Standardization in the Professional VoIP Market
Making Compatibility Continuous

Carina Suchanek

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University of Maastricht

Faculty of Economics and Business Administration

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Suchanek, C.

I193194

Infonomics student

Supervisors: Dr. M. Strobel and Dr. R. Peeters

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Abstract

This thesis analyzes the implications of the new possibility for continuous compatibility in the market for IP PBX systems. The introduction of VoIP into the PBX market has set off remarkable changes in terms of market structure. When modelling the market as a two-firm Undercut-Proof Equilibrium, it turns out that the optimal firm strategy is to choose for a certain degree of partial compatibility. This way, firms can maximize their pay-off compared to full compatibility or incompatibility by making the best trade-off between additional network externalities and switching costs for their consumers. The welfare effects represent an improvement over the situation with complete incompatibility. Nevertheless, welfare would still be optimal under complete compatibility. Given the available empirical information, the situation of consumers is likely to slightly improve over that under incompatibility. The major theoretical contribution of this work is the extension of a discrete choice model for continuous compatibility.

Contents

Preface

"One definition of an economist is somebody who sees something happen in practice and wonders if it will work in theory" (Ronald Reagan)

If this definition applies, the present master thesis is a truely economic one. The whole idea of this work developed when I was experiencing network economics in practice. When completing an internship in the Unified Communication Solutions team at Computacenter AG in 2005, I was fascinated to see how a network technology like the Internet Protocol can turn an entire market on its head. In this case, "an entire market" refers to the professional voice market. The market which sells PBX (private branch exchange) systems, the little boxes sitting in each firm's basement handling the internal phone traffic. On top came the rather short time, in which the market seemed to change. Market structures that had been incrusted for decades suddenly stood at disposition. Certainly, the business market is not as exciting as Skype's story, but it is still enticing to observe how IP is worming its way into every corner of doing business in the professional voice market.

Despite all the excitement, many questions about the future developments remained. After several slow years, VoIP had only recently started to replace legacy technology on a larger scale. In network economic terms, it looked as if a critical mass had been reached. More terms like "lock-in" or "standardization" kept popping up and finally gave me the idea to look to economics in the hope of answering some of the many left over questions. Who and how many companies would win the market? Who would gain, companies, consumers, society? Would there be chance for compatibility? In other words, I was wondering what the professional VoIP market would look like in theory.

So far the quote fits quite well. I am not sure, however, whether Ronald Reagan anticipated the difficulties that can arise when employing economic analysis to examine a specific real-world market. In any case, it turned out to be a tightrope walk as models quickly became unsolvable or showed themselves to be immune to even the seemingly smallest extensions. The real world at times seemed to come up with ever new complexeties I had not thought of before.

Ronald Reagan might answer “Why bother anyways, reality works”. It does indeed, but as actors within a market, we want to make sure we get the best out of it. For that matter, a structured view on the market development and its underlying mechanisms is essential. In my opinion, economics can provide such a view and thereby deliver deeper insights to all market players. Firms can determine their optimal strategies while governments might consider intervening in the case of understandardization. Network can help prioritize the elements of a complex network market like the professional VoIP market and thereby discern the most important contingencies for future development. From this thesis, I draw the conclusion that it might not always be feasible but still an option worthwile to be investigated. Afterall, economists might be people who see something happen in practice, wonder if it can be explained by theory and then develop an optimal strategy.

Last but not least, I would like to thank all those who have supported me in one or another way while writing this thesis: My family for support in any kind of sense, Martin Strobel for his help whenever needed, Hartmut Leyendecker, Guido Thater and Christian Louis from Computacenter for their expert input, Ronald Peeters and Kasper Leufkens for their mathematical aid and my friends for all the proof-reading and many hours at the library, especially Heiko Lampe, Katharina Eckartz, Christian Mondorf, Marc Eschenburg, Gerlinde and Fleur.

Chapter 1

Introduction

"Architecture is politics."

- by Mitchell Kapor, currently chair of the Open Source Applications Foundation, amongst others designer of Lotus 1-2-3, former CEO of Lotus and founding chair of the Mozilla Foundation

1.1 VoIP - recent developments

In 2003, Niklas Zennström and Janus Friis, developed Skype, a piece of software enabling internet telephony. Two years later, Skype was sold for $2.6bn to Ebay. Even though Skype did not comprise much more than "an authentication server with a bunch of accounts sitting on that" (Stofega in Sanders, 2005), eBay sensed its potential of becoming the future de facto standard for consumer internet telephony. The fact that Skype has amassed 100 million customers within three years, probably proves them right (skype.com).

This thesis is not about Skype, but about similarly remarkable events in a similar market, the professional VoIP market. This is the market for IP-based PBX systems, which are boxes handling a company's internal phone traffic. With the proliferation of the Internet Protocol into the voice area as such, remarkable developments have set off in the business VoIP market as well. In countries like Germany, the world of Private Branch Exchanges (PBX) has been a rigid market for decades (computerwoche.de, n.d.). Since the take-off of VoIP technology in 2002/2003, the peaceful coexistence of a handful of oligopolistic vendors has ended. Seemingly immovable market shares started to float and new entrants like Cisco have managed to attract as much as 20% of IP PBX sales over a short period of time (Gruber, 2005).

The specific characteristics of information technology and phenomena like critical mass and positive feedback enable skype-like success stories. In this sense, the Skype story illustrates many aspects of the economics of the information society and especially of the IP generation. One of these aspects is the importance of standardization. In the run for network markets, standardization plays a major role in ultimately determining the winner, who often takes it all, and the loser, who is left with nothing. As argued above, Skype has managed to move beyond the point of critical mass and establish itself as the standard for consumer internet telephony. In the case of the professional VoIP market, the standards as well as the winners have yet to be determined. Future variety, prices, profits and not to forget social welfare will largely depend on standardization, i.e. the choice of compatibility.

When looking ahead, one should not restrict one's view to the professional VoIP market. All in all, the analysis of that market can be seen as an illustration for other IP-based forms of communication. Many fundamental characteristics of the corporate PBX market extend to technologies like instant messaging, the current consumer VoIP technology and future PSTNs (Public Switched Telephone Network). In the case of instant messaging, for example, an open platform called Jabber is currently being developed. Existing market players like ICQ, MSN Messenger or AOL-Instant Messenger can now decide whether they allow their users to chat to users of rival networks by implementing Jabber. But this is not all, they can also decide whether features like personal pictures, extensive search functions or chat protocols will be interoperable or not. Thus, models of continuous compatibility can be of help in analysing these markets in the future.

1.2 Professional VoIP market - future developments

This master thesis employs several network economic concepts to shed more light on the current and future developments in the business part of the VoIP market. The business, or professional, VoIP market is made up of companies' private telephone networks. These include PBX systems, the lines and telephones attached to them as well as the different applications they sustain. Network externalities exist because the individual parts of the PBX are complementary. Those in turn bring about the crucial importance of standardization and the choice of compatibility. As mentioned above, the chosen degree of compatibility between the PBX systems, telephones and software applications will be a major determinant for the future market coordinates, like prices and profits.

The crucial question to ask then is, which factors determine the degree of compatibility that will result. Considering the financial stakes, such insights can be essential for strategic decision-making by market participants. Furthermore, the present analysis can be helpful for political decision makers and standards-setting bodies. Several past studies have found the possibility of socially suboptimal amounts of standardization (e.g. Jonard & Schenk, 2003 or Church & Gandal, 1992). Such findings might be arguments in favour of state intervention. Moreover, standard setting bodies should realize the incentives individual companies might have when involved in the standards setting process (Farrell, 1996).

To answer the question for determinants of compatibility and welfare implications, an empirical research design as well as a theoretical model can be considered. An empirical analysis can currently not be conducted, the main reason being that empirical data is not available. This is because the transition from the old proprietary technologies to VoIP is far from being completed. This implies that the market is still very dynamic. The outcomes of these dynamics and of the standards setting process have yet to be seen.

In order to explore the determinants of future market outcomes, one should therefore turn to a theoretical model. As it turns out several microeconomic models have dealt with the question of compatibility and standardization in the past (e.g. Katz & Shapiro, 1985, Church & Gandal, 1992, Shy, 2001 or Jonard & Schenk, 2003). These models are, however, only partly applicable for the corporate PBX market because they exclusively allow for yes/no decisions regarding compatibility. The introduction of the IP protocol has not only given competitors the opportunity to decide between compatibility and incompatibility. The possibility to combine other open as well as proprietary communication standards with the Internet Protocol, allows producers of PBX systems to select from a range of different levels of compatibility. Consequently, the current theoretical models need to be extended for continuous compatibility to answer the question at hand. The Undercut Proof Equilibrium (UPE) by Shy and Morgan (2000) is best fit for such an extension as the trial and error of different models of discrete choice within the context of this thesis showed.

In summary, this thesis seeks to determine the factors influencing decisions regarding compatibility in the professional VoIP market and the effects different decisions will have on social welfare as well as prices and profits. This will be investigated via a theoretical research design. To do this, the status quo of the applicable microeconomic literature demands an extension for continuous compatibility.

1.3 Outline

This thesis is organized as follows. In chapter two, a closer look is taken at the professional VoIP market. Once the relevant product has been defined, the developments of the market from a proprietary oligopoly to VoIP are described. This is necessary to understand the current situation as well as companies' incentives. Consequently, an outlook to the future trends in professional VoIP is given. Two in-depth interviews that the author conducted with experts in the field serve as the basis. Such an outlook is crucial in order to identify the most important questions when it comes to determining future market developments. In addition, it will be relevant when setting assumptions for the theoretical model. It should be noted that all market-specific information, including the outlook, mainly refers to the German market as this information was more readily available. Even though the German market features a few special attributes, its general trends are representative for other European and most transoceanic markets. There, VoIP is replacing proprietary legacy systems as well (EITO, 2005).

Chapter three represents an account of attempts that have been made at answering questions similar to the ones asked in this paper. To be able to understand the microeconomic models employed for those attempts, one first has to clarify several (network) economic concepts. Clear definitions of network externalities as well as switching costs and compatibility are needed. Next, there is a general introduction to discrete choice models, the basic ingredient for all relevant models which are discussed. From the family of discrete choice models, a small sub-sample will be described in terms of specification and results.

Chapter four introduces a theoretical model which is based on previous works as described in chapter three. First of all, the chapter discusses the pros and cons of the chosen model variant, the Undercut Proof Equilibrium. After lying out the concept of the UPE, assumptions and parameters are specified. Finally, the chapter contains a symmetric UPE model including a description of results.

Representing the conclusion, chapter five is divided into four parts. In the first two parts, the results of the model are related back to the professional VoIP market. On the one hand, the implications on profits, consumer surplus and social welfare in that market are analysed. Next to that, the finding of partial compatibility is translated into concrete technological solutions. In the last two parts, limitations of the present research are pointed out and ideas for future research are suggested.

Besides the body of the work, the content of the appendices are worth mentioning. In the process of preparing this master thesis, several types of discrete choice models were used. As it turned out, the UPE could deliver the only feasible solution. In the interest of further research, however, appendix A describes alternative model types. These include the multinomial logit as used by Jonard and Schenk (2003), a linear probability model based on Anderson, de Palma and Thisse (1992) as well as different Hotelling models. Appendix B contains the interview protocols of the discussions the author had with three different experts from the field.

Chapter 2

The Professional VoIP Market

PBX systems have been handling phone traffic within companies for more than 70 years (Todd, n.d.). Until recently, they were characterized by proprietary technology, each supplier employing his own technology standards for communication protocols and operating systems (Costello & Lassman, 2005). Because of these proprietary standards, customers were locked in for the duration of a contract (not seldomly five to ten years) and beyond, since most systems were built and installed to last for 10-15 years (Ghemawat, 1991). With the advent of the Internet Protocol in this market, proprietary technology gives way to standardized protocols like IP, SIP or H.323 as well as standard operating systems (Costello & Lassman). This change in technology has not only greatly reduced lock-in effects, but has also set off a process of fundamental change in the market structure (Blood & Lock, 2004).

Before examining these fundamental changes, the professional VoIP market needs to be properly demarcated from the private market. For this purpose, the terms IP telephony and internet telephony need to be differentiated. In the business customer market, VoIP most often stays within the company's LAN or WAN. It hardly ever extends to the internet as does private customer internet telephony like Skype. Instead, voice signals are converted back onto the traditional Public Switched Telephone Network (PSTN) as soon as they leave the company. The main reason for this is a lack of security and quality of service (QoS) on the internet. Very few companies have started to abolish their local telephone connection nevertheless. Those are not considered here. For the purpose of this work, the term IP telephony will be reserved for VoIP within company networks, whereas internet telephony, or "Voice over the Internet" (Eito, p.161) denotes the private VoIP market, exclusively including traffic outside of private LANs.

2.1 Product components and functions

According to Ghemawat (1991, p.161) “Private branch exchanges (PBXs) are switches located on customer premises to concentrate telephone calls to central exchanges”. In other words, a PBX handles a business’s internal phone traffic and bundles inbound as well as outbound calls. For that matter, all telephones within a company are directly connected to it. Telephones are, however, not the only connected peripherals. The PBX system has traditionally been at the heart of a diversified network mainly consisting of itself and phones but also fax machines, modems and specialized software applications.

In the past, this PBX system could be imagined as a large box, sometimes the size of a wardrobe. In the VoIP era, it is hosted on a server like many others on the network. Next to this server, gateways are responsible for call signalling and handing over from the LAN to the PSTN. This also implies that the separate voice network of copper cables has physically joined forces with the data network as depicted in the figures below (Nölle, 2006).

