	.0037716	3.30	0.001	.0050151	.0198625
Delta_pop_1998to2007	.1271217	.0095838	13.26	0.000	.1082576	.1459858
Urbanization	.0128719	.0054672	2.35	0.019	.0021107	.0236331
Incommuting_share_2007	.0256722	.0089558	2.87	0.004	.0080443	.0433001
_cons	-.0069358	.0038377	-1.81	0.072	-.0144897	.000618

Table 4-8: Regressing Results: Excess of Migration 2008-2010 on FTTH Penetration 2007 at Households and 3 other factors

Source	SS	df	MS
Model	.046885038	4	.011721259
Residual	.034271505	285	.000120251
Total	.081156542	289	.000280818

Number of obs	290
F(4, 285)	97.47
Prob > F	0.0000
R-squared	0.5777
Adj R-squared	0.5718
Root MSE	.01097

log_excess_share_08~10	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
FN_households_2007	.0094365	.0031323	3.01	0.003	.0032711	.0156019
Delta_pop_1998to2007	.1275748	.0096387	13.24	0.000	.1086027	.1465469
Urbanization	.0141562	.0054105	2.62	0.009	.0035066	.0248057
Incommuting_share_2007	.0274602	.0089629	3.06	0.002	.0098183	.0451022
_cons	-.0079101	.0038176	-2.07	0.039	-.0154244	-.0003958

These regression results tell us that statistically the FTTH penetration in both workplaces and residential places have a significant impact on the excess of migration, with every 10% increase in FTTH penetration in 2007 leading to 0.12% of increase in excess of migration at workplaces and 0.09% of increase in excess of migration at households in the next three years. This can be explained as workplaces that have access to fiber are able to employ more people (as argued in chapter 2), the increased job opportunities will lead to more people moving to those municipalities. In parallel people are also happy to move to residential places where households have access to fiber. Because these two are highly correlated we cannot separate the two variables. Figure 4-4 and Figure 4-5 illustrate the linear prediction of the share of net immigration at workplaces and at residential places respectively. The dots show the excess migration and the red linear fitted lines predict the trends based upon the fiber penetration in the two separate types of places.

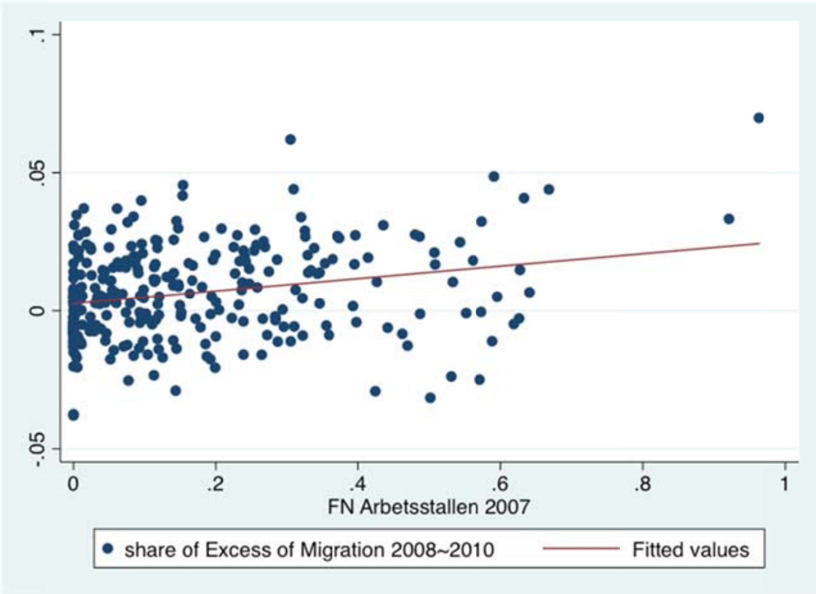

Figure 4-4: Linear Prediction of Excess of Migration on FTTH Penetration at Workplaces

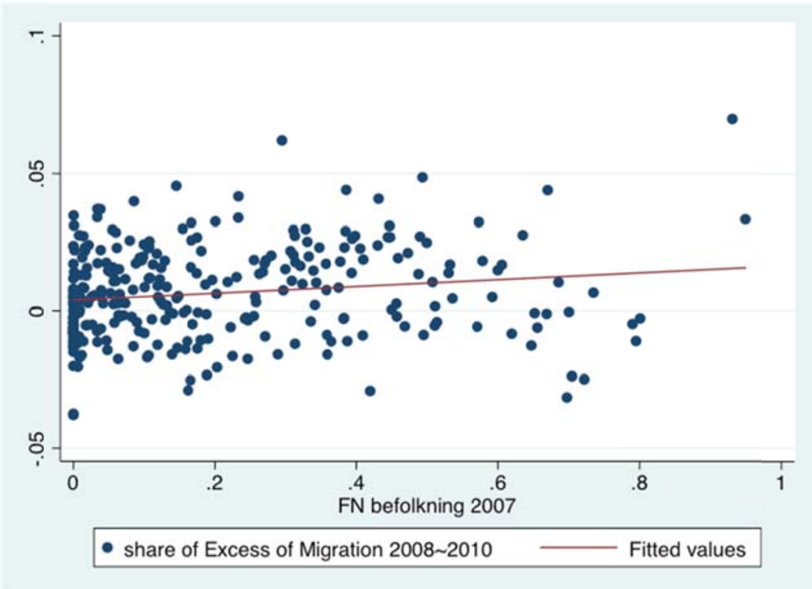

Figure 4-5: Linear Prediction of Excess of Migration on FTTH Penetration at Households

The original trend of population growth was considered in the regression because we believe it has a positive influence on the number of people moving into the municipality during the next couple of years. The results shown in both tables proved that this trend dominates the trend of excess of migration with high significance at a level of approximately 13%. This is because those who moved into the municipality are the main constituent of population change beyond the number of births (minus deaths), and these ones who already moved into and settled down in the municipality may attract their families or relatives to move to this municipality, which leads to an increase in the amount of excess of migration.

The statistics also indicate that the degree of urbanization of a municipality naturally attracts more migrants to move in, and similarly, a municipality that more people are regularly travelling to, leads to a higher probability that these commuters will settle there as residents.

4.1.4 Birth Rate

High numbers of foreign citizens and family building are interrelated in many cases, because most immigrant groups tend to have a higher birth rate shortly after immigration to Sweden[75]. Therefore the proportion of foreigners (i.e., fs_{i,t_0}) is included in *Equation 4.9*. As one can see in this model the degree of urbanization is no longer included, as we observed no significant correlation with birth rate.

$$\boldsymbol{B}_{i,(2008\sim 2010)} = \boldsymbol{\kappa_P} \cdot \Delta \boldsymbol{P}_{i,(t_0-T)} + \boldsymbol{\kappa_F} \cdot \boldsymbol{F}_{i,t_0} + \boldsymbol{\kappa_{IC}} \cdot \boldsymbol{IC}_{i,t_0} + \boldsymbol{\kappa_{fs}} \cdot \boldsymbol{fs}_{i,t_0} + \boldsymbol{\varepsilon_t}$$

Equation 4.9

Where:

fs_{i,t_0} is the proportion of foreigners in the municipality i in year $t_0 = 2007$.

Table 4-9 and Table 4-10 present the regression results of Birth Rate at work and residential places, the resulting coefficient with their 95% confidence interval are:

$\alpha_F = 0.006 \pm 0.002$ $\quad$ $\beta_F = 0.005 \pm 0.002$

$\alpha_P = 0.048 \pm 0.005$ $\quad$ $\beta_P = 0.049 \pm 0.005$

$\alpha_U = 0.016 \pm 0.005$ $\quad$ $\beta_U = 0.017 \pm 0.005$

$\alpha_{IC} = 0.019 \pm 0.014$ $\quad$ $\beta_{IC} = 0.021 \pm 0.014$

$\alpha_0 = 0.027 \pm 0.001$ $\quad$ $\beta_0 = 0.027 \pm 0.001$

Table 4-9: Regressing Results: Birth Rate 2008-2010 on FTTH Penetration 2007 at Workplaces and 3 other factors

Source	SS	df	MS
Model	.007056648	4	.001764162
Residual	.002933092	285	.000010292
Total	.00998974	289	.000034567

Number of obs	290
F(4, 285)	171.42
Prob > F	0.0000
R-squared	0.7064
Adj R-squared	0.7023
Root MSE	.00321

log_birth_share_08to10	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
FN_workplace_2007	.0064766	.0010618	6.10	0.000	.0043866	.0085666
Delta_pop_1998to2007	.048171	.0025859	18.63	0.000	.0430811	.0532609
Incommuting_share_2007	.0156721	.0026152	5.99	0.000	.0105247	.0208196
Foreign_share_2007	.0191582	.0071295	2.69	0.008	.005125	.0331914
_cons	.0271725	.0004537	59.90	0.000	.0262796	.0280654

Table 4-10: Regressing Results: Birth Rate 2008-2010 on FTTH Penetration 2007 at Households and 3 other factors

Source	SS	df	MS
Model	.006988235	4	.001747059
Residual	.003001505	285	.000010532
Total	.00998974	289	.000034567

Number of obs =	290
F(4, 285) =	165.89
Prob > F =	0.0000
R-squared =	0.6995
Adj R-squared =	0.6953
Root MSE =	.00325

log_birth_share_08to10	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
FN_households_2007	.0049306	.0009023	5.46	0.000	.0031546	.0067067
Delta_pop_1998to2007	.0488389	.0026163	18.67	0.000	.0436891	.0539886
Incommuting_share_2007	.0167981	.0026257	6.40	0.000	.0116298	.0219663
Foreign_share_2007	.0207051	.0072193	2.87	0.004	.0064951	.0349151
_cons	.0270654	.00047	57.59	0.000	.0261403	.0279905

One can see that all the listed indicators are significantly influencing the birth rate trend by the 95% confidence interval, and the model explains the data with $R^2 = 0.70$. As for fiber penetration, a 10% increase in fiber penetration at workplaces or residential places in 2007 is respectively correlated with a 0.06% or 0.05% increase in birth rate in the following three years. This can be interpreted as places with more fiber attract more people in the birth-giving age group. In a recent research on Swedish FTTH deployments* where interviews in a sample municipality – Säffle were carried out, fiber had been installed in all public housing in the municipality, and the interviewees saw that having fiber attracted more young people to live there[76]. As anecdotal evidence, it was observed that vacancies in the public housing were filled after fiber was installed. The regression result supports the claim that the availability of a high-speed access connection (such as FTTH) affects people's choice of residence[7,31]; which suggests that instead of having empty housing or housing with older people that deploying fiber would attract young people to move in and have children in a relatively short term. Another perspective is that high-tech companies, which typically attract younger people to work for them, tend to benefit more than average from fiber deployment. Some people in this young age group would tend to move to a municipality in order to reduce their commuting, and these young people would tend to have children.

A higher birth rate could be mediated through higher employment rate[4]. In other words, fiber contributes to the success of companies (e.g. reducing costs, improving quality of communications) so they are able to employ more people[71], and the consequent increased disposable income may make it more affordable to have children.

One can also see that a 10% increase in the proportion of foreigners in 2007 lead to a 0.21% increase in birth rate in the next three years, which confirms that immigration by foreigners tends to be correlated with a higher rate of childbearing shortly after immigration. It should be noted that those who have not acquired citizenship include child foreigners who may build families and continue to reside in Sweden[77,78].

* A study on four Swedish municipal FTTH networks, in which the author of this thesis assisted in the data collection.

Figure 4-6 and Figure 4-7 show the effect of fiber penetration on birth rate graphically. The points represent each municipality (290 in total), the x-coordinate shows the municipality's fiber penetration in 2007, and the y-coordinate shows the birth rate change between 2008 and 2010. The red fitted line represents the model's forecast, and the slope of the fitted line are the coefficients of FTTH penetration, with $\alpha_F = 0.006$ in Figure 4-6 and $\beta_F = 0.005$ in Figure 4-7.

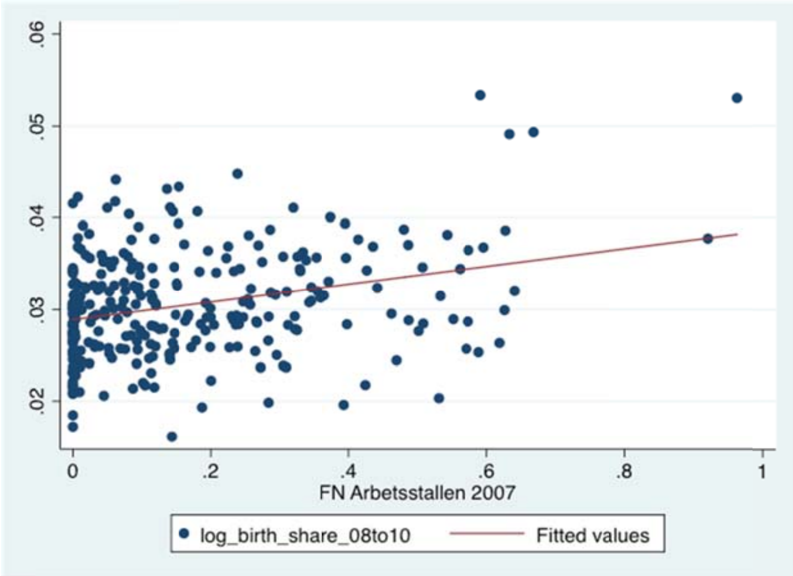

Figure 4-6: Linear Prediction of Birth Rate on FTTH Penetration at Workplaces

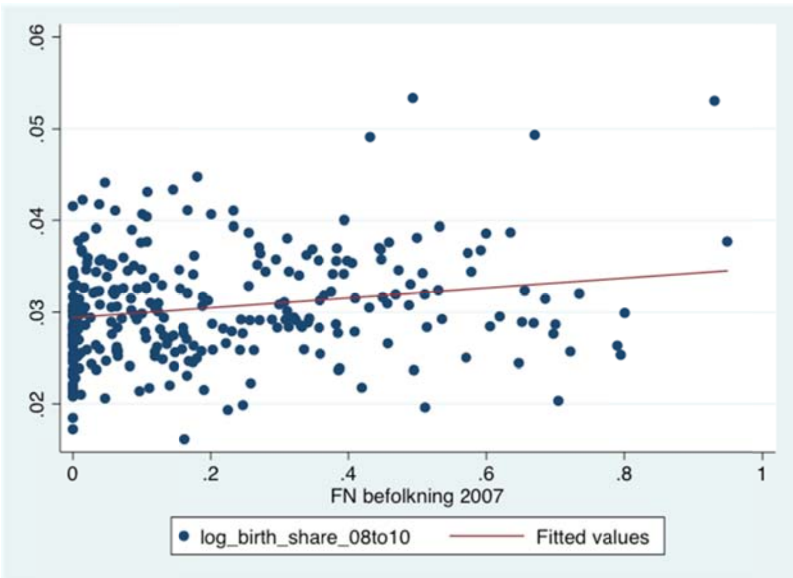

Figure 4-7: Linear Prediction of Birth Rate on FTTH Penetration at Residential Places