When a phone call to a certain staff member comes in over the PSTN, the PBX systems routes the call through to the appropriate telephone. In the same way, all outgoing calls need to pass the PBX system. The big box in the cellar can, however, do much more than routing calls. For a long time, the most important differentiation characteristics of a PBX system have been its call features. Functions like Call-Back When Busy or the Personal Secretary Functions are examples. Call-Back When Busy implies that when an employee is busy, the caller can be called back automatically once the called person hangs up. The Personal Secretary Function includes many small features a secretary and her boss might need. For example, such simple features as the ringing of both the secretary’s and manager’s phone when somebody calls the manager’s number, or the possibility to put through calls or simply put callers on hold. In decade-long development, many vendors, especially in Germany, have developed hundreds of such features. The description of features of one PBX system might comprise several hundred pages (Leyendecker & Thater, 2006).

Last but not least, the applications connected to PBX systems deserve further mention. This is especially so in the face of their increasing importance in the VoIP era. Many companies make use of additional software applications. One very common example is Automatic Call Distribution (ACD). It is mostly used in call centers. But additional software applications can also be found in more traditional companies like banks, who often employ CTI (Computer Telephony Integration) solutions to improve customer service.

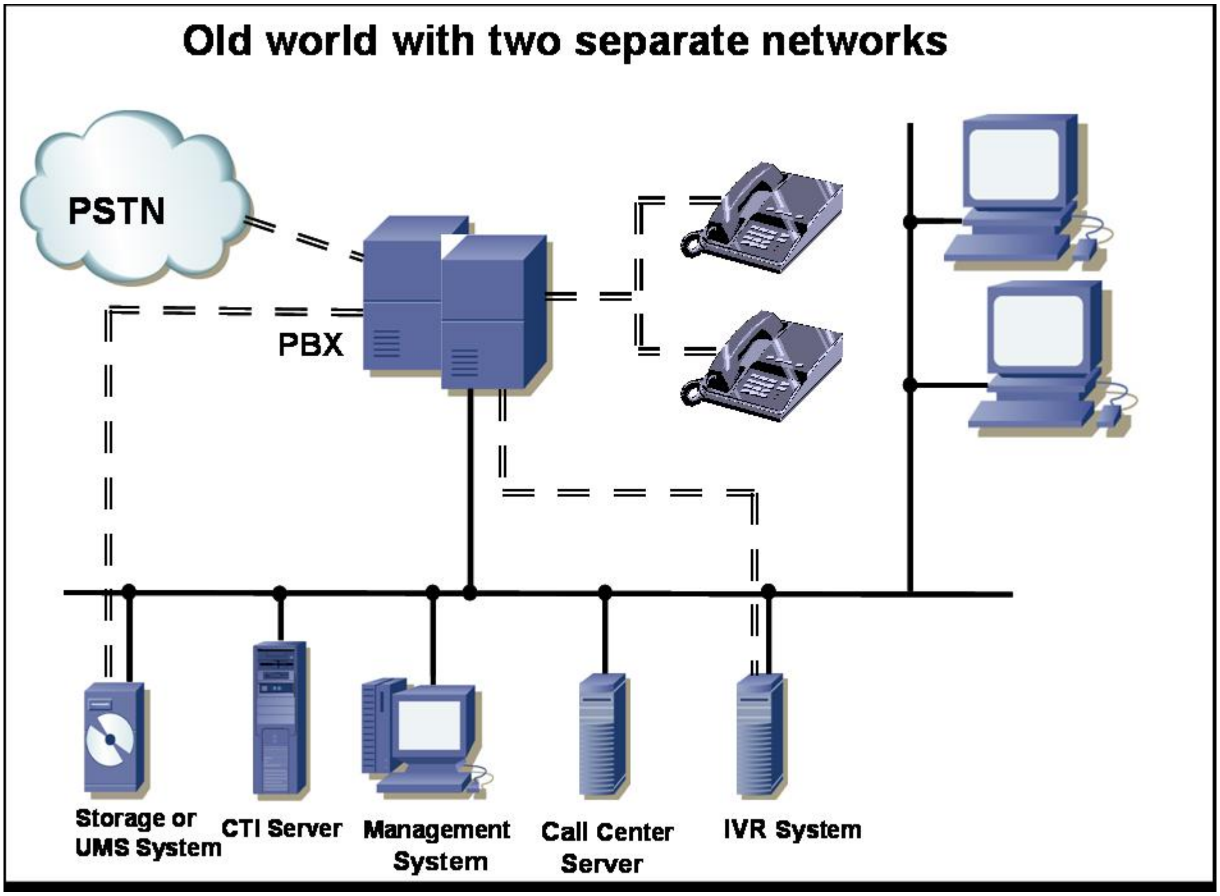

Figure 2.1: Old world telephony

In conclusion, it can thus be said that the PBX is inseparable from its many peripherals. We are therefore rather examining a system of complementaries than a single standalone product. Next to its traditional role as a private telephone switch, features and software applications have successively gained in importance. The following section highlights the most important steps in this development and explains how the introduction of VoIP has elevated the importance of complementary products, especially applications.

2.2 IP dynamics

2.2.1 The market as it was

As mentioned above, PBX systems have been around for more than 70 years (Todd, n.d.). Their penetration only took off though with telecommunications deregulation; at least in large companies that stood to save much in internal communication costs (Corley, 1998).

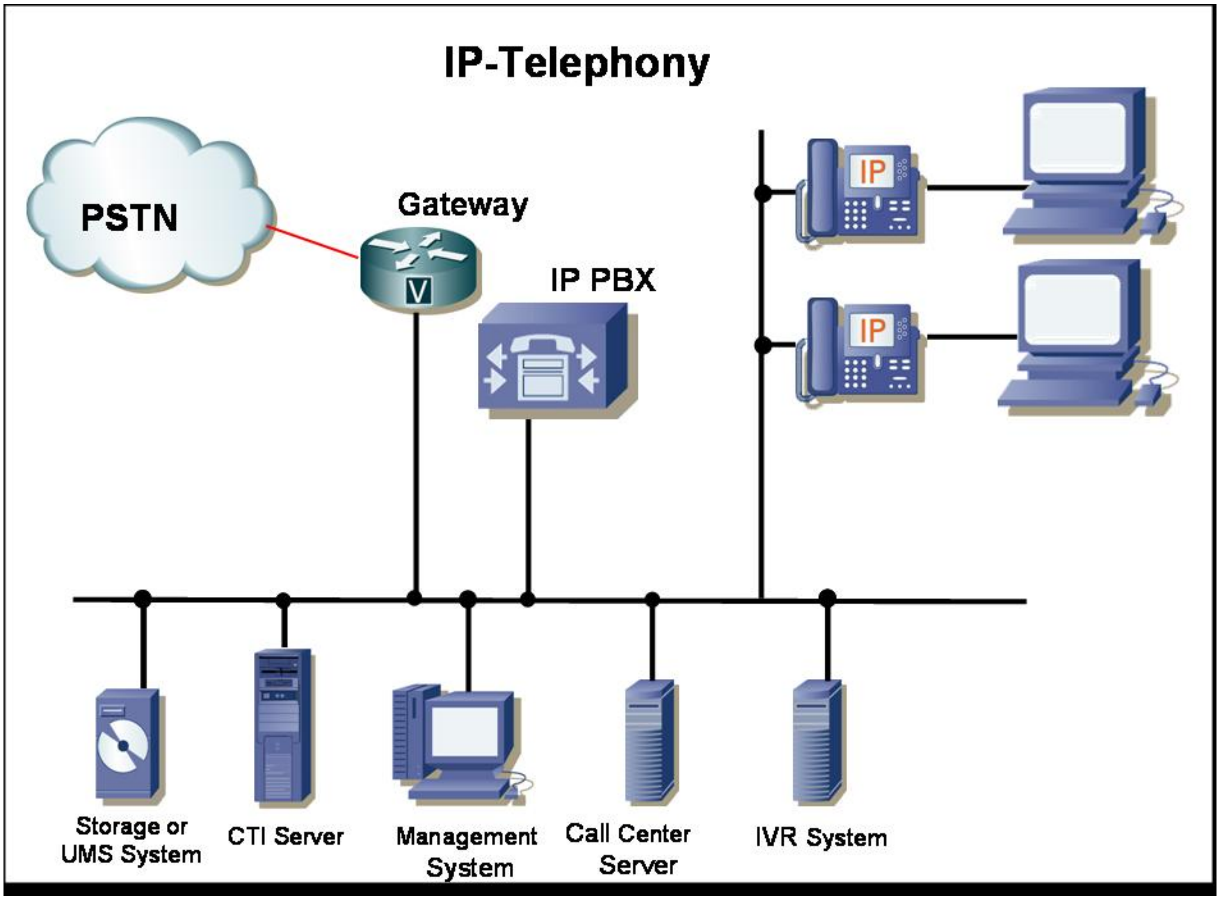

Figure 2.2: IP telephony

On the supply side, the PBX market has traditionally been dominated by a handful of large suppliers and some small market fringe. They have steadily developed their technologies so that PBX systems finally spread to include even the smallest companies. As Ghemawat (1991), however, points out, the market incumbents have been rather reluctant to fast technological progress.

A major reason for that resulted from the through and through proprietary technology employed (Ghemawat, 1991). This implies that technology was both generally incomptible and closed, i.e. the producers had full control over which products would be allowed to be compatible. Hence, proprietary operating systems including proprietary applications led to consumer lock-in and high switching costs. Combining this with the fact that PBX systems were supposed to last between 10 and 15 years, the market developed into a mature and relatively stable oligopoly.

Nevertheless, by the end of the conventional telephony era, the major German and international incumbents had developed sophisticated products including hundreds of call features and advanced applications. Because of their proprietary technology, however, especially the integration of applications was prohibitively expensive. In 1995, something happened which had the potential to change this situation, the first transmission of voice signals over the Internet Protocol (Moos, 2006).

2.2.2 The market coming to be

The ICT community had long been looking for ways to integrate the various seperate data and communication networks like Datex-P, Datex-L or Btx. In reaching this objective, the transmission of voice over data networks represented an important milestone (Moos, 2006). Why would it be so important to merge those different networks? Two very important reasons are interoperability and standardization (Moos, n.d.). These and other advantages directly result from the new technology employed. It is therefore useful to take a closer look at the two most influential protocols, IP and SIP.

2.2.3 IP and SIP

There is a whole army of protocols on different layers in terms of the OSI model, which are needed to make VoIP work. Amongst their colleagues like MGCP, SCCP, RTP or RTCP, the Internet Protocol and the Session Initiation Protocol (SIP) stick out. The Internet Protocol does so because it essentially represents the paradigm shift from traditional telephony to VoIP. Whereas SIP has caused most discussions, gained most in popularity literally causing a hype, and is more crucial for the further market developments than any other protocol.

When talking about the Internet Protocol, most people actually have the entire internet protocol suite in mind. This family of network protocols counts around 500 members and is needed to enable network communication on the internet (Siegmund, 2002). The most important difference between the internet protocol suite and the POTS (Plain Old Telephony Service) world can be described by the terms packet switching and circuit switching. In circuit switching networks, one wire is blocked by a single phone call. The packet switching internet, on the other hand, separates separates voice signals into small packages. Many phone calls can thus take place simultaneously on the same wire.

While this packet switching is already inherently more efficient, VoIP brings about further gains in efficiency. The merger of the physical voice and data network implies greatly reduced maintenance and building costs in the case of green field investments. Furthermore, one instead of two specialized groups of staff for maintenance of the network and adjacent technology will be enough (Moos, n.d.).

These being mainly cost advantages, more potential added value is associated with the Session Initialisation Protocol (SIP). According to Cumming (2003, p.1), SIP "is a signalling protocol for controlling multi-media sessions. In other words, it provides a way to establish voice, video and messaging communication between devices". Regarding added value, special attention has to be paid to the word "multi-media". SIP fits very well to make phones interoperable with other devices and applications, because it does not have its origin exclusively in the world of voice, but can also be used to start video or instant messaging sessions (Cumming, 2003).

This essentially boils down to enabling compatibility between pure telephony and applications like Computer Telephony Integration (CTI) whenever the respective features of SIP are used. Even more importantly, SIP could enable compatibility between phones and PBX systems. This is because the SIP protocol is essentially responsible for implementing most of the call features that used to be implemented by proprietary protocols in the old world. On the one hand, the prospect of compatibility being brought up by SIP represents a potential source of savings for consumers. Under compatibility, at least simple products are likely to become cheaper. On the other hand, companies might not allow consumers to profit from full compatibility. They still have the choice which features to implement in SIP and which to implement in proprietary protocols. Especially with respect to new features, it might be more profitable to employ proprietary mechanisms (Cumming, 2003).

There are other potential advantages connected with SIP that might convince producers to use it nevertheless:

The protocol greatly contributes to the fact that IP phones mimic plug and play devices in terms of the company network. Within the old world, every time an employee would move from one desk to another, physical patching or a programming effort from the PBX vendor or specialized in-house staff became necessary (Moos, n.d.).

All in all, these represent only some of the potential improvements associated with the SIP protocol. Easier conferencing, click-to-call applications or improved presence management are others. As the protocol has continuously been extended, further innovations are expected (Leyendecker & Thater, 2006).

In conclusion, the most important change brought about by the introduction of SIP, IP and co. is the move from a proprietary technology to open standards. If all networks and network applications consist of the same basic technology, large economies of scale are to be gained from their operation. Furthermore, customers clearly attach value to the savings and innovative potentials of open and common ICT standards (Shapiro & Varian, 1999).