It is worth mentioning that the sum of the coefficients of fiber penetration in the case of excess of migration ($\alpha_F = 0.012 \pm 0.007$, $\beta_F = 0.009 \pm 0.006$) and birth rate ($\alpha_F = 0.006 \pm 0.002$, $\beta_F = 0.005 \pm 0.002$) are roughly equal to the coefficient of population change from 2007 to 2010 ($\alpha_F = 0.017 \pm 0.008$, $\beta_F = 0.013 \pm 0.007$), respectively at working places and residential places. This essentially confirms our model as stated in *Equation 4.7*.

4.2 Competition and Price of Internet Service

In the previous sections one can already see that fiber penetration has a significant impact on population evolution, especially in terms of excess of migration. Looking at why people want to move to a municipality, the explanation goes beyond fiber penetration per se: possibly the open access model, which goes hand in hand with fiber deployment in Sweden, leads to lower prices due to competition which indirectly makes a municipality more attractive. Price is a crucial factor that directly affects broadband adoption. This could in turn also implicitly affect the economy and society. Therefore, we investigated the price of Internet service (specifically symmetric 10/10 Mbps Internet access, as it is the mostly accessed speed in Sweden) and the effect of competition in fiber networks across the country.

Open access is an open market. In light of basic market economics, more service providers in the fiber-based open market increase the competition, which will accordingly lead to better offers and lower prices. Therefore we set out (see Hypothesis 2) to verify whether price indeed is lower when there are more ISPs in the market providing fiber-based Internet services, with respect to the market disciplines.

Hypothesis 2: Competition and Price of Internet Service

H_0 : More SPs competing in a FTTH open network does **not** lower the price of 10/10Mbps fiber-based Internet services in Sweden.

H_1 : More SPs competing in a FTTH open network does lower the price of 10/10Mbps fiber-based Internet services in Sweden.

The estimated model is:

$$\boldsymbol{P_{i,t} = \kappa_0 + \kappa_{ISP} \cdot N_{ISP_{i,t}} + \kappa_2 X_2 + \ldots + \kappa_n X_n + \omega_t}$$

Equation 4.10

Where:

$t = 2012$

$\boldsymbol{i}$	is the municipality ID and equals *1,2,3,……290*
$\boldsymbol{P_{i,t}}$	is the to date lowest price of subscribing to fiber-based high-speed Internet services (with 10/10 Mbps or above) in the municipality i in 2012.
$\boldsymbol{N_{ISP_{i,t}}}$	is the number of ISPs that is presenting on the fiber network with high-speed Internet services (with 10/10Mbps or above) in the municipality i in 2012.
$\boldsymbol{\omega_t}$	is the error term, which is the sum of all possible unknown factors that were not taking into account in this model.

Regressing the simplest model given in *Equation 4.10* with the only explanatory variable $\boldsymbol{N_{ISP_{i,t}}}$, one can see the robust relation between price and the number of ISPs. As shown in Table 4-11, the price that ISPs charge for every subscription decreases statistically significantly with an increase in the number of ISPs (t-stat = -9.78) as expected. The price that the model predicts is ***250.97*** SEK per month if there is only one ISP present in the market; each additional SP leads to a ***8.08*** SEK per month (with a 95% Confidence Interval from 9.71 to 6.45 SEK per month) decrease in lowest price from the base line. From R^2 one can estimate that ***41%*** of the variance in price can already be explained by the number of ISPs.

The equilibrium price is dependent upon the agreement between the seller and buyer, due to the interaction between supply and demand. The regression shown in Table 4-11 is based upon the lowest prices of 10/10 Mbps services subscription via fiber/fiber LAN, offered by different ISPs who are competing in the open-access fiber networks (i.e. mostly *Öppna Stadsnät* in our case). These networks are operated by various NPs. One can see that it is a highly competitive fiber-seller market, and this is in line with the open market principle: the more sellers (i.e. SPs) competing in the market, the lower the price offered by SPs as a strategy to attract and retain subscribers.

For comparison, the lowest price of symmetrical 10/10 Mbps services offered by national vertically integrated operators was approximately ***280*** SEK per month in 2012 [79], which is higher than our estimated price level in Sweden.

Table 4-11: Robust Regression: Price vs. Number of ISPs

```
Linear regression                               Number of obs =        189
                                                F(  1,    187) =     95.65
                                                Prob > F       =    0.0000
                                                R-squared      =    0.4146
                                                Root MSE       =    22.065
```

price	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
isps	-8.080491	.8262394	-9.78	0.000	-9.710439	-6.450542
_cons	250.9723	5.381019	46.64	0.000	240.357	261.5876

On the other hand, the population change of a municipality in the past 10 years is a rough measure of the attractiveness and dynamicity of a municipality. We hypothesize that its residents are more broadband inclined, therefore more discerning when choosing an Internet service provider; hence there is more competitive pressure. Population change (i.e., Delta_popchange_2011 in the table) is included as a potential explanatory variable ($\Delta P_{i,(t_0-\mathrm{T})}$) in the model, and the regression results obtained are shown in Table 4-12. These results supports our hypothesis that the more dynamic the population in a municipality, the greater the competitive pressure on the supplier, hence the more favorable price subscribers can get.

One can see that the two instrumental variables can explain 43.5% of the variance (as $R^2 = 0.435$) in price, but there is still a lot of variance that remains unexplained. To improve the model and to raise the R^2 value, we introduce more variables. Network providers (NPs) are a big stakeholder in the value chain of open access network, therefore we will consider their effect.

Table 4-12: Robust Regressing Results: Price 2012 vs. Number of ISPs 2012 and Population Change 2002-2011

```
Linear regression                               Number of obs =      189
                                                F(  2,    186) =    51.23
                                                Prob > F       =   0.0000
                                                R-squared      =   0.4354
                                                Root MSE       =   21.728
```

price	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
isps	-7.482375	.8109407	-9.23	0.000	-9.082198	-5.882551
delta_pop~2011	-56.51519	21.9191	-2.58	0.011	-99.7572	-13.27318
_cons	249.4208	5.298583	47.07	0.000	238.9678	259.8739

A NP in the open access network model is the business actor that operates the active infrastructure over a fixed period contract with a physical infrastructure provider (PIP). As already introduced in section 2.3.2, the NP in the open access value chain pays a monthly connection fee to the PIP, and receives revenue from SPs for each subscriber that an SP sells a subscription to.

Sometimes the PIP is also plays the role of NP. This may also affect the price because we believe that the PIP normally is a local company that is owned by the municipality or possibly by other utility, such as a power distribution utility. These companies are generally small, hence there are small economies of scale. They are also local and generally have little ICT-specific competence. As a consequence, their OPEX may be higher than the OPEX of larger national professional NP companies such as *Opennet*, *iTux*, *Zitius*, etc., because the latter companies may run hundreds of switches rather than dozens of switches, and hence they can afford to have personnel that knows the equipment very well – thus they can fix network problems in less time, optimize their network, introduce new technologies, etc. The resulting lower OPEX may be passed on to the SPs who in turn pass it on to the end users in the form of a lower monthly service price. For all of these reasons we decided to include various NP flags in the model.

The NP flags are given to the main NPs operating in the Swedish municipal network market according to our collected *Stadsnät* list, along with the flag PIPNP for the case where the PIP is also operating in the market as a NP. The NP flags include: ***OpenNet, iTux, Telia (stadsnät), Zitius, ViaEuropa, Quadracom, Biggnet, Openbit,*** and ***PIP/NP***, as well as ***Others*** representing networks operated by other small NPs in the extended model.

As shown in Table 4-13, the R^2 coefficient of determination raises to ***51%*** when the NP flags are added. As a result of robust regression, the instrumental NP variable ***iTux*** among various NPs was found to contribute significantly in explaining the degree of variation with a statistically high significance (*t*-stat = -9.43).

Table 4-13: Robust Regression Results: Given NP Flags

```
Linear regression                               Number of obs =       189
                                                F(  3,    185) =    89.61
                                                Prob > F       =   0.0000
                                                R-squared      =   0.5106
                                                Root MSE       =   20.286
```

price	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
isps	-6.916225	.8010295	-8.63	0.000	-8.496552	-5.335898
delta_pop_c~2011	-41.54073	20.49173	-2.03	0.044	-81.96825	-1.113215
itux	-28.34646	3.004942	-9.43	0.000	-34.27481	-22.4181
_cons	248.1297	5.239795	47.35	0.000	237.7922	258.4671

This regression result tells us that ***iTux*** is able to offer a lower price to SPs compared with other NPs. In this way SPs would be able to charge less for their services to their subscribers. From Table 4-13 one can observe that in networks operated by ***iTux***, SP prices tend to be lower (at ***28.35*** SEK per month, all other things being equal). Part of this could be explained by the longer contract periods of the service package details of the different NPs via *Stadsnät*. Normally consumers are bound for a fixed contract period (varing from 0 to 18 months) when subscribing for Internet services via *Stadsnät*. Meanwhile, subscribers are not allowed to cancel their contract immediately, but must inform their contractor earlier (typically 3 months or more) if they would like to terminate their contract or subscribe to another SP. This means subscribers are bound for at least 3 months *even* if they wish to subscribe to another SP after the first second of being connected. The contract period for ***iTux*** is 12 to 18 months, with a 3-month notice period of termination. These are among the highest durations of any NP. This allows ***iTux*** to offer lower prices, because they have a longer period of guaranteed revenue from the subscribers.

On the other hand, ***TeliaSonera*** is the largest provider (i.e., they have the most market share). They offer higher prices than average. Yet considering its strong brand and long-standing good reputation, although it always offers a relatively higher price, their loyal customers continue to buy services from them, as they have a high degree of satisfaction. ***TeliaSonera*** offers different fiber networks to meet their customers' specific demands, i.e. ***Telia Stadsnät*** and ***Telia Öppen fiber®***. ***Telia Stadsnät*** was introduced in the previous regression. This NP seems not to significantly contribute to lower prices. Here we introduce another detailed regression particularly for the ***Telia Öppen fiber®***; differentiated as ***Telia Öppenfiber Lägenhet*** for apartments and ***Telia Öppenfiber Villa*** for single homes, for these offering prices are considerably different, arguably because of the higher installation costs.

Table 4-14 shows the robust linear regression within ***Telia Öppen fiber*** network. One can see that the significance of ***Telia Öppenfiber Lägenhet*** is statistically high (*t*-stat = -8.46), yet instead of saying that subscribing to *Telia Öppenfiber Lägenhet* is better than subscribing to *Telia Öppenfiber Villa*, the subscription cost of subscriber living in a Lägenhet would be lower than for a subscriber living in a Villa where the ***Telia Öppen fiber*** network is present. One may also notice that the number of ISPs becomes less significant and the indicator of population change (in the last 10 years) is not present in this table because it is no longer significant. This is because TeliaSonera mostly offers the same level of price to various SPs when present in any lägenhet or villa, **without** geographic or regional differences. The only difference is that the price level on average is slightly lower via *Telia Öppenfiber Lägenhet* than via *Telia Öppenfiber Villa, simply* because the installation cost in a lägenhet (i.e., apartment) is lower than for in a villa (i.e., single home). Having a strong brand and loyal customer base means that TeliaSonera is not necessarily competing with others in a price war, consequently the number of ISPs available via Telia Öppenfiber is less and the competition less pronounced, with every additional ISP offering services via Telia Öppenfiber, the consumers benefit by a ***2.5*** SEK reduction in the monthly subscription fee, as presented in Figure 4-8.

Table 4-14: Robust Regression Results: via Telia Öppen Fiber

```
Linear regression                               Number of obs =        66
                                                F(  2,     63) =     45.65
                                                Prob > F      =    0.0000
                                                R-squared     =    0.6066
                                                Root MSE      =    11.678
```

price	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
isps	-2.45052	.6824839	-3.59	0.001	-3.814355	-1.086685
lagenhet	-26.4735	3.127681	-8.46	0.000	-32.72367	-20.22333
_cons	261.198	5.393701	48.43	0.000	250.4195	271.9764

To explain the outliers, it is interesting to see which is the SP gives a lower price. Looking at the Figure 4-8, in which x-coordinate shows the number of ISPs presenting in the Telia Öppenfiber network, and the y-coordinate represents the lowest price that is offered by these ISPs. We found ***Bixia*** is present elsewhere, but for all the municipalities that have the lowest prices, it is Bixia that is present. In contrast, ***AllTele*** always has a higher price of 299 SEK/month for villas, so if there is no other competitor, the price will stay high. Additionally, ***T3***, ***Bredband2***, and others do not offer lower price, as they tend to offer the same price for all municipalities where they are present in the Telia Öppenfiber network. As it happens these two operators (***T3*** and ***Bredband2)*** have a relatively higher price than others.