2.2.4 The status quo

Before all these advantages were to be gained, several technical difficulties had to be overcome. Even though the first German firms employed VoIP in 2000, the market did actually not take off until 2004/2005 after sufficient QoS could be reached and a slump of the ICT industry was overcome (Moos, 2006). From 2003 to 2004, there was a 72% increase in the market share of IP PBX (Gruber, 2005) and in 2007 or 2008 the market volume of IP PBXs is expected to exceed the market volume of traditional systems (Gruber, EITO, 2005). However, the PBX market is not simply facing a switch in technologies. VoIP has rather set off a process of fundamental change in the market structure (Blood & Lock, 2004). Where previously market shares were hardly moving, new entrants, mainly Cisco, have been able to take on the market lead in pure IP systems (IDC in Hübner, 2005). But VoIP is also reshuffling the cards among the incumbents (Gruber, 2005). By now, there exists a common understanding among experts that IP PBX will completely replace the current legacy systems in the medium term (EITO, 2005, Nölle, 2006).

However, there are several reasons why this will not happen in the short run. The first and foremost reason are switching costs. As mentioned above, formerly, PBX systems were meant to last 10-15 years. This implies that many maintenance and or rental contracts are still running. And even if a contract runs out, it is often both possible and cheaper to keep many of the old phones instead of buying a completely new set of IP phones. Thus, virtually all traditional PBX manufacturers have come up with soft migration strategies to overcome the problem of switching costs and keep their own consumers. Even new entrants' systems can integrate simple analog phones. This implies that many companies have bought "IP-enabled" or so-called "hybrid" PBX systems. On the one hand, this opens the door for IP, but on the other hand, it might also slow down the development towards a pure IP world. All in all, it will take several years more before the current voice world gets close to a pure VoIP world.

2.3 The market ahead

This future VoIP world, in which there are few legacy systems left, is exactly what this thesis is concerned with. The question asked here is what will be the market outcome once all players have made their choices in a one-shot, simultaneous game. Instant equilibrium is assumed rather than exploring the intricate dynamics that are currently evolving among players of different heritage, weight and capabilities. In this sense, the present thesis is an analysis of comparative statics. From the above description of technology, it is clear that companies can make technology decisions in a strategic manner. Chapter three will show that they also have incentives to make use of this possibility. By deciding on proprietary protocols vs. SIP, they can determine compatibility and thereby other important market variables as described above.

But, what is exactly meant by "compatibility"? These and further concepts need to be defined before plunging further down into the details of future market development. This will be done in the next chapter. A second topic to understand before looking at the market of the future are the specifics of the German market. That is since the outlook will largely be based on that market and the interviewed experts work in this market as well.

2.3.1 An excursion into the specifics of the German market

Since especially the market outlook has been based on the German market, the specifics of this market are important to mention.

If call features were mentioned above to be of major importance for PBX buyers, they have been vital in the German market (Leyendecker & Thater, 2006). Accordingly, German producers of PBXs like Siemens have adapted to this need and manufactured particularly feature-rich systems. Naturally, this means that these companies also have a relatively larger share within Germany compared to US companies and less feature-rich products in general.

Even more importantly, the strong preference for feature-variety implies a slower adoption of VoIP or at least standardized VoIP by the German market. This is due to the current trade-off between VoIP/SIP and feature variety as described above. As long as the SIP protocol and pure IP PBX in general offer less features, Germans are less likely to adopt them.

This trend is reinforced by a latent reservation towards certain types of innovation in many German companies (Wewartz et al., 2006, Leyendecker & Thater, 2006). In this sense, German companies might be less willing to sacrifice a traditional features or 0.1% of system availability in return for innovative software applications.

Even though these specialties might lead to a somewhat slower adoption of VoIP or the SIP standard in the medium term, experts agree that this will merely cause a temporary delay (Nölle, 2006).

Chapter 3

From Externalities to Standardization - Basic Concepts

So how come that IP has enabled such remarkable changes? The answer can be found in the special features of the professional VoIP market as a network market, namely network externalities, switching costs and the resulting issue whether to standardize or not.

Among other things, the present chapter will answer the question of how exactly these phenomena contribute to the impact of IP on the market. First of all, the concepts of network externalities, switching costs, standardization and compatibility will be explained and properly defined for the purposes of this thesis. This does not only entail a definition against the present economic literature, but also an applied definition towards the professional VoIP market.

3.1 Network externalities and switching costs - "The root of all evil"

3.1.1 Network externalities

Network externalities and switching costs are nothing new. Network externalities have been known to economic thought since Marhall's time during the industrial revolution (Liebowitz & Margolis, 1994). However, the phenomenon only became prevalent with the advent of modern information and communication technologies (Varian, 2001). With their diffusion through many new markets, the concept of network externalities steadily became more debated and also refined. This calls for a clarification of the precise meaning of network externalities for the purposes of this thesis as well as their degree of presence in the professional VoIP market.

In general, goods exhibit network externalities if "the utility derived from the consumption of these goods is affected by the number of other people using similar or compatible products" (Shy, 2001, p.3). Strictly speaking, another prerequisite must be satisfied in order to speak about externalities, namely unexploited gains from trade in equilibrium (Liebowitz & Margolis, 1994, p.2). Otherwise one could merely talk about network effects. Nevertheless, this work will not strictly apply such a distinction as it is not crucial for the analysis at hand. Hence, goods with **positive** network externalities are understood so that the utility derived from using a good increases with the number of others using the product (Liebowitz & Margolis).

During the development of the concept, authors started to further differentiate between direct and indirect network externalities. Early proponents of this differentiation can be found in Katz and Shapiro (1985). According to them, direct network externalities occur "through a direct physical effect of the number of purchasers on the quality of the product" (p.424). This would include communication markets like landline telephones or fax machines. The usefulness of a fax machine directly depends on the total number of other users that can be reached with that fax machine. These physical networks are opposed to indirect network externalities, which arise whenever "complementary goods become more plentiful and lower in price as the number of users of the good increases" (Liebowitz & Margolis, 1994, p.3). Since this mainly concerns technological systems that include several complementary components, it has been dubbed the "mix and match approach" by others (Jonard & Schenk, 2003). The users of such complementary products usually do not form a physical network but rather virtual networks. Examples are CD players and CDs, hardware and software or operating systems and applications. Users receive benefits in case of a larger network through the higher availability or lower price of complementary products. Furthermore, there is more learning-by-doing for products with larger networks and hence more product improvements (Katz & Shapiro, 1994, Varian, 2001).

The present example obviously involves a case of indirect network externalities or a mix-and-match problem. To be more precise, PBXs are a part of a system with two other major complementaries, telephones and software applications. Telephones basically need to be adjusted to every vendor's systems, as long as proprietary standards are used. This is because of all the different call features. As the virtual network of vendor A's PBX users grows, more phones should be produced for that PBX. Alternatively, phones can be produced at a cheaper price as economies of scale can be exploited. In the case of applications, the technological system at hand resembles the classical hardware/software relation, in which more software is produced for the more common type of hardware, at least under incompatibility. Naturally, more software producers are attracted if they can reach a larger market potential with their product.

If companies are able to exploit consumers' preferences for larger networks, network externalities gain major importance. Together with switching costs, they form the elementary particles of network economics. Phenomena like critical mass and positive feedback mechanisms result from them. Through such mechanisms, they effectively enlarge the set of strategic choices a company might have. Network externalities imply that customer value crucially depends on the compatibility of products. Hence, the choice of compatibility becomes strategically crucial - "architecture is politics" as Mitchell Kapor once put it (in O'Reilly, 2005). Furthermore, network externalities and switching costs are "the root of all evil" in the sense that it is them, who ultimately lead up to peculiar market outcomes, in particular socially undiserable outcomes, i.e. market failures.

3.1.2 Switching costs

Before being able to pursue the mechanisms via which companies can interfere with network externalities, namely compatibility and standardization, their second building block, switching costs, needs to be defined.

Switching costs occur when switching from one technological system to another. They result from different kinds of direct and indirect costs that are associated with the move to a new technology. Costs are actually incurred from the moment that the search for a new product starts. Besides search costs, Shapiro and Varian (1999) identify several other categories of switching costs. The relevant categories in this case mainly stem from system conversion and contracts, but also involve training and learning.

System conversion refers to the fact that you might have to replace all the components of your system when moving to a new one. If a new and incompatible PBX system is bought, every telephone in the company might have to be replaced if the customer does not want to lose most of the call features. The same holds true for software applications, which are attached to the PBX, unless costly converters are available.

Contract costs are also well-known in the professional VoIP market where contract durations of five to ten years have not been uncommon. Recently, many service and maintenance contracts have shortened, not least because of the introduction of VoIP. Training and learning costs might be present in case of new phones with different user interfaces or alternative implementations of certain call features. Furthermore, the ICT staff must be retrained.

In sum, switching costs commonly result in "lock-in". That lock-in does not need to be absolute, but it can nevertheless influence firms' strategies to a great deal (Shapiro &

Varian, 1999, p.12). The strategic choice for or against compatibility and standardization influences both switching costs and the size of network externalities.

3.2 Compatibility and standardization

Companies have complete control over being incompatible or adhering to the market standard by choosing how to implement their products technologically. It turns out that the current and future technological architecture of the professional VoIP market has a rich set of tools to offer when it comes to compatibility. Before taking a look at this set, a clear definition of compatibility as well as a quick comparison of compatible and incompatible systems is needed. Once the theoretical definition and comparison have been translated to the VoIP market, we will finally be ready to approach the theoretical model.

In the network-economic literature, two goods are compatible, "if it is feasible for consumers to combine them costlessly into a working system" (Jonard & Schenk, 2003, p.146). Vice versa, the combination of incompatible system components is virtually impossible; at least the costs would be prohibitively high. Many markets, for example the market for PC operating system, are not standardized and hence many system components are incompatible with each other. Accordingly, one can only operate certain applications on the Linux and Windows operating systems respectively. Conversely, in standardized markets virtually any complementary goods can be combined with the others; there is free mixing and matching.

Whether there is standardization or not has marked effects on network externalities and switching costs as well as on consumer welfare and profits. Therefore, it is worthwile to explore such effects under a standardized regime versus an unstandardized market.

First, let us consider the situation under non-standardization. This implies that only complementary goods especially produced for a certain system can be combined. Starting with network externalities, it is clear that consumers would prefer to buy the system that is bought by most of their peers and hence has the largest variety or the cheapest price for complementary goods. In some markets this can lead to a single winning technology or type of system. One feature to prevent one single winner are switching costs. In the information economy they are a pervasive phenomenon (Shapiro & Varian, 1999) and with durable complementary goods they certainly exist as explained above. Due to them, it is hard to switch for consumer groups who have chosen different products due to an initial coordination problem.

For competition, these switching costs imply a considerable degree of lock-in once customers have opted for a certain product. Together with the prospective network externalities, this results in tough competition for consumers who want to buy new systems and are not locked in, yet. Since once the customers are locked in, the vendor basically becomes a monopolist and can thus extract superior returns from his customers.

With standardization, this competition for the market effectively turns into competition within the market (Katz & Shapiro, 1994). When products are standardized, the virtual network of users naturally becomes much larger and therefore the experienced network externalities do the same. Simultaneously, switching costs decrease significantly as replacing individual components of the system with competitive products becomes possible.

3.2.1 Compatibility and standardization in the VoIP pro market

Up to a certain degree, the story above can be translated to the VoIP market. This section first explains the parts that run analogously to the known theory before moving to the specialty of the market, partial compatibility.

When attempting to translate the above definition of compatibility to the VoIP market, one has to note that completely costless combination would be difficult to achieve. Even with "compatible" products, testing and possibly some minor bug-fixing remain necessary. However, once tested, products can indeed be combined in a plug-and-play manner. Furthermore, the costs involved with testing are not comparable to those resulting from making two initially incompatible products interoperable. For the purpose of the present work, phones and applications are seen to be compatible with a PBX if no more effort than minor testing is involved in order for the desired call features to function or in order for the software applications to work at their full potential.

In terms of standardization, the old telephony world was clearly not standardized. Phones would have to be produced specifically for a certain PBX and applications would need a different and expensive interface for every kind of system. The expected competition structure resulted, i.e. strong competition for the market and afterwards little movement in market shares because consumers had been locked-in. In accordance with this, PBXs and peripherals could initially be bought at comparably low prices. When an extension of the workforce was due three years later, phones might easily cost three times the price (Ghemawat, 1991, Leyendecker & Thater, 2006). Lock-in was considerable with the described contract lengths and some very durable system components. The integration of applications was especially costly because specific interfaces had to be bought and license fees had to be paid.

Today, companies actually have the choice. If SIP and other protocols were able to replace the proprietary ones completely, standardization and the according market outcomes could be achieved. Consumers would experience far greater network externalities in terms of higher variety of phones and at least cheaper applications. Moreover, lock-in would become difficult as switching costs fell. For example, firms would not have to replace every single phone in the company without losing most of the functionality. As a matter of fact, VoIP has nevertheless put pressure on the margins of traditional vendors, even though it is not yet the primary choice for all companies. Thus, several authors (Cumming, 2003, Moos, n.d.) agree that the employment or even the availability of standardized protocols like SIP and the internet protocol suite puts pressure on profit margins and service quality.

However, as mentioned above, a complete replacement of proprietary protocols is unlikely for at least two reasons. First of all, VoIP standards have often “lagged behind the requirements” (Cumming, 2003, p.7). Hence, companies at times had no other choice than implementing individual and especially innovative features in proprietary protocols. Second of all, “architecture is politics”. Reading the above description of competition in non-standardized markets indicates that firms might have incentives to choose for incompatible technology. If companies can choose surgically which features to make compatible, this extends their set of both technological and strategic choices.

This leaves the professional VoIP market in a peculiar situation. As seen above, certain call features might be implemented in a general standard like SIP while others will be handled by proprietary protocols. This could imply that certain phones are only able to reproduce certain call features when connected to determined PBXs. Effectively, this means the possibility of partial compatibility; namely that certain call features can be implemented almost costlessly while others are inaccessible. While this definition of partial compatibility between phones and the PBX is rather clear, a second look needs to be taken at applications.