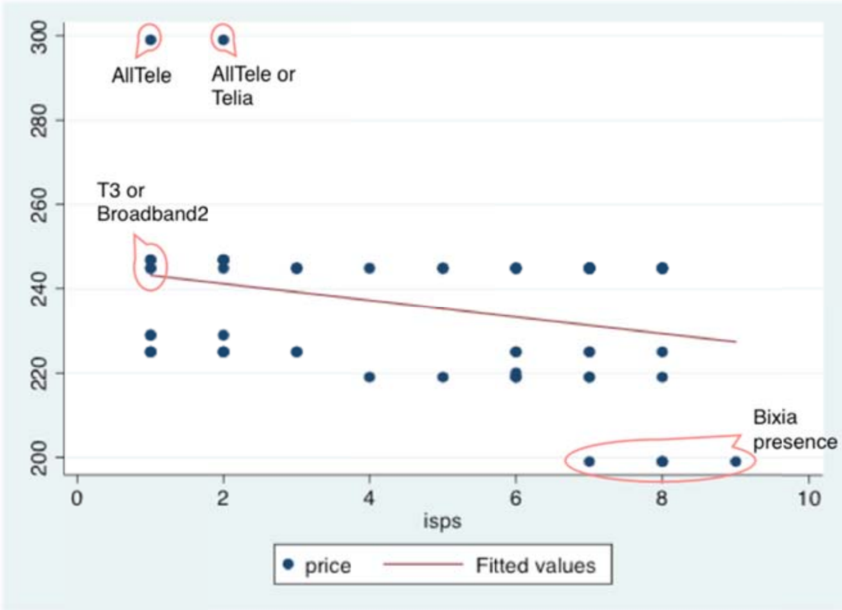

Figure 4-8: Linear Prediction of Price vs. number of ISPs via Telia Öppen Fiber

In our study we found there is a discrepancy, which clearly indicates that there are completely different conditions in different municipalities. In Sweden the 290 municipalities are grouped to 21 regions (Län). We assumed that different conditions (e.g. economies of scale, demographic difference, urbanization degree, technology development, and regional authorities' cooperation, etc.) in different regions might also have various degrees of impact on price, therefore ***Regional dependent factors*** were considered interesting indicators that might drive the price up/down. The regression result is shown in Table 4-15.

Table 4-15: Robust Regression Results: Given Län Flags

```
Linear regression                               Number of obs =        189
                                                F(  5,    183) =     65.58
                                                Prob > F       =    0.0000
                                                R-squared      =    0.5700
                                                Root MSE       =    19.118
```

price	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
isps	-6.933326	.7581319	-9.15	0.000	-8.429129	-5.437523
delta_pop_c~2011	-50.87413	20.07747	-2.53	0.012	-90.48722	-11.26103
itux	-25.73095	3.131903	-8.22	0.000	-31.91023	-19.55167
vasternorrland	32.3792	5.291948	6.12	0.000	21.93812	42.82027
stockholm	12.42234	4.910099	2.53	0.012	2.73466	22.11003
_cons	245.6729	4.939031	49.74	0.000	235.9282	255.4177

The result suggests that regions such as ***Västernorrlands Län*** and ***Stockholms Län*** have statistically contributed to driving up the price of Internet service via fiber networks.

Considering the correlations among the regressors as shown in Table 4-16, if a municipality belongs to *Stockholms Län*, then it tends to have a ***12.42*** SEK/month higher price, but the population change rate of the municipality would compensate to reduce the price somewhat. Most municipalities have higher rate of population change than *Stockholms Län* as they are mostly urbanized to a great enough extent that they are attractive for people to move to, so the increase in price is actually lower than what we would have expected for the average in *Stockholm Län* because there is some correlation with population change rate. On the other hand, we noticed that if we remove the Stockholm flag in the regression, then the population change in the last 10 years (i.e. named *delta_pop_change_2011* in the regression) becomes less significant with a low significance (t-stat$= -1.33$) due to the correlation between these factors. Moreover, it is statistically significant that if a municipality belongs to *Västernorrlands Län,* it tends to have a ***32.38*** SEK/month higher subscription price. This is because municipalities within *Västernorrlands Län* that have fiber networks are mainly only open at the service level, as the PIP also plays the role of NP (as an integrated *PIPNP*). Subscribers pay a monthly network connection fee (i.e. an NP fee) to the PIP in addition to the service fee. This NP fee is relatively high and varies from ***169*** SEK/month (in *Härnösand* municipality) to ***205*** SEK/month (in *Örnsköldsvik* municipality), which leads to a higher total Internet service expense in Västernorrland.

Table 4-16: Pearson Correlation of Price Regression Model

	price	isps	del~2011	itux	vaster~d	stockh~m
price	1.0000					
isps	-0.6439	1.0000				
delta_p~2011	-0.3390	0.3138	1.0000			
itux	-0.4168	0.2043	0.1924	1.0000		
vasternorr~d	0.2657	-0.0377	-0.1889	-0.0617	1.0000	
stockholm	0.0309	0.0860	0.4375	-0.0564	-0.0712	1.0000

Taking a look at the regression results presented in Table 4-15, there are still other factors that are driving prices which have not yet been explained, but we observe quite a significant impact due to the number of ISPs, which is basically independent without being affected by the other factors. To draw a robust conclusion, robust tests were done (see Appendix A were residuals are normally distributed and multicollinearity is tested,) we present the final model in *Equation 4.11*.

$$\boldsymbol{P_{i,t} = \kappa_0 + \kappa_{ISP} \cdot N_{ISP_{i,t}} + \kappa_{ISP} \cdot \Delta pop_{i,(t_0-T)} + \kappa_{iTux} \cdot iTux_{i,t} + \kappa_{vastn} \cdot V_{i,t} + \kappa_{sthlm} \cdot S_{i,t} + \omega_t}$$

Equation 4.11

Where:

$t = 2012, t_0 = 2011, T = 10$

i is the municipality ID and equals *1,2,3,……290*

$P_{i,t}$ is the to date lowest price of subscribing to fiber-based high-speed Internet services (with at least 10Mbps or above) in the municipality i in 2012.

$N_{ISP_{i,t}}$ is the number of ISPs that is presenting on the fiber network with high-speed Internet services (with at least 10Mbps or above) in the municipality i in 2012.

$\Delta P_{i,(t_0 - \mathrm{T})}$ is the population change in the past 10 years, from year 2002 to 2011 in municipality i.

$iTux_{i,t}$ is a binary NP flag, in which 1 indicates that the network provider iTux is presenting in the market in the municipality i in 2012, whereas 0 means not present.

$V_{i,t}$ is a regional binary flag, in which 1 indicates that municipality i belongs to the Västernorrlands Län while 0 means it does not.

$S_{i,t}$ is another regional binary flag, in which 1 indicates that the municipality i belongs to the Stockholms Län while 0 means it does not.

ω_t is the error term, which is the difference between what the model predicted and what the actual measurement is.

Based upon the statistics of robust regression that were illustrated in Table 4-15, the estimated parameters are then obtained as listed below with ***95%*** confidence intervals, with ***57%*** variance ($R^2 = 0.5700, p = 0.000$) explained by the introduced variables.

$$\kappa_0 = 245.673 \pm 9.681 \qquad \kappa_{0ISP} = -6.933 \pm 1.486$$

$$\kappa_P = -50.87 \pm 39.352 \qquad \kappa_{iTux} = -25.731 \pm 6.139$$

$$\kappa_{vastn} = 32.379 \pm 10.372 \qquad \kappa_{st\hbar lm} = 12.422 \pm 9.624$$

One can now estimate that 245.67 SEK/month is the base line for monthly subscription price of 10/10 Mbps fiber-based Internet service, with every additional ISPs competing in a network lead to a reduction of 6.93 SEK/month from this base line. A one percent increase in the rate of population change brings a decrease of 50.87 SEK/month. Moreover, the monthly cost would be 25.73 SEK/month lower when subscribing via **iTux's** fiber network. Furthermore, if the municipality one lives in belongs to **Västernörrlands Län**, one pay an extra 32.38 SEK/month more than in other regions, except for those living in **Stockholms Län** where an extra 12.42 SEK/month is charged on top of the base line. The variation in prices in these regions is because the economies of scale and geographical conditions are different, which in turn may influence the business models that are adopted (e.g. an externally contracted NP or a municipality-owned NP) thereby causing a price variation.

Figure 4-9 displays a plot in which each point represents a fiber network (i.e., Stadsnät), where the *x*-coordinate indicates the number of ISPs that is offering the same services in a network, and the y-coordinate indicates the lowest prices of among these ISPs that are competing in the same network. The red fitted line exhibits a linear prediction of our pricing model. One can observe graphically that the number of ISPs via *Stadsnät* negatively affects the price of subscribing to fiber-based network services, thus more ISPs competing in the same fiber network (i.e. *Stadsnät*) would eventually benefit the consumers with a lower price. The prices in the network with just one SP for the same service vary between 209 - 299 SEK per month, whereas the same service in networks with more than 10 different SPs cost between 139 - 163 SEK per month at most. If one compares the lowest price deals, the difference is between 70 - 136 SEK per month. A comparison between the most expensive network with only one SP and the lowest priced option in the network with the most competitors, gives a large different of 160 SEK/month, hence a higher cost by 1920 SEK/year for the same service depending on where one lives. Note the actual measurement can be slightly different from the prediction because there are possibly specific properties of each individual price, which are not modeled due to random fluctuations in prices, and the error variance is minimized by the other parameters considered in our model.

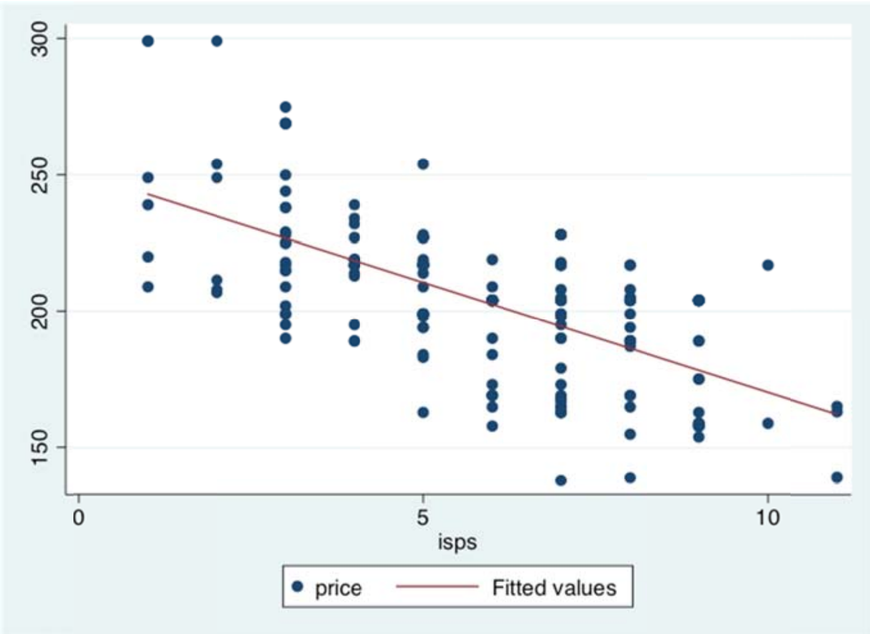

Figure 4-9: Linear Prediction of Lowest Price vs. Number of ISPs via Stadsnät

Is the price decreasing (going down) because competition puts pressure on all business sectors to reduce their prices, or is the case that different SPs have different prices and the probability of having a SP with a lower price present in network is higher, meaning a price decrease is more probable when there are a larger number of operators? We will perform a quick check of the average price.

One can see from Figure 4-10 that on average, all the SPs tend to lower their prices when there are more competitions, and the lowest price available is going down even more. Hence, we conclude that H_0 in Hypothesis 2 is rejected, meaning price is pushed down due to the fact that there is competitive pressure on SPs to lower their price. The subscribers thus have a broader choice in terms of service price when the number of SPs increases, hence the possibility to save money is greater even than just the average price. Comparing Figure 4-9 and Figure 4-10, it is clear that increasing the number of SPs will reduce the Internet service price considerably. In particular, for each new SP present in an open fiber network, the average price goes down by about 5 SEK per month and the lowest price will decrease by approximately 7 SEK per month. This is in line with the traditional market law that stronger competition is expected to lower prices.

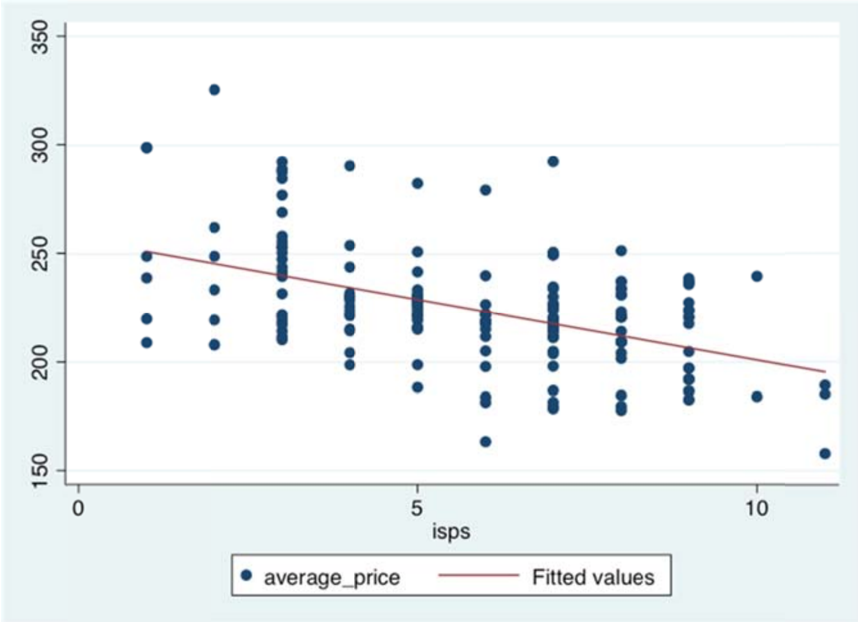

Figure 4-10: Plot of Average Price vs. Number of ISPs via Stadsnät

5 Conclusions and Future Work

This chapter summarizes the conclusions of this thesis project, along with discussions of the constraints during the research process and suggestions for possible future work. Reflections with respect to social, economic, and ethical issues associated with the project are reviewed as the end of the chapter.

5.1 Conclusions

The aim of this study was to shed light on the impacts of FTTH on aspects of society and the economy based upon quantitative evidence. This is important because FTTH as the next generation broadband access technology is considered a key ingredient in the development of knowledge economies and societies. While many studies have highlight the importance and effects of traditional broadband, little has been written based upon quantitative evidence from the perspective of FTTH deployment. Given the importance of filling this information gap in terms of the substantial benefits of FTTH, two earlier identified socio-economic indicators are examined empirically by means of multivariate regression analysis using the data collected from 290 municipalities in Sweden.