According to Leyendecker and Thater (2006), “Vendors can make their PBX systems partly compatible with applications by only opening their systems to a certain extent. [...] Next to this, the vendors can choose exactly with which systems, e.g. SAP, to make their products compatible. [...] Finally, PBX vendors can orchestrate different applications by extracting individual functions that match single business processes.” Hence, the possibility of partial compatibility also exists between applications and the PBX, even though in a less obvious way. Furthermore, one has to note that the development of such possibilities for partial compatibility is less advanced compared to phones. While SIP stands ready to be the common standard for implementing call features, no common interface has surfaced, yet, for the integration of software applications. The definition of partial compatibility with applications thus remains hazy, but can be determined as either referring to a subset of the selection of applications or to extracting individual functions from application. At any rate, an increase in the availability of applications is expected now that many PBXs are employing standard operating systems and standardized protocols. Because of the superior multi-media abilities of SIP, mostly applications in the area of unified messaging or presence management are expected (EITO, 2002, Louis, 2006).

Again, the author would like to emphasize that this work is concerned with the VoIP market in the future. Insecurity about future developments remains in any case. Nevertheless, the trends discussed in this work are based on expert market knowledge.

Now that compatibility in the professional VoIP market has been properly defined, one can move on to the analysis of factors influencing the compatibility decision and the resulting implications on welfare.

3.3 Underlying models of discrete choice

To understand how choices are made in the economy, economists have long used models. According to Anderson, de Palma and Thisse, (1992) very early micro-economic models faced the problem of discontinuity. Bertrand and Edgeworth examined competition among homogeneous goods, where a slightly lower price of one product would immediately lead to a market share of 100% and therefore discontinuity. In reality, however, such extreme fluctuations are rarely observed. Heterogeneous preferences by consumers and thus differientated products are the reason. Already in 1933, Chamberlin (pp.57, in Anderson et al., 1992, p.1) noted that "it is evident that virtually all products are differentiated, at least slightly." Any difference might be relevant to consumer behaviour, from functioning to color and form of the design.

This insight has led to the development of so-called discrete choice models to explain how heterogenous individuals make choices among discrete alternatives. In their book "Discrete Choice Theory of Product Differentiation", Anderson et al. give a comprehensive account of discrete choice models, which are based on product differentiation. According to the authors, "The discrete choice approach provides an ideal framework for describing the demands for differentiated products, since it deals explicitly with a population of heterogeneous consumers making mutually exclusive choices from a set of substitutable goods. First, the distribution function can be parameterized to capture intricate patterns of substitution [...] Second, the variables that determine the observable utility are the natural marketing variables that firms can use strategically to attract customers. This means that discrete choice models are tailor-made for analyzing competition by firms over price, quality, product range, location, and so forth." (Anderson, de Palma & Thisse, 1992, p.6). The professional VoIP market is just such a case. This paper especially attempts to analyze the price and technology decisions.

As can be learned from the above paragraph, heterogeneous preferences make the possibility of product differentiation a crucial asset for companies, effectively giving them market power. Hence, potential gains from differentiation can be seen as often the single most important factor determining company choice.

More recent developments, especially the coming about of the information economy, have led to the identification of additional decision factors and their incorporation into economic theory. One such factor are the potential gains from network externalities. The idea is that products with larger real or virtual networks attract higher numbers of customers. Furthermore, each existing customer will experience a higher surplus from the increased network size. The company might be able to extract part of that additional surplus through a higher price. Consequently, the size of network externalities is another important factor determining company decisions.

As a matter of fact, potential gains from network externalities run contrary to gains from product differentiation. The reason is that product differentiation is usually maximised when products are not standardized. In that situation, consumers will be able to consume the products that best fit their preferences, but because of the incompatibility, the experienced network externalities will be smallest. If products are standardized, limitations in technology might lead to products becoming more similar and thus less fit to heterogeneous consumer preferences. On the other hand, network externalities will be maximized.

In the past, there have been several models of discrete choice which analyzed the influence of network externalities or even the trade-off between network effects and product differentiation. Being economists, these researchers have in all cases paid attention to the social optimality of companies' choices for or against compatibility. Most of them find at least some room for socially suboptimal choices and hence market failure

One of the earliest models has been a general model with consumption externalities by Katz and Shapiro (1985). When exploring the compatibility decision by firms, they "find that firms with good reputations or large existing networks will tend to be against compatibility, even when welfare is increased by the move to compatibility" (p.425).

This finding of understandardization has been explained in a later model by Farrell and Saloner (1986). They pointed out that Katz and Shapiro actually did not take into account the costs to standardization, namely a decrease in product differentiation. Once this is accounted for, there can still be understandardization but also overstandardization in equilibrium. However, the latter "cannot occur if equilibrium is unique" (p.71).

Potential for understandardization has also been found by Church and Gandal (1992) and Jonard and Schenk (2003), even though their models do account for the trade-off between network effects and product differentiation. In their model, Church and Gandal "examine the software provision decision of software firms" (1992, p.85). They "show that when consumers place a high value on software variety, there is a suboptimal amount of standardization by the market." Similarly, Jonard and Schenk (2003, p.143), find that "Compatibility is achieved provided the compatibility premium is not offset by the intensity of price competition."

It can be concluded that more potential has been found for understandardization rather than overstandardization in the past literature. Furthermore, the optimal social choice essentially seems to depend on the relative strengths of consumers' preferences for network effects or differentiated products. "Although compatibility has obvious benefits, obtaining and maintaining compatibility often involves a sacrifice in terms of product variety or restraints on innovation." (Katz & Shapiro, 1994, p.95)

When attempting to apply these findings to the professional VoIP market, a problem arises. None of the models provides for partial compatibility. Standardization is always seen as a black and white decision. The following chapter therefor develops a model which accounts for partial compatibility. It can then be checked whether the known welfare implications still apply.

Chapter 4

The Model - Making Compatibility Continuous

4.1 The Undercut Proof Equilibrium (UPE)

The present model is based on the UPE as laid out in Shy (2001). Since the UPE deviates from the concept of Nash equilibrium which is mostly used nowadays, a quick explanation is needed, followed by a short recapitulation of the pros and cons of this equilibrium concept. All explanations and the model developed below refer to the duopoly case. This restriction still leaves sufficient room for the quest of this work while keeping the analysis tractable.

4.1.1 UPE explained

In a Nash equilibrium, players assume their competitor's choice is fixed. Then, they react with a best response to their competitor's choice. In an Undercut-Proof equilibrium, "players keep their own strategy fixed and reason whether the opponents have an incentive to undercut (asking a price low enough to attract the complete demand)." (Peeters & Strobel, 2005). In Shy's terms, "In an Undercut-Proof equilibrium, each firm chooses its price so as to maximize profit while ensuring that its price is sufficiently low that any rival firm would *not* find it profitable to set a lower price in order to grab all of the first firm's customers." (Shy, 2001, p.307)

For illustration of this definition, consider the following example. Imagine a market, in which there are two firms, A and B. Firm A sells red boxes while firm B sells blue boxes. Their production costs are nil. Furthermore, there are two different types of consumers in the market. Consumers of type A like the red boxes better, while consumers of type B prefer the blue ones. There are η_A type A consumers and η_B type B consumers. When buying a good, consumers experience a utility of β. From that base utility, price p_i has to be substracted, where $i \in \{A, B\}$. Furthermore, consumers experience an additional disutility of $\delta \geq 0$ if they do not consume the product with their favourite colour. This leads to the following utility scheme:

$$u_i \equiv \begin{cases} \beta - p_i & \text{if consumer } i \text{ buys from firm } i, \\ \beta - p_j - \delta & \text{if consumer } i \text{ buys from firm } j, \\ 0 & \text{otherwise,} \end{cases} \tag{4.1}$$

where $i, j \in \{A, B\}$ and $i \neq j$. In general, consumers choose in order to maximize their utility. If they are indifferent between buying a box or buying none, it is assumed that they buy the box. Similarly, if they are indifferent between buying the preferred color and buying the alternative, it is assumed that they buy the box with the preferred colour. At the same time, this assumption is welfare-maximizing (Peeters & Strobel, 2005).

Now, the situation can be seen as a sequential game with two stages. In the first stage, firms choose their prices p_A and p_B. Afterwards, consumers observe these prices and choose for one of the two goods or none. Solving this game through backward induction, the consumer decisions in stage two can be computed as follows,

Stage 2: Consumers' choice

$$q_i = \begin{cases} \eta_i & \text{if } p_j - \delta \leq p_i \leq p_j + \delta \ , \\ \eta_i + \eta_j & \text{if } p_i < p_j - \delta \text{ and } p_i < \beta - \delta, \\ 0 & \text{if } p_i > p_j + \delta \text{ or } p_i > \beta \end{cases} \tag{4.2}$$

where q_i is the demand of firm i and $i, j \in \{A, B\}$ and $i \neq j$.

Assumption 1 From this point onwards, we will assume that each consumer needs one of the boxes and hence all consumers participate in the market. In particular, this implies a large enough β, so that a wide range of prices becomes feasible. The *participation assumption* then allows a simplification of the demand function:

$$q_i = \begin{cases} \eta_i & \text{if } p_j - \delta \leq p_i \leq p_j + \delta \ , \\ \eta_i + \eta_j & \text{if } p_i < p_j - \delta, \\ 0 & \text{if } p_i > p_j + \delta, \end{cases} \tag{4.3}$$

where $i, j \in \{A, B\}$ and $i \neq j$.

Stage 1: Price setting

Before consumers make their purchasing decision, the two firms have to set their prices simultaneously and independently. In a UPE, each firm will make sure that its rival has no incentives to undercut. Undercutting would occur if one of the firms would set its price so low as to subsidize the distaste costs, which some consumers would experience when buying its product.

Definition 1 Firm i *undercuts* firm j if $p_i < p_j - \delta$, where $i, j \in \{A, B\}$ and $i \neq j$. With this definition of undercutting, we are now ready to define the UPE.

Definition 2 "In an *undercut-proof equilibrium*, each firm sets its price so as to maximize its profit while ensuring that its price is sufficiently low that any rival firm would *not* undercut." (Peeters & Strobel, 2005). Therefore, a UPE is a pair of prices p_i and p_j satisfying the following conditions:

(a) For a given p_j and q_j, firm i chooses the highest possible p_i subject to

$$\pi_j = p_j q_j \geq (p_i - \delta)(\eta_i + \eta_j), \tag{4.4}$$

where $i, j \in \{A, B\}$ and $i \neq j$.

(b) The quantity q_j is determined in equation 4.3 for a given p_i and p_j.

Since both firms will make sure that they are not undercut by their rival, while still setting their price as high as possible, two more important simplifications can be made. First, the above inequalities hold with equality. Second, the quantities in the inequalities above can be substituted by the respective amounts of red and blue box lovers: $q_i = \eta_i$. The above inequalities then simplify to

$$p_j \eta_j = (p_i - \delta)(\eta_i + \eta_j). \tag{4.5}$$

This simplifys to the following prices:

$$p_i = \delta \frac{(\eta_i + \eta_j)(\eta_i + 2\eta_j)}{\eta_i^2 + \eta_i \eta_j + \eta_j^2}, \tag{4.6}$$

where $i, j \in \{A, B\}$ and $i \neq j$.

4.1.2 UPE evaluated

Peeters and Strobel (2005) point out that the prices in equation 4.6 can behave in rather counter-intuitive ways. This is especially the case in specifications with asymmetric costs or network sizes. These concerns are backed up by empirical evidence. Peeters and Strobel (2005) as well as Orzen and Sefton (2004) conducted experiments, in which experimental subjects behaved much more according to the Bertrand-Nash equilibrium than the UPE. The details of the UPE's deviations from regular equilibrium concepts and the consequences that this has for the current research will be laid out in the limitations section.

In spite of its undeniable drawbacks, the UPE has proven to be the most appropriate equilibrium concept for the present analysis. First of all, Nash-Bertrand equilibrium prices in pure strategies do often not exist (Shy, Peeters & Strobel). What is more, equilibria in mixed strategies are often difficult to find and/or very complex. "The big advantage of the UPE is that a unique solution in pure strategies always exists" (Peeters & Strobel, 2005, p.2). What is more, the UPE proved to be most flexible to extensions as it can be seen as "the simplest possible differentiated products environment" (Shy, 2001, p.307). During the research for this paper, several other discrete choice models had to be abandoned. A multinomial logit model, a linear probability model as well as various versions of Hotelling's model turned out to be insolvable or intractable when extended for partial compatibility. In the interest of future research, the appendix provides an overview over the different specifications employed and the problems encountered.

4.2 An undercut proof equilibrium for the VoIP pro market

Before laying out a model with partial compatibility, the simple example above needs to be extended for network externalities. When both important decision factors have been included, namely product differentiation and network externalities, a symmetric model with partial compatibility will be stipulated.

When extending the above model for network externalities, the standardization decision by firms becomes relevant. Consequently, the game extends to three stages. First, firms choose whether to be compatible or not. Afterwards they observe each others' decisions and set their prices independently and simultaneously. Finally, consumers make their purchasing decisions. The following analysis through backward-induction is based on Shy (2001, chapter 2.2.3).

For convenience, it is assumed that $\eta_A = \eta_B = \eta$. Next to the distaste costs of $\delta \geq 0$, consumers now experience network externalities of $\alpha\eta$, where $\alpha \geq 0$. Hence, α can be considered as the strength of network externalities. It is assumed that the basic utility from a PBX, β, is high enough so that every customer buys a PBX system for sure. This assumption is actually not irrealistic. When a service contract runs out or new features are needed, a firm does not have the choice but to acquire a new PBX system. Telephony is a vital means of communication for any business.