It is evident from the statistics presented in this thesis that fiber-based access networks have gradually replaced the copper-based access networks, and these fiber-based access networks have increasingly benefited society in recent years. Specifically, a higher fiber penetration of 10% at workplaces and 13% at residential places in a municipality in 2007 lead to a 0.17% improved population evolution between 2007 and 2010. The excess of migration and birth rate account for the majority of the population growth, respectively with a positive change of approximately 0.12% net immigration and 0.06% birth rates in the next three years.

Regarding the current FTTH network market, the study (included 282 different networks, both municipal and private ones) found that an open network with multiple competing service providers has a wider range of services and especially lower prices. Particularly, with 245.67 SEK as the base line of the monthly price for subscribing to Internet services via fiber, every additional ISP competing in a network leads to a reduction of around 5 SEK per month for the average service price and a decrease of approximately 7 SEK per month for the lowest service price, except for Telia Öppen Fiber. This result is in line with the traditional market discipline that stronger competition is expected to lower prices. However, Telia Öppen Fiber is found not to be influenced by the number of SPs presented in the network, although the price level on average is slightly lower via *Telia Öppenfiber Lägenhet* than via *Telia Öppenfiber Villa*, because the overall installation cost is lower for a lägenhet (i.e., apartment) than for a villa (i.e., single home).

Apart from FTTH, demographic factors such as the previous trend of population change, the proportion of foreigners, and proportion of people who commute regularly into a municipality for work, as well as socio-economic factors such as urbanization have effects on the population change in a municipality in Sweden since 2007. In particular, on top of the original population trend that a 10% population increase in 1998-2007 leads to an approximately 2.45% positive growth between 2007 and 2010, with all other things equal, the degree of urbanization was found to be significantly related to the population change of a municipality. This is reasonable because urbanized areas are currently still attracting people (including foreigners) to work, commute, and reside in Sweden. Moreover, the study found that a 10% higher population who regularly commute into a municipality in 2007 contributes to more than 0.45% growth in population between 2007 and 2010, indicating this dynamic group commonly tends to settle down in a municipality to which they regularly commute. It was also noticed that in many cases a high portion of foreign citizens and family building are interrelated, because the significant statistic result supports the theory that immigrant groups tend to have a higher birth rate shortly after immigrated to Sweden, with a 10% more immigrants in 2007 tending to give at least 0.19% positive growth in births between 2008 and 2010. Part of the effects of both in-commuting and immigrants can also be explained by the degree of urbanization, as this may attract persons to move into a municipality to a great extent.

As to the FTTH open market, we clearly see that the competition is mainly on the service level (i.e., competition among SPs). Nonetheless, the price is not affected only by number of competing SPs. It was observed that competition exists also at the NP level, yet not as intensely as among SPs. Although we observe some difference in the price offered by various NPs, it should be noted that prices are always associated with a diverse bundle of services in the Swedish fiber open market. That is, a lower price is normally complemented by higher requirements on bundled services, with a longer contract period (e.g., 12 to 18 months) and a long required notice period for termination (e.g., 3 months). These NPs are able to offer lower price to SPs, which will eventually pass this savings on to their subscribers because they have guaranteed revenue from the associated bundled services. Moreover, the study found some regional factors that suggest that service prices varies depending on the overall development context of municipalities, the openness of the local fiber market, and more importantly the local authorities' initiates and involvement. Demographically, increased dynamicity of population change in the past 10 years in a municipality was found conducive to more favorable prices due to further competitive pressure on the suppliers, as this group of people is considered more broadband inclined and discerning in their choice of Internet services.

All results presented in this thesis are found statistically sound according to the robustness tests (see the Appendix).

5.2 Future Work

In this study we are able to capture some early positive impacts of FTTH in Sweden, particularly on population evolution, and more specifically on the benefit to subscribers of lower service costs. Nevertheless, a number of economic impacts are not observable yet. Part of this is due to the fact that the rapid deployment of FTTH in recent past has not yet allowed for wide availability of data that focus on different aspects related to the FTTH technology, which is also the main limitation of this study. As to the telecommunication market, the available information is unfortunately a mess. The lack of an integrated data source (e.g. price and other service details) increases the difficulties in regards to data collection, in this study information was collected manually from the websites of each NP, SP, and each municipality, and it requires quite extensive work and is very time consuming to collect this data. During the study, a database was established for data stability and security purposes, and an analysis method (i.e. econometric regression model) for quantifying effects was developed. It is believed a more advanced/intelligent mechanism for data collection would simplify the data processing to a certain degree and would save a lot of time.

This study could be extended by incorporating richer and more descriptive variables to see if FTTH impacts many other aspects, such as policies/decisions of authorities, location of newly created companies, etc. These aspects were not found statistically significant at the early stage of our study due to the lack of data. It is highly recommended to incorporate as many socio-economic effects in the analysis as possible in order to draw a complete picture for all interested sectors, including concerned authorities, local governments, market players, and private investors.

In addition, our findings on the price level (base line: 245.67 SEK per month) that we obtained is coincidently found to be generally in accordance with the very latest report published by PTS[79], which collected data in a different way, yet it supports our results to a great extent – but gives us greater confidence in our data collection and analysis. Nevertheless, one should be aware that some of the effects observed in this study, especially the practical competition in the open access network and the price of Internet service have certain provisionally, because the statistics obtained are based on the information (e.g. price) currently available online. It is noticed that market information such as prices of Internet services vary frequently on SPs' websites (as the latest data for the prices have been updated 2 to 3 times during our research). Although the price changes could be in the order of 10 to 20 SEK magnitudes, they occur seldom enough to change anything significantly; especially the regression results have never been changed. Nevertheless it would be interesting to take this into consideration in a further study, to figure out whether these changes in prices are due to changes in marketing strategies based upon the current market and economic situation, or if these changes in prices are due only to periodically price adjustments for all SPs, thereby enhancing the current econometric model for a more comprehensive analysis.

Furthermore, the competition in the open access fiber network is measured in this study in terms of the number of competing SPs for the 10/10Mbps Internet service, NPs operating different fiber networks, and regional dependent factors. The study draws a clear picture of the main influential factors; however, it is not a complete picture of the competition, as some variance still remains unexplained. We noticed from the study that besides lowering prices, networks with more SPs seemed also leading to increased service differentiation (e.g., 10 Mbps, 100 Mbps, 1Gbps, 10 Gbps, Triple-play, etc.), however, we were not able to investigate in more detail and will leave for future work. Prices of a specific operator (e.g., Broadband2, Bahnhof, etc.) when plotted as a function of the number of competitors they have would also be interesting to explain the competition and change in price from another angle. Last but not least, what other external factors influence the Internet service price (e.g., construction costs for fiber infrastructure, local socio-economic situation and hence market size as well as price elasticity, other potential strategic and commercial factors) and current pricing mechanism from SPs' internal perspective (e.g., aggressive pricing) are worth further studies, as SPs could therefore create corresponding pricing strategies with more structure and greater service differentiation.