Stage 3 (Consumer choice) Incorporating the above assumptions, the new utility function looks like the following:

$$u_i \equiv \begin{cases} \beta + \alpha\eta - p_i & \text{if consumer buys box } i\text{; box } i \text{ is incompatible} \\ \beta + \alpha\eta - p_j - \delta & \text{if consumer buys box } j\text{; box } j \text{ is incompatible} \\ \beta + 2\alpha\eta - p_i & \text{if consumer buys box } i\text{; boxes are compatible} \\ \beta + 2\alpha\eta - p_j - \delta & \text{if consumer buys box } j\text{; boxes are compatible,} \end{cases} \tag{4.7}$$

where $i, j \in \{A, B\}$ and $i \neq j$. When applying the UPE to the professional VoIP market, δ can alternatively be interpreted as switching costs instead of distaste costs. Both types of costs have the effect of raising the barriers to switching products.

Assumption 2 (Multi-product equilibrium) In order to reach realistic results we need to make one more assumption on the above utility function. It is important that the "brand differentiation effect in consumers' preferences has a stronger influence on utility than the network sizes. Formally, $\delta > \alpha\eta$." (Shy, 2001, p.28). This so-called multi-product equilibrium assumption assures that more than one product is sold in equilibrium. If network externalities were stronger than the effects from product differentiation, only one product would win the market. This is often seen in reality, consider for example the standards war between VHS and Betamax. The professional VoIP market, however, has traditionally been a multi-product market. Since externalities are only indirect, this is not likely to change either, which justifies the assumption.

Stage 2 (Price setting by producers) The structure of the utility function under network externalities requires a split-up of the price-setting process under compatibility and incompatibility.

Under incompatibility, the following UPE conditions result:

$$\pi_j = p_j\eta \geq (p_i - \delta + \alpha\eta)2\eta \tag{4.8}$$

where $i, j \in \{A, B\}$ and $i \neq j$.
Under compatibility, the following situation results:

$$\pi_j = p_j \eta \geq (p_i - \delta) 2\eta \tag{4.9}$$

where $i, j \in \{A, B\}$ and $i \neq j$.
The difference between the two, namely the additional $\alpha\eta$ in equation 4.8 indicates that consumers gain additional utility when one firm undercuts the other. This stems from an increase in the network size once the two individual networks are combined through undercutting. In the case of compatibility, consumers experience the maximum amount of network externalities, no matter which product they buy.

Since both firms want to maximize prices given the above constraints, the equations hold with equality. Solving the two equations simultaneously results in

$$p_i = 2(\delta - \alpha\eta) \tag{4.10}$$

under incompatibility and

$$p_i = 2\delta \tag{4.11}$$

under compatibility, where $i \in \{A, B\}$.

Stage 1 (Producers' compatibility decision) From these prices, the following profits result:

$$\pi_{ic} = 2\delta\eta - 2\alpha\eta^2 \text{ and} \tag{4.12}$$

$$\pi_c = 2\delta\eta, \tag{4.13}$$

where π_c and π_{ic} stand for each firm's profit under compatibility and incompatibility respectively. When comparing profits under compatibility and incompatibility, it becomes clear that profit-maximizing firms will choose for compatibility in the setting at hand.

Shy explains this finding with the ability of companies to extract consumer surplus. In the logic of the UPE, it is easier to extract consumer surplus under compatibility since competition is less fierce. Under compatibility, it is more difficult to undercut since customers do not gain extra network externalities when switching to the other provider.

This result seems peculiar considering the findings outlined above. Usually it has been the case that firms are more inclined to make their products incompatible. The reason is decreasing differentiation as one moves from incompatibility to compatibility. Shy leaves changes in product differentiation out altogether. In his model, the degree of product differentiation would be represented by the size of δ. In his example, however, the size of δ does not change between the state of compatibility and incompatibility. This assumption is certainly not realistic for many kinds of products, as the existing research cited above documents. Therefore, we will now develop a model that takes account for changes in the degree of product differentation as compatibility choices are made on a continuous scale.

Welfare Analysis In light of the objectives of this thesis, it is wise to also compare the welfare levels that result under compatibility and incompatibility in Shy's model and the corresponding consumer surplusses.

In order to calculate welfare, one first needs to know profits and consumer surplus. While the relevant profits are given in equations 4.8 and 4.9, consumer surplus can be obtained by plugging the equilibrium prices into the utility functions and then multiplying by the amount of consumers, 2η.
Under incompatibility,

$$u_i = \alpha\eta - p_i \tag{4.14}$$

in equilibrium, where $i \in \{A, B\}$. Furthermore, we know that

$$p_i = 2(\delta - \alpha\eta) \tag{4.15}$$

with $i \in \{A, B\}$. Since the equilibrium is symmetric, the consumer surplus then becomes

$$U_{ic} = 2\eta(3\alpha\eta - 2\delta). \tag{4.16}$$

Adding the profits of the two firms to this results in the total welfare:

$$W_{ic} = 2\eta[2(\delta - \alpha\eta) + 3\alpha\eta - 2\delta] = 2\alpha\eta^2. \tag{4.17}$$

Under compatibility, the situation is the following:

$$u_i = 2\alpha\eta - p_i \tag{4.18}$$

in equilibrium, where $i \in \{A, B\}$. Furthermore, the price under compatibility is

$$p_i = 2\delta \tag{4.19}$$

with $i \in \{A, B\}$. Since, again, the equilibrium is symmetric, the consumer surplus then becomes

$$U_c = 2\eta(2\alpha\eta - 2\delta). \tag{4.20}$$

Adding the profits of the two firms to this results in the total welfare under compatibility:

$$W_c = 2\eta(2\delta + 2\alpha\eta - 2\delta) = 4\alpha\eta^2. \tag{4.21}$$

Comparing the compatibility scenario with the incompatible one shows that firms actually maximize welfare when choosing for compatibility, since $W_c > W_{ic}$. This is the case because the gross utility in terms of network externalities is largest under compatibility. Nevertheless, consumers would be better off under incompatibility ($U_{ic} > U_c$). On the one hand, this does again seem peculiar. Afterall, consumers have a higher basic utility from network externalities under compatibility. On the other hand, however, competition relaxes and companies can hence extract a disproportionately high share of consumers' utility. This more than makes up for the gain from network externalities. Again, this result might change if changes in δ are taken into account. This can bee seen in the next section.

4.2.1 Continuous compatibility

Assume that the degree of compatibility is represented by $\phi \in [0; 1]$ where

$$\begin{aligned} \phi &= 0 \text{ refers to incompatibility and} \\ \phi &= 1 \text{ refers to compatibility.} \end{aligned} \tag{4.22}$$

Then, the UPE conditions in 4.8 and 4.9 can be reduced to the following equation:

$$\pi_j = p_j\eta \geq (p_i - \delta + \alpha\eta(1 - \phi^b))2\eta, \tag{4.23}$$

where $i, j \in \{A, B\}$ and $i \neq j$ and $0 < b < 1$. At this point, a short excursion on b, the externalities exploiter, becomes necessary. It is called the "externalities exploiter" since it indicates how well companies are able to exploit network externalities for themselves as they move from incompatible to compatible products. Consider that the equation

$$E(\phi) = \alpha\eta(1 - \phi^b) \tag{4.24}$$

indicates the additional network externalities that a consumer can gain by switching to his less preferred product. As technology moves from incompatible to compatible, these additional network externalities diminish. Hence, undercutting becomes more difficult. Because of this, it is safe to assume that companies would make those features compatible first, which let consumers experience the relatively highest network externalities. This would decrease the additional network externalities to be gained from switching to the other network as much as possible. Less tough competition would result. According to this logic, $E(\phi)$ must be a quickly-decreasing function. This can, for example, be achieved by limiting b to be between 0 and 1. Figure 4.1 below gives an example for $E(\phi)$ when $b = \frac{1}{2}$.

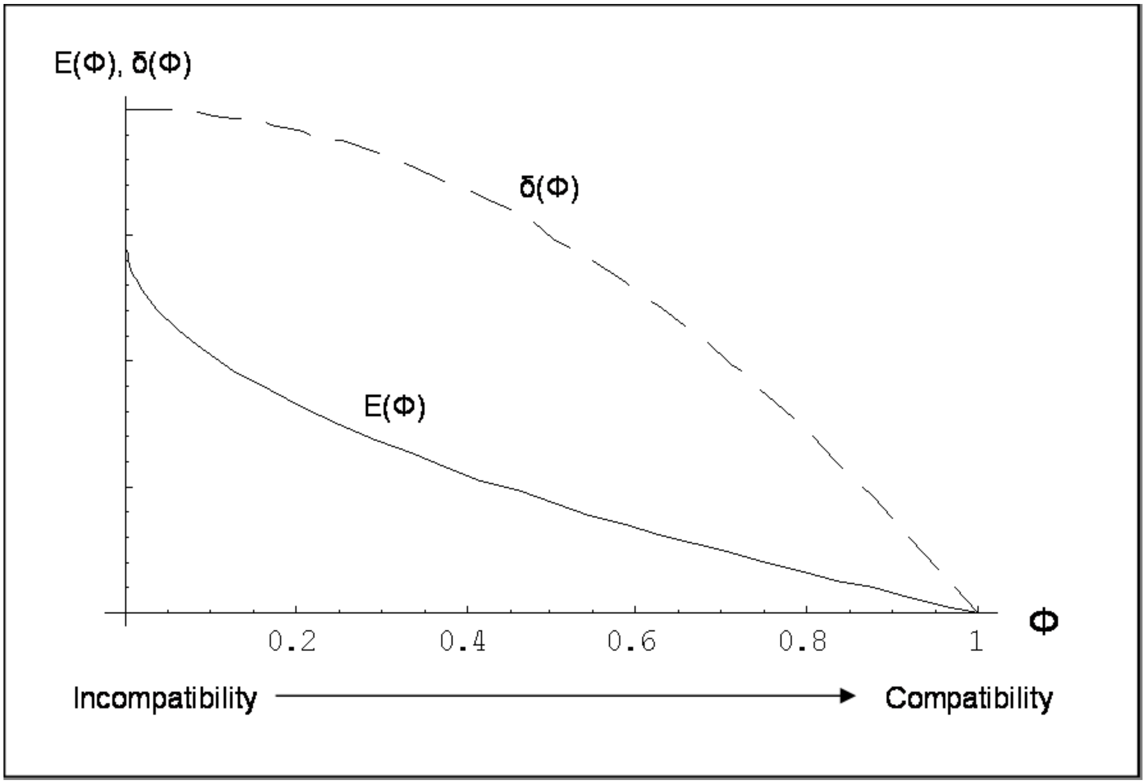

Figure 4.1: $E(\phi)$ and $\delta(\phi)$ for $a = 2$ and $b = \frac{1}{2}$

With the externalities exploiter in mind, we can now calculate the new equilibrium prices and profits. According to Shy's argumentation, inequality 4.23 holds with equality in equilibrium. The equilibrium prices and profits thus become:

$$p_i = p_j = 2(\delta - \alpha\eta(1 - \phi^b)) \text{ and} \tag{4.25}$$

$$\pi_i = \pi_j = 2\eta(\delta - \alpha\eta(1 - \phi^b)), \tag{4.26}$$

where $i, j \in \{A, B\}$ and $i \neq j$.

Stage 1 (Producers' compatibility decision) Having determined the equilibrium profits, we can now move to determine the compatibility decisions. At this stage, we need to take product differentiation into account. To be more precise, firms try to keep the "switching costs" that consumers experience when consuming their less preferred product as high as possible. Those switching costs consist of distaste costs as well as traditional switching costs as described above. In the VoIP market, switching costs are likely to play a more important role than product differentiation. According to Louis (2006) as well as Leyendecker and Thater (2006), PBX systems do not differentiate themselves greatly compared to the magnitude of lock-in that exists at times. Considering that product differentiation negatively depends on the degree of compatibility, we define δ as a function of ϕ and set

$$\delta(\phi) = s(1 - \phi^a) \tag{4.27}$$

where $a \geq 1$ and $s > 0$ can be interpreted as the maximum height of switching costs. This functional form for $\delta(\phi)$ is reasonable because companies would want $\delta(\phi)$ to reduce as slowly as possible as one moves from incompatibility to compatibility. This is because a higher δ makes undercutting more difficult. The more difficult undercutting becomes, the higher the prices that the companies can set and profits that they can achieve. $\delta(\phi)$ should therefore be a slowly decreasing function. This can be achieved by setting $a \geq 1$. Figure 4.1 gives an example for $a = 2$. While b represents the externalities exploiter, a stands for the ability of firms to exploit switching costs and is hence called the "switching costs exploiter".

Plugging $\delta(\phi)$ into 4.26 results in the following equilibrium profits

$$\pi_i = \pi_j = 2\eta[s(1 - \phi^a) - \alpha\eta(1 - \phi^b)]. \tag{4.28}$$

By optimizing this equation with respect to ϕ, one can now find the optimal level of compatibility.

$$\frac{d\pi_i}{d\phi} = 2\eta(-as\phi^{a-1} + b\alpha\eta\phi^{b-1}) = 0 \tag{4.29}$$

$$\Leftrightarrow \phi = \left(\frac{b\alpha\eta}{as}\right)^{\frac{1}{a-b}} \tag{4.30}$$

The second order condition shows, that this is indeed a maximum:

$$\frac{d^2\pi_i}{d\phi^2} < 0 \tag{4.31}$$

$$\Leftrightarrow 2\eta\left[-as(a-1)\left(\frac{b\alpha\eta}{as}\right)^{\frac{a-2}{a-b}} + b\alpha\eta(b-1)\left(\frac{b\alpha\eta}{as}\right)^{\frac{b-2}{a-b}}\right] < 0 \tag{4.32}$$

$$\Leftrightarrow (b-1)\frac{b\alpha\eta}{as}\left(\frac{b\alpha\eta}{as}\right)^{\frac{b-2}{a-b}} < (a-1)\left(\frac{b\alpha\eta}{as}\right)^{\frac{a-2}{a-b}} \tag{4.33}$$

$$\Leftrightarrow (b-1)\left(\frac{b\alpha\eta}{as}\right)^{\frac{a-2}{a-b}} < (a-1)\left(\frac{b\alpha\eta}{as}\right)^{\frac{a-2}{a-b}} \tag{4.34}$$

$$\Leftrightarrow b < a \tag{4.35}$$

Since $0 < b < 1$ and $a \geq 1$, we have that $b < a$ and hence the second order condition for a maximum holds true.

When using the example of $a = 2$ and $b = 1/2$ from above, then

$$\phi = \left(\frac{\alpha\eta}{4s}\right)^{\frac{2}{3}} \tag{4.36}$$

Note that the equilibrium is symmetric and hence both firms would choose for the same ϕ ($\phi_A = \phi_B = \phi$). The equilibrium is actually not only symmetric by virtue of the model. When thinking back to the real market, it becomes clear that technically no producer can be more or less compatible than the other. This is true since incompatibility simultaneously implies proprietary, closed protocols. When one company has less features standardized than the other, phones that were originally produced for the more open type of PBX, can still only work the smaller subset when connected to the less open PBX. Hence, the minimum of ϕ_A and ϕ_B always applies to the entire market. Given that the two firms in this model have symmetric profit functions, $\phi_A = \phi_B$ automatically results.

Having found the equilibrium degree of compatibility as well as the equilibrium price levels, we are now ready to compare profits, utilities and total welfare.

Starting with profits, we find that firms are much better off in this model when they have the possibility to choose compatibility from a continuous scale. Consider the general function of firm profit in equilibrium

$$\pi_i = \pi_j = 2\eta[s(1-\phi^a) - \alpha\eta(1-\phi^b)] \tag{4.37}$$

Under incompatibility, $\phi = 0$ and hence

$$\pi_{IC} = 2\eta(s - \alpha\eta). \tag{4.38}$$

Under compatibility, $\phi = 1$ and hence

$$\pi_C = 0. \tag{4.39}$$

Since $s > \alpha\eta$ by the multi-product equilibrium assumption, this implies that $\pi_{IC} > \pi_C$ in the model at hand. Furthermore, $\pi^* > \pi_{IC}$ (note that from now on "*" always denotes an equilibrium parameter):

$$\pi^* > \pi_{IC} \tag{4.40}$$

$$\Leftrightarrow 2\eta(s - \alpha\eta - s\phi^{*a} + \alpha\eta\phi^{*b}) > 2\eta(s - \alpha\eta) \tag{4.41}$$

$$\Leftrightarrow -s\left(\frac{b\alpha\eta}{as}\right)^{\frac{a}{a-b}} + \alpha\eta\left(\frac{b\alpha\eta}{as}\right)^{\frac{b}{a-b}} > 0 \tag{4.42}$$

$$\Leftrightarrow \left(\frac{as}{b\alpha\eta}\right)^{\frac{a-b}{a-b}} > \frac{s}{\alpha\eta} \tag{4.43}$$

$$\Leftrightarrow a > b, \tag{4.44}$$

which is true since $a \geq 1 > b > 0$. This implies that firms profit most when they can choose the degree of compatibility from a continuous scale. This result will be discussed in more detail in the conclusion.

One purpose of this thesis is to evaluate the implications of the new possibilities in the VoIP market on social welfare. As mentioned above, social welfare consists of profits and total utility. A comparision of utility levels and social welfare under incompatibility, full compatibility and optimal compatibility can be found below. The conclusion will give an interpretation of the results and explain the differences to Shy's model.

Regarding utilities, each consumer is better off under compatibility compared to incompatibility ($U_C > U_{IC}$). This can be seen by plugging $\phi = 0$ and $\phi = 1$ into the general equilibrium utility function. Note that every type of consumer buys his preferred product in equilibrium by definition. Hence, the general equilibrium utility function looks like the following:

$$u_i^* = \alpha\eta(1+\phi) - p_i^* \tag{4.45}$$

$$\Leftrightarrow u_i^* = \alpha\eta(3+\phi-2\phi^b) - 2s(1-\phi^a), \tag{4.46}$$

where p_i^* is the euqilibrium price for product i with $i, j \in \{A, B\}$ and $i \neq j$. When the utility is aggregated over all consumers, one gets

$$U^* = 2\eta[\alpha\eta(3+\phi-2\phi^b) - 2s(1-\phi^a)] \tag{4.47}$$

Plugging in $\phi = 0$ for incompatibility and $\phi = 1$ for compatibility, one finds that

$$U_{IC} = 2\eta(3\alpha\eta - 2s) \text{ and} \tag{4.48}$$

$$U_C = 4\alpha\eta^2. \tag{4.49}$$

Again, since $s > \alpha\eta$, $U_C > U_{IC}$. Contrary to Shy, consumers in this model experience larger utility under compatibility. When trying to compare U_{IC} and U_C to U^*, things become less straight forward. Consider U^* versus U_{IC}:

$$U^* > U_{IC} \tag{4.50}$$

$$\Leftrightarrow \alpha\eta(\phi^* - 2\phi^{*b}) + 2s\phi^{*a}) > 0 \tag{4.51}$$

$$\Leftrightarrow \frac{2s}{\alpha\eta} > 2\phi^{*b-a} - \phi^{*1-a} \tag{4.52}$$

Unfortunately, this inequality cannot be shown to hold without further restrictions. Therefore, the example $a = 2$ and $b = \frac{1}{2}$ will again be used to show that utility can actually be minimum under the firm-wise optimal degree of compatibility. Equation 4.52 now reads

$$\begin{aligned}
\frac{2s}{\alpha\eta} &> 2\left(\frac{\alpha\eta}{4s}\right)^{-1} - \left(\frac{\alpha\eta}{2s}\right)^{-\frac{2}{3}} && (4.53)\\
\Leftrightarrow 1 &> 4 - \left(\frac{4s}{\alpha\eta}\right)^{-\frac{1}{3}} && (4.54)\\
\Leftrightarrow 3 &< 2^{\frac{1}{3}}\left(\frac{\alpha\eta}{4s}\right)^{\frac{1}{3}} && (4.55)\\
\Leftrightarrow 3 &< 2^{\frac{1}{3}}\phi^{\frac{1}{2}} && (4.56)\\
\Leftrightarrow \phi^* &> \frac{9}{4^{\frac{1}{3}}} && (4.57)
\end{aligned}$$

This cannot be the case, since $\phi \in [0,1]$. Therefore, we have that $U_C > U_{IC} > U^*$ for $a = 2$ and $b = \frac{1}{2}$, implying that consumers might actually be worse off when products can be partially compatible. However, this does not need to be the case. Examples where $U^* > U_{IC}$ are also conceivable. Consider the case where $a = \frac{11}{10}$ and $b = \frac{9}{10}$. Then

$$\begin{aligned}
\frac{2s}{\alpha\eta} &> 2\left(\frac{0.8\bar{1}\alpha\eta}{s}\right)^{-1} - \left(\frac{0.8\bar{1}\alpha\eta}{s}\right)^{-\frac{1}{2}} && (4.58)\\
\Leftrightarrow 0.089s &< \alpha\eta, && (4.59)
\end{aligned}$$

which holds true for many possible values of s and $\alpha\eta$.

Yet, when looking at total welfare again, the story is different. Plugging the above-obtained values into the general welfare function

$$W = 2\pi + U, \qquad (4.60)$$

results in the following welfare levels:

$$\begin{aligned}
W_{IC} &= 2\alpha\eta^2 && (4.61)\\
W_C &= 4\alpha\eta^2 && (4.62)\\
W^* &= 2\alpha\eta^2(1+\phi^*) && (4.63)
\end{aligned}$$

Since $\phi \in [0,1]$, this means that $W_C \geq W^* \geq W_{IC}$. When taking a look at $\frac{dW}{d\phi}$, one sees that more compatibility is always better from a social welfare perspective.

$$\begin{aligned}
W &= 4\eta[s(1-\phi^a) - \alpha\eta(1-\phi^b)] + 2\eta[\alpha\eta(3+\phi-2\phi^b) - 2s(1-\phi^a)] && (4.64)\\
\Leftrightarrow W &= -4\alpha\eta^2(1-\phi^b) + 2\alpha\eta^2(3+\phi-2\phi^b) && (4.65)\\
\Rightarrow \frac{dW}{d\phi} &= 4\alpha\eta^2 b\phi^{b-1} + 2\alpha\eta^2 - 4\alpha\eta^2 b\phi^{b-1} && (4.66)\\
\Leftrightarrow \frac{dW}{d\phi} &= 2\alpha\eta^2 > 0 && (4.67)
\end{aligned}$$

Having specified the model as well as the resulting levels of profits, utility and welfare, we are now ready to interpret the results.

Chapter 5

Conclusion

While interpreting the results of the continuous compatibility model which was developed in the previous chapter, the problem statement will be answered. For that purpose, we will first take a look at the situation of firms under continuous compatibility and what are the factors determining their optimal choices. Afterwards, the likely implications on consumers and social welfare will be discussed. Finally, some findings are markedly different from what Shy (2001) finds in his basic UPE with network externalities. Hence, the due comparison will be made and differences explained.

5.1 Results

5.1.1 Firms

First, let us consider the implications of new VoIP technology on the situation of firms. These effects are the most important ones for the entire market, since firms are the main decision makers. If firms did not have the possibility to choose for continuous compatibility, they would rather not be compatible at all in the model at hand ($\pi_{IC} > \pi_C$, see equations 4.38 and 4.39). Under compatibility, economic profits would equal zero. This Bertrand-type competition results because switching costs are nil. Furthermore, undercutting is more difficult than under incompatibility because consumers are not compensated for distaste or switching costs by an extra amount of network externalities when switching to their not-preferred product. This situation can be compared to the market as it was before the introduction of VoIP. As described above the market was characterized by proprietary technologies and effective incompatibility. When the possibility of continuous compatibility is introduced, however, we saw that firm profit can even rise beyond the level it has under incompatibility (see equaions 4.37 and 4.38). This is possible if firms manage to first marginally reduce switching costs while delivering comparatively large amounts of network externalities. In reality, one could imagine that PBX vendors implement the most popular and general call features in open, standardized protocols like SIP. Highly specific and innovative features might be kept proprietary. This would be especially advantegous to large customers, who have many workplaces that require basic telephone connectivity but also several work stations with the need for innovative call features. Such a customer could profit because higher network externalities would make the basic phones cheaper. At the same time, the PBX vendor could still charge a premium for its innovative PBX with high switching costs. Of course, the high profit under continuous compatibility is largely dependent on a firm's ability to identify such features. The situation will differ from customer to customer. In cases where only basic telephony is needed, it might be hard to hold up switching costs or greatly differentiate one's product from the competition. Yet, on average, firms should be able to make features compatible in a manner exploiting the trade-off between network externalities and switching costs to their own best.

To sum up, firms are better off when they have the possibility to choose compatibility from a continuous scale. To ensure additional profits, however, they must consider the trade-off between increasing the total size of consumer surplus through network externalities and the ability to extract large shares of the consumer surplus thanks to lock-in. How well firms are able to exploit such a trade-off as shown in figure 4.1 will heavily depend on the development of technological standards and technological innovations themselves. This implies that companies must already keep the trade-off in mind when involving themselves in standards-setting or inventing new features and products.

5.1.2 Consumers

Since producers might be able to exploit the new technological possibilities to their own best, consumers might rather suffer than profit from the new developments in the professional VoIP market. In the example above, consumers are even worse off than under incompatibility when companies have continuous compatibility at their discretion (see equation 4.53 and following).

In either case, consumers would prefer complete compatibility over the other alternatives for two main reasons. First, they experience the highest gross utility in terms of network externalities when PBX systems, phones and applications are fully compatible. Second, prices are lower under compatibility since switching costs are lower and no extra externalities support undercutting. When moving to incompatibility, firms are able to extract more surplus because of lock-in. At first sight, it might seem strange that the situation gets even worse, when products are partially compatible. Afterall, companies increase total consumer surplus by providing rather large extra network externalities. The crux is in the switching costs, however. If companies manage to keep switching costs and/or differentiation at a high level while introducing high network externalities, they are able to capture a disproportionally large part of consumer surplus. The captured part can actually exceed the additional gains in gross utility. Imagine, for example, a situation in which many popular applications are written for an interface which is common to all PBX systems. At the same time, important proprietary call features might keep switching costs high. The PBX vendors could then capture the additional surplus from consumers' love of variety for applications. This actually indicates further new strategic possibilities for vendors. As long as they can keep switching costs sufficiently high with any peripheral, they might be able to capture consumers' surplus from other peripherals as well.

Nevertheless, we have also seen that consumers might be better off under partial compatibility than under complete incompatibility (see equation 4.58 and following). This is the case, when firms are not able to keep switching costs high while allowing consumers to experience higher network externalities. Furthermore, one should keep in mind that undercutting becomes more difficult the higher the network externatlities consumers experience in equilibrium. This is because undercutting is subsidized by less additional externalities if consumers experience high externalities in the first place.