5.3 Required Reflections

This study acts as a starting point for assessing the macroeconomic impact of fiber-based access technologies (i.e. FTTH) on social development and economic growth. We have identified the main benefits of having FTTH, their beneficiaries, and the mutual interactions among them. The positive analysis results indicate a great potential for FTTH, which specifically, may significantly benefit smaller municipalities in terms of improved population evolution (less people are forced to move away), as well as benefit consumers by decreasing the cost of Internet service but with better QoS and this may stimulate consumption and hence economic growth. For instance, to give an idea of the magnitude of savings that open access on full competition leads to, a closed network changing to full openness to attract many service providers (e.g., from 1 SP to 11 SPs), would lead to a lower prices of 50 SEK/month at the lowest price and 70 SEK/month as an average price, meaning one could potentially induce 600 to 840 SEK/year in savings per end user. Making a very rough calculation, assuming 15% out of 4 million households who do not currently have access to an open network[80] would have access to a fully competing open network, this might lead to an approximately 500 million SEK/year in savings.

The substantial benefits of having FTTH suggest that there is a need for local authorities and investors to take these benefits into consideration, since the promotion and adoption of such ICT advancement will both benefit them and eventually benefit the whole society via development and economic growth.

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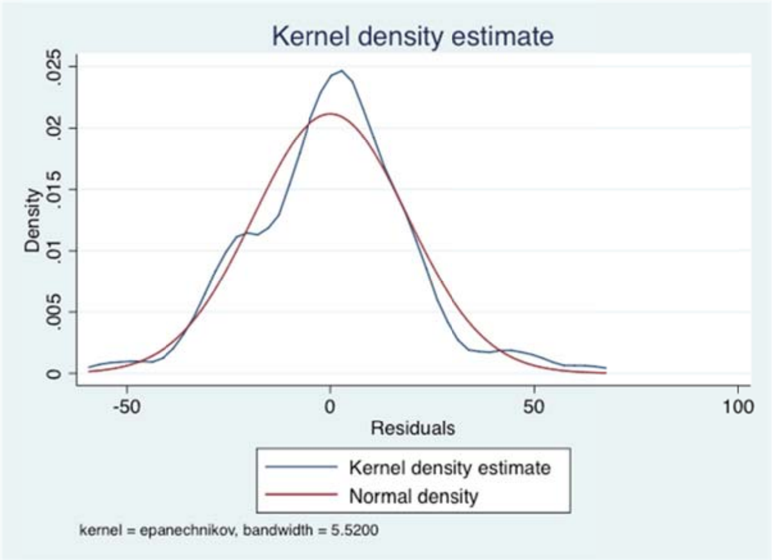
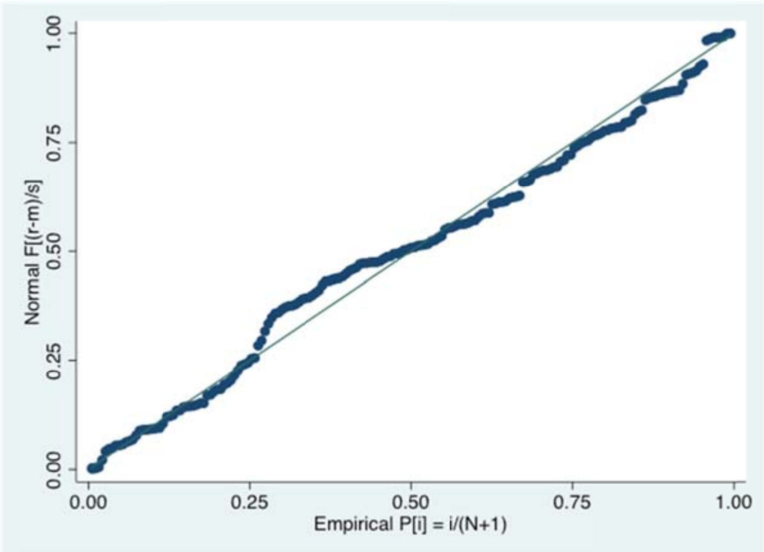
Appendix A – Robustness Test

A-I. Normality Test

In a regression model, residuals need to behave "normal" in order to ensure the validity of all tests (e.g., p-, t- and F-test). Here residuals are the difference between the observed values and the predicted values. The figure shown below will help us check for normality in the residuals. It seems that the residuals follow a normal distribution in general.





The above standardized normal probability plot (pnorm) checks for non-normality in the middle range of residuals, and indicates that the residuals are normally distributed since they lie around the normality line.

A-II. Multicollinearity Test

It is important for our multiple regression model that independent variables should not be a linear function of each other. Hence a Variance Inflation Factor (VIF) test is performed:

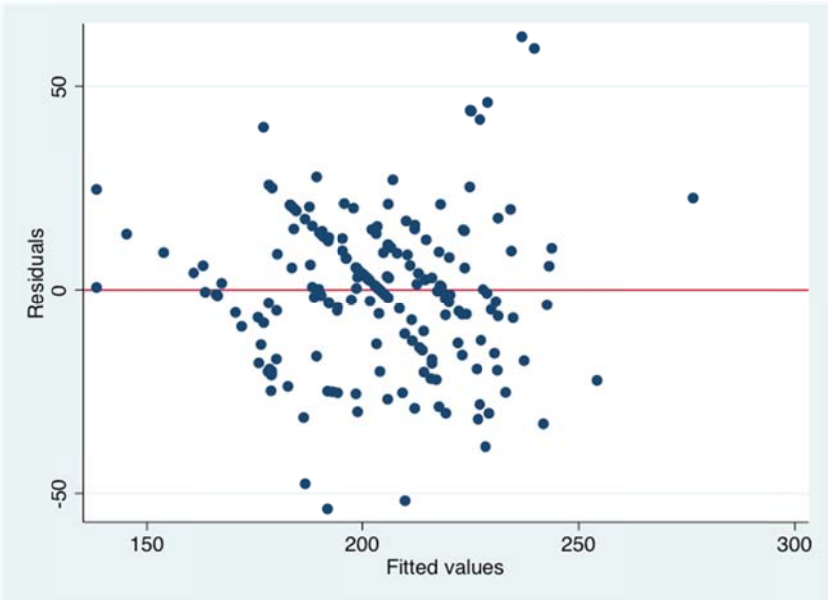
Variable	VIF	1/VIF
delta_p~2011	1.46	0.685701
stockholm	1.27	0.786977
isps	1.14	0.878154
itux	1.09	0.917514
vasternorr~d	1.04	0.962829
Mean VIF	1.20	

VIF test result suggests no multicollinearity among instrumental variables that is used in our regression of price model, as the VIF value is within the acceptable range.

A-III. Heteroskedasticity Test

There are plenty of ways to test Heteroskedasticity in Econometrics. Here a graphical method was chosen in order to detect it intuitively.

Homoskedasticity means that the variance is constant over the range of values for all the explanatory variables, otherwise heteroskedasticity exists. To exam if there is any alarming pattern in our model, a visual inspection of residuals against the predicted value of the estimated model is plotted as shown below:



We do not see a specific pattern of the scattered residuals, suggesting that we do not have any issues of heteroskedasticity.

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