Hence, from the model above, it does not become quite clear whether consumers will be better or worse off with partial compatibility compared to incompatibility. Looking to the current situation in the market can actually help answer that question. Certain features of the VoIP market let the more positive possibility appear more likely. Several experts from Computacenter (Leyendecker & Thater, 2006) described the market as a "buyers market", in which "customers have a strong bargaining position". Hence, companies will most likely not be able to extract excessive amounts of surplus in the future. Furthermore, the differences in terms of call features across products are limited, so that costs are a major decision-making factor. But less differentiation also implies a smaller δ or distaste cost and hence easier undercutting.

To sum up, the new possibilities in the professional VoIP market likely have small positive effects on consumer surplus compared to the proprietary equilibrium. Yet, consumers will not be as well off as under full compatibility. Afterall, several experts have agreed that recent developments seem to put pressure on competition. The exact implications for consumers will also vary wildly from case to case. The heterogeneity of customers must not be forgotten. Those customers who mainly employ basic phones and applications might strongly benefit from reduced prices. Others might depend on innovative features and hence experience high switching costs, reducing their chances to gain extra utility from lower prices.

5.1.3 Social welfare

Even though the new technological possibilities can ultimately have negative effects on consumers, they clearly bring improvements in terms of welfare over the incompatible equilibrium. This can easily be seen since welfare equals gross utility, utility plus prices, in our model (see equation 4.61 and following). Here, gross utility is equal to the aggregate of experienced network externalities. Obviously, users experience more network externalities in equlibrium, the more compatible products become. Again, this is also due to the multi-product equilibrium assumption.

Nevertheless, welfare under optimal compatibility is strictly smaller than total gains under complete compatibility. Hence, the current model aligns with many of its predecessors who have found understandardization. This opens the question of public intervention. In their paper, Church and Gandal (1992, p.99) see the role of a more formal standard-setting body emerge as a result of "suboptimal standardization for many parameter values". Such a body could enforce standards or at least conduct an active expectations management if multiple equilibria were possible. Regarding this market, one must weigh the likelihood and the social implications of a socially suboptimal outcome against the costs and success chances of public intervention. On the one hand, the standards setting process could be advanced on a world-wide scale by reforming certain processes at the Internet Engineering Taskforece (IETF) or the International Telecommunication Union (ITU). On the other hand, the market for PBX is a rather small sub-market of the ICT industry as the limitations in terms of empirical data show (see section on limitations). Therefore, negative impacts on welfare might be present but limited. On top of this, public intervention comes with some disadvantages in itself. Available information is limited, which implies that a public intervention will not necessarily bring about an improvement at all. Furthermore, Farrell (1996) points out that formal standard setting can cause considerable delays, which might result in a loss. Last but not least, public intervention in whatever form disrupts the economy by the pure need for funding. Hence, large-scale public interventions are not desirable. Nevertheless, the implications of standard-setting on social welfare should be kept in mind when reforming (inter)national standards setting bodies. All in all, it should be ensured that the influence of large multinational companies does not exceed a socially desirable level.

Overall, the analysis has shown that there exists a social trade-off between network sizes and product differentiation including switching costs. The new technical possibilities that are opened up in ever-more complicated network products might lead to a general improvement in social welfare as this trade-off is relaxed. With compatibility not being a black and white decision any more, more good things of both could be gained. But still, higher social welfare does not always imply higher consumer surplus.

5.1.4 Continuous compatibility vs. Shy

As mentioned above, several findings in Shy seem peculiar in light of past economic research. In particular, firms always prefer full compatibility, which is actually harmful to consumers. This is in spite of an increase in their gross utility. In line with most other research, the model of this thesis finds that firms rather were incompatible while consumers gain most from complete compatibility. The reason for these opposing results lies in the switching or distaste costs. In Shy's model, those costs do not change with compatibility. In reality, however, switching or distaste costs are likely to become lower when products become compatible. Afterall, consumers do not need to exchange all their system components but only the PBX when they want to switch to a different vendor. Under Shy's assumption of steadily high switching costs, however, more surplus than the additional gross utility can be appropriated by firms.

5.2 Looking at the market ahead

The analysis in the previous section answers the question of the social implications coming about with the switch to VoIP. This section will take a closer look at the other part of the problem statement, the coming developments of the professional VoIP market. Of course, just as with stock prices, no definite prophecy can be made. Nevertheless, a structured view on possible scenarios and the according contingencies can be provided.

The analysis of firm profits has clearly shown that firms prefer partial compatibility. Given the current technological possibilities and consumer preferences, two possible scenarios for partial compatibility between the PBX and telephones emerge.

To be more precise, experts expect the current consumer preferences to lead to a split in the market. Two groups of consumers can be identified. One group only needs the PBX and its peripherals to provide simple telephony services including the most common features. Another, more innovative group is looking to work with the most up to date features to support their dynamic businesses. Furthermore, a split within individual businesses is possible, where the vast majority of employees consumes simple services while the work of others relies on advanced processes. Because of this, experts expect two different strategies to develop on the producer side, cheap mass production and constant innovation. Compatible phones with the most basic features will be available cheaply. Full-fledged products, including the most innovative but proprietary features, on the other hand, will only be available from a few vendors without further and possibly considerable adjustment costs.

This scenario is supported by the current technical possibilities. As described above, SIP is a comparatively new standard and not capable, yet, of incorporating all traditional call features. Hence, proprietary solutions become necessary. Given the past and current technological developments, it is, however, likely that the proprietary and non-proprietary features are dynamic. SIP is constantly being developed. Naturally, the most successful features are incorporated first. As this reduces product differentiation, the constant need for new and innovative features emerges. Similar developments can be seen, e.g. in the browser market. Think about internet browsers. One can surf the web with Firefox as well as Internet Explorer. Furthermore, the best innovative features like tabbed browsing, seem to be more or less quickly adopted by competitors. Hence, the technological perspective implies that partial compatibility is realized trough the constant development and vanishing of proprietary features, which is triggered by the constant attempt to enhance product differentiation or copy the best trends from competitors.

One might think that this constant development of new features must reach its limits shortly, especially considering the abundance of features that have already existed in the old telephony world. However, at least for the medium term, SIP holds ready potential innovations in the field of media convergence. Both the multimedia features of SIP and the accompanying increased intelligence of individual phones leave room for innovation. The convergence with computers has already started with Computer Telephony Integration (CTI). When one's IP phone is connected to the PC, a double-click in Outlook suffices to call a colleague. The combination of instant messaging with voice communication is a very promising one as well. In general, unified messaging over different communication channels like email, instant messaging, mobile and fixed phones is a clear trend (EITO, 2002, Leyendecker & Thater, 2006).

So far, little has been written about partial compatibility with applications, the main reason being that compatibility in applications will most likely not be realized shortly (Louis, 2006). Compatible applications would require standardized interfaces which are not to be seen anywhere near. Nevertheless, XML and co. are promising possibilities for standardization in this area as well. Another point in the case of partially compatible applications is the diminishing borderline between phones and software. In the case of a so-called "softphone", the telephone is nothing but software running on a computer.

Furthermore, hard phones become more and more like a computer as well (Louis, 2006). This trend is reinforced by SIP, which puts more power to the phone. The question then is whether the actual phone is the hardware or the constantly updated software on a durable piece of hardware. The interviewed experts agreed that compatible applications are sure to come, but the timing does not seem to be immediate.

This section naturally contains many "woulds" and "maybes". Hence, it is important to finally point out the key developments that are capable of turning the professional VoIP market into one or the other direction. The concrete development of the SIP standard will play a first and foremost role for that matter. Among other things, it determines which features can be made compatible and which cannot. If for some reason, certain features or innovations cannot be implemented in SIP but only in proprietary technology, this would be a major blow against compatibility. Furthermore, companies have a high strategic interest in the development of SIP. They might try to advance or block certain developments through strategic alliances. Such developments being a major contingency, more research should be devoted to the topic.

Last but not least, consumer preferences might alter with a change in the system philosophy from closed and incompatible to open and compatible. This will then have an effect on the relative importance of network externalities and lock-in. As call features become even more alike, issues like user-friendly interfaces might move to the foreground. This falls under product differentiation but has little to do with network externalities. Hence, product differentiation would become relatively more important with likely effects on compatibility. The applications' story is a different one. As the importance of applications rises, the indirect network externalities rise as well.

To sum up, close attention should be paid to the further development of SIP and changes in consumer preferences if one is to anticipate future developments in compatibility and hence important market variables.

5.3 Limitations

Regarding the present thesis, there are at least three types of limitations that the reader should be aware of. Those concern the research model used, the balancing act between a complex reality and an economic model as well as the availability of empirical information on the professional VoIP market.

5.3.1 Research model

Regarding the research model, conceptual problems of the UPE have been pointed out earlier. It turns away from the ubiquitous Nash equilibrium. With this renunciation, several seemingly counterintuitive strands of reasoning come along.

When leaving out any asymmetries, the UPE follows the known results of product differentiation models. Accordingly, "prices rise with distaste (transportation) costs and monotonically decline to zero as distaste costs approach zero" (Shy, pp.310-311). This means, the more products are differentiated, the more market power firms have and the higher they can raise their price. If goods are homogeneous, prices are driven down to marginal costs.

However, in asymmetric situations the UPE does not match the predictions of standard product differentiation models any more. In their experimental comparison of the UPE with a Bertrand Nash equilibrium, Peeters and Strobel point out that the firm with the higher costs or the larger network should also charge the higher price. The UPE predicts exactly the opposite. The reasoning in the case of asymmetric costs is that prices are made up of costs and a certain mark-up. If costs are higher and the mark-up is relatively constant, then the firm with the higher costs will charge a higher price. According to the UPE, the firm with the higher costs knows that it is relatively easy for its rival to undercut. The rival simply has more leeway. Knowing this, the firm with the higher costs sets a lower price to begin with. The case of asymmetric network sizes works similarly. The logic of the UPE implies that the firm with the smaller network stands more to gain when undercutting. Hence, the firm with the larger network has to set a relatively lower price to prevent undercutting from happening.

To ultimately evaluate the predictions of the UPE and the Nash equilibrium against each other, one has to take empirical evidence into account. Regarding the latter point of asymmetric networks, Shy (2001) claims that the prediction of the UPE comes closer to reality. When looking to super market chains, this seems plausible. Large chains usually seem to be cheaper. As Peeters and Strobel (2005, p.3) point out, however, "the question of causality" remains. Either the price is lower due to a larger network of consumers or more consumers are attracted by the lower price.

The empirical evidence against the UPE becomes more problematic when considering the experiments conducted by Peeters and Strobel (2005) as well as Orzen and Sefton (2004). Peeters and Strobel (p.18) find that "firms with higher cost as well as firms with larger consumer bases set significantly higher prices". Sefton and Orzen's experimental evidence on 2-player and 4-player settings also fits the mixed strategy equilibrium much better than the UPE.

What is more, undercutting takes place in reality while the UPE avoids this by definition. This is also confirmed through the experimental evidence of Peeters and Strobel. On the one hand, this is particularly worrisome since the multi-product equilibrium assumption has played an important role in the above analysis. On the other hand, whether undercutting takes place might also depend on the degree of product differentiation. As Katz and Shapiro (1994, p.106)) point out, there needs to be sufficient "consumer heterogeneity and product differentiation to [...] sustain multiple networks." Furthermore, the world is known to be an imperfect place. It could well be that firms are not able to perfectly set UPE prices each time, but on average, they might do quite well.

To sum up, there exists strong experimental evidence against the UPE. Nevertheless, for two reasons this does not necessarily imply that the above-findings are irrelevant. First of all, much of the evidence refers to asymmetric settings. These shortcomings do not apply to the symmetric model here. Second, the experimental evidence has several limitations of its own. The studies suffer from the usual drawbacks of experiments. Hence, the evidence in favour of the Nash equilibrium might partly be due to how subjects were remunerated and matched during the experiment (Peeters & Strobel). Furthermore, the experiments took place in static settings. In a real dynamic market, the UPE might well perform differently. These shortcomings of the available evidence shows that there would have to be more studies, not only experiments, to ultimately validate or discharge the UPE for different settings.

This also holds true for a final point worth mentioning. One more peculiarity of the UPE becomes apparent when dealing with network externalities. Namely the fact that companies are able to extract more surplus under compatibility than under incompatibility even though competition should become tougher under compatibility. According to Jonard and Schenk (2003), the intensity of price competition increases as products become standardized because differentiation and hence market power decreases. In the logic of the UPE, competition becomes less fierce under standardization since the potential gains from undercutting decrease. These alternative explanations have, however, not been tested empirically at all. Hence, there is little evidence in favor of one or the other explanation. Furthermore, the introduction of $\delta(\phi)$ in this thesis as opposed to Shy's model mitigates this effect somewhat. When switching costs negatively depend on compatibility, they have an intensifying effect on competition under full compatibility.

In conclusion, there undeniably exists experimental evidence against the UPE. However, the advantages of the UPE that have been pointed out above outweigh this limited evidence. Pricing behaviour does not always need to be optimal in a dynamic real world and furthermore, different markets might exhibit different pricing behaviour. Therefore much more empirical evidence is needed to evaluate the validity of the present analysis. As the section on empirical data below shows, it might take some time till such evidence is available for the professional VoIP market in particular.

5.3.2 Fitting a theoretical model to a complex reality

The true challenge of an analysis like this is to walk the thin line on which the necessary simplifications of the theoretical model and the complex details of reality fall together. This section gives further information about the areas left and right of the line.

The area with the largest tension between model and reality is heterogeneity of consumers and producers. On the one hand, customers in the professional VoIP market are very heterogenous, especially with respect to network externalities and switching costs. The degree to which companies value network externalities depends on a variety of factors like size or innovativeness (Gruber, 2005). If companies do not need additional software applications, for example, network externalities will be greatly reduced. A similar argument holds true for switching costs. They largely depend on the situation of the company. If a service contract is still running for the coming five years, lock-in might be nearly absolute. A company with 15-year-old phones, on the other hand, might be more willing to make a replace. All in all, a continuum of comapanies along different axes like size or current contracts can be imagined with each company consequently having different preferences over PBX systems.

In contrast to that, the UPE being used here only allows for two different types of customers. Consequently, it leaves out many customers on the continuum. Because of that, the present analysis is of little use when looking to one particular company in the market. Nevertheless, the analysis is still helpful in looking at the average company in the market and where the market is moving as such. The limitation could be somewhat mitigated if one could find ways to extend other, more elaborative types of models for continuous compatibility. The multinomial logit as well as the Hotelling model, for example, feature a continuum of consumers. As the appendix shows, however, this has proven difficult.

Producers in the VoIP pro market are heterogenous as well. Contrary to that, the two producers of the model above are assumed to be homogenous. This simplification has been necessary to keep the analysis tractable. Furthermore, the section above showed that more peculiarities of the UPE arise if firms are asymmetric in one way or the other. When the number of firms moves beyond two, the UPE features additional irregularities (Morgan, P. B. & Shy, O., 2000). The lack of asymmetries should not worry the reader too much though. There are few large market players who form a rather homogeneous group in terms of market shares (Gruber, 2005).

Next to the homogeneity vs. heterogeneity issue, one more point deserves explanation. The utility functions above aggregate consumer preference to a very general level. Those readers familiar with the professional VoIP market might ask themselves where important topics like availability and reliability of the PBX system are integrated. Very high reliability was a positive effect of the long-term relationships between customers and vendors in the old telephony world. The almost legendary "five nines" (99.999%) availability has also been a product characteristic of major importance to customers (Krapf, 2002). Such characteristics and others are only integrated into the utility function in a very general sense. Imagine that PBX A has a higher availability than PBX B. Customers with a stronger preference for reliability would buy type A while the others would buy type B. In terms of undercutting, the disutility that type A customers would incur when moving from product A to product B, would be represented by δ. This simplification has been necessary to be able to focus the analysis on the issue of compatibility.

In conclusion, the simplifications of the VoIP market that had to be made in the model above are not small. This is particularly due to the limited choice of models for the quest at hand. The consequence is that the results must be considered on an aggregate level, i.e. as referring to the professional VoIP market as such. The model can hardly be applied to individual, heterogenous customers.

5.3.3 Empirical information

Empirical information is necessary for two main reasons. First, a limited amount of information is needed to come to accurate assumptions for the model above. Second, more empirical data is needed to test the model and claims made and ultimately assess the future market development. In the following, it is laid out how the information for the former purpose has been collected and why it is difficult to accumulate sufficient information for the latter.

Much of the existing information about the professional VoIP market is contained in studies and papers by private market research companies. Even if these studies are available to certain companies in the market, it is extremely difficult to quote such studies or even reuse data in a necessarily public work like this. To a large extent, these sources have been replaced by publicly available alternatives. Those alternatives sometimes consist of information from competitors in the market and might thus seem prone to potential bias. Furthermore, the author has included some technical descriptions from own experience at

Computacenter.

For the detailed empirical analysis of the market developments or at least the empirical validation of the present analysis, much more data is needed. As mentioned above, such data exists to a certain degree from private sources. While those are only available at high costs, public data is currently not available at all. It is usually only available at a more aggregate level or for the consumer market (Greiner et al., 2006). In addition, the current mingling of traditional telephony with IP and hence computer technology makes a clear statistical view on the PBX market even harder. Before PBX systems might have been discernable as telephony equipment other than phones, but now they have been replaced by servers. It is hard to say whether both telephony hard- and software are counted towards telecommunications equipment or rather go to other hard- and software. The market seems too small to tell from public data.

The reader should be aware of the above limitations when reading this thesis. They clearly limit the possibilities for extracting information from this work for alternative purposes. Nevertheless, they do not touch upon the purpose of the work, namely to develop an analytical view on the evolving developments in the professional VoIP market. One way to overcome at least certain limitations and hence confer a wider applicability on the analysis is future research.

5.4 Future Research

Future research could bring further insights into the validity of this analysis, the developments in the professional VoIP market and continuous compatibility in general. For this purpose, both theoretical and empirical research methods would be necessary.

In terms of validity, the necessity for an empirical test has been pointed out. Detailed empirical data could also bring further information on the relative importance of network externalities, switching costs as well as product differentiation. Such information is of special interest since it is a major determinant of the degree of compatibility and hence the most important market characteristics.

As long as data is only scarcely available, one could refine the theoretical model employed. Many different functional forms for modelling network externalities and switching costs are conceivable. A further theoretical extension to models with more heterogeneous customers and asymmetric firms could deliver further insights into the market at hand.

When thinking about models, dynamic and strategic interaction are very important points that have not been assesed above. Dynamics refer to the long-term relationships between producers and consumers. Research in this direction would be important for two different reasons. First, the UPE might possess a higher empirical validity when looking at more long-term and dynamic models (Peeters & Strobel, 2005). Second, long-term relationships have played an important role in the professional VoIP market. Since voice is a sensitive service, trust in a product's and provider's reliability and availability is the foundation for each sales success. In terms of strategic interaction, this analysis does not consider the possible interaction and coordination between individual companies. Strategic interaction can, however, be decisive, as the outcomes of standard-setting can be of utmost importance and actually determine winners and loser of the game. The importance of strategic interaction is underlined by the SIP hype. According to Cumming (2003, p.7), this hype largely initiated from the strong support for the protocol by the venture capital community and "a number of well-funded companies set up to develop SIP-based products". Some research in the area of strategic interaction in standards setting has already been conducted. Hofacker (2000), for example, shows how the federation to corporate networks can allow companies to make their own standard the winning one. Regarding the VoIP market, Leyendecker and Thater (2006) see strategic partnerships between firms as one possible scenario for continuous compatibility. Nevertheless, more theoretical and empirical work is needed on this topic to determine further factors of success and failure.

As continuous compatibility might become a more pervasive phenomenon in IP-based communication technologies, such insights can also be of help in understanding the wider phenomenon of continuous compatibility. Vice versa, the professional VoIP market could gain from empirical but also theoretical research in similar markets. Gathering data on open standard chat programs like Jabber might actually be more feasible.

List of Abbreviations

ACD Automatic Call Distribution

AIM AOL Instant Messenger

CTI Computer Telephony Integration

ICQ “I seek you”, an instant messenger

IETF Internet Engineering Taskforce

IP Internet Protocol

ITU International Telecommunication Union

LAN Local Area Network

MGCP Media Gateway Control Protocol

OSI Model Open Systems Interconnection Reference Model

PBX Private Branch Exchange

POTS Plain Old Telephone Service

PSTN Public Switched Telephone Network

QoS Quality of Service

RTCP Real-time Control Protocol

RTP Real-time Transport Protocol

SCCP Skinny Client Control Protocol

SIP Session Initialisation Protocol

TCP Transmission Control Protocol

UPE Undercut Proof Equilibrium

WAN Wide Area Network

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Appendix A

Alternative Models of Discrete Choice

This appendix gives a short account of alternative models of discrete choice which have been tried out before resorting to the UPE. The main purpose of this account is to aid any further research into the area of partial compatibility. Over the different types of models, two major problems ocurred. Firstly, the extension for continuous compatibility makes many more evolved models insolvable. Secondly, if models are solvable, only corner solutions in terms of complete compatibility or incompatibility can be found.

A.1 A Linear Probability Model

The linear probability model is based on probabilistic utility. Again, imagine two mono-product firms, producing IP PBX systems 1 and 2 respectively. In a two-stage game those companies can first decide on a level of compatibility ϕ, where $\phi \in [0;1]$. In the second stage, the two firms compete on price.

Consumers can buy either one of the two IP PBX or go for the outside alternative with utility $U_0 = u_0 + \epsilon_0$. Utilities for the two IP PBX systems are probabilistic and are represented through the following linear probability model:
The utility of a consumer from purchasing product i, where $i \in \{1, 2\}$ is

$$U_i \equiv y + a\phi - p_i + \epsilon_i, \tag{A.1}$$

where $a > 1$ is the maximum additional utility from compatibility and ϵ_i is the error term in a customer's choice. Note that the error term may have different interpretations. Thus it might simply be a probabilistic element in consumer choice, which stems from imperfect information. Now let $f(x)$ be the density of ϵ where $\epsilon \equiv \epsilon_2 - \epsilon_1$. Furthermore, assume that ϵ is uniformly distributed along the interval $[-L, L]$. Then the density function of ϵ becomes

$$f(x) = \begin{cases} \frac{1}{2L} & \text{if } p_2 - p_1 < -L \\ 0 & \text{otherwise.} \end{cases} \tag{A.2}$$

The cumulative probability of buying product 1, given the customer does not purchase the outside alternative is then

$$P_{IP}(i) = \begin{cases} 0 & \text{if } p_2 - p_1 < -L \\ \frac{p_2 - p_1}{2L} + \frac{1}{2} & \text{if } -L \leq u_1 - u_2 \leq L \\ 1 & \text{if } L < p_2 - p_1. \end{cases} \tag{A.3}$$

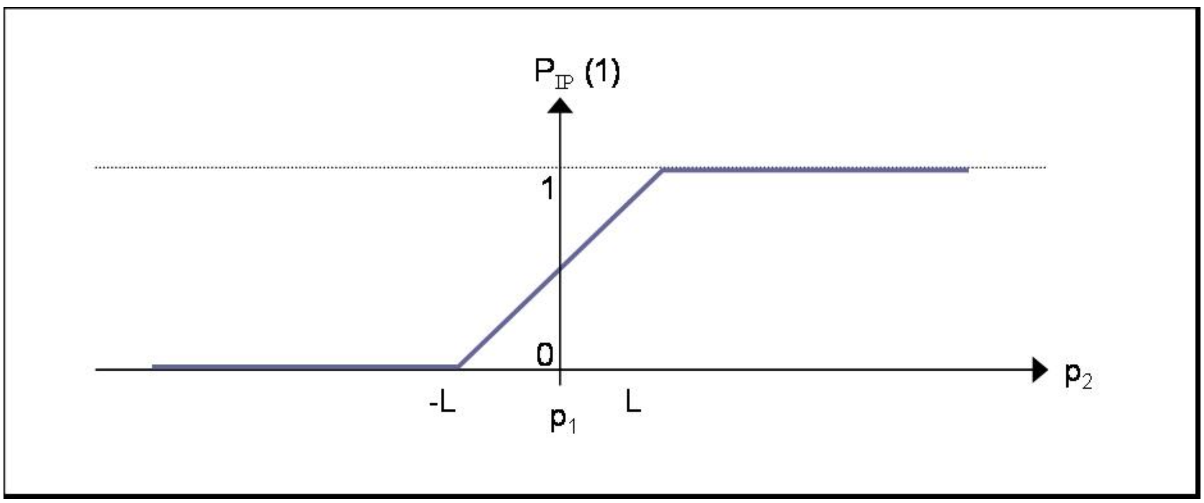

Figure A.1: Cumulative probability for buying product 1

We are now ready to define the firms' profit functions:

$$\pi_i = (p_i - c)P(i)N, \tag{A.4}$$

where $i \in \{1, 2\}$, N is the market size and $P(i)$ is the probability that a consumer buys product i. From figure A.3 it becomes clear that $P(i) = P_{IP}(i)P(IP)$ since probabilities have to be multiplied along different branches of a tree diagram.

The profit function hence becomes

$$\pi_i = (p_i - c)NP(IP)P_{IP}(i). \tag{A.5}$$

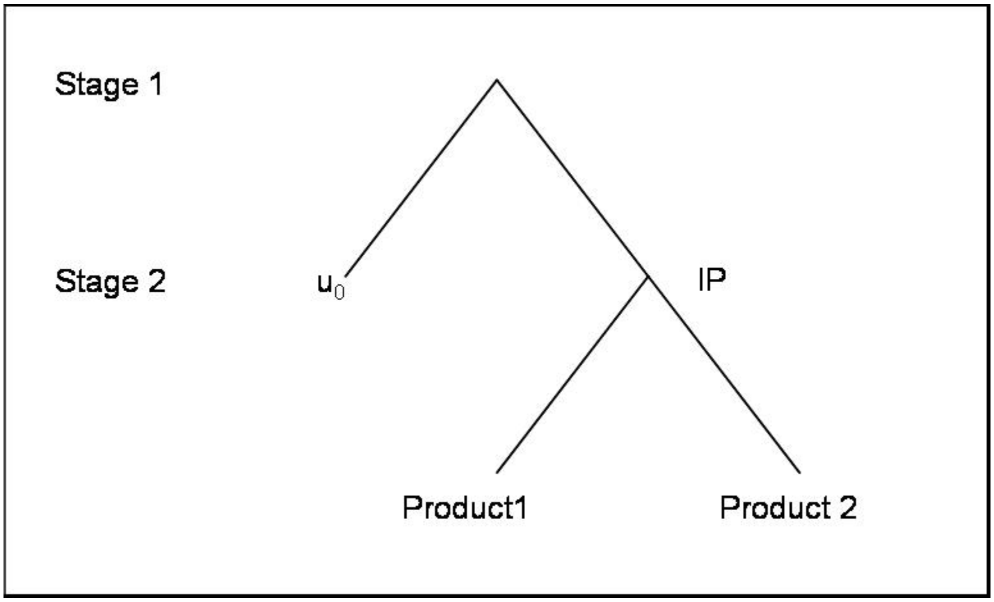

Figure A.2: Two-stage consumer choice with an outside alternative

In order to solve for the optimal prices and levels of compatibility, one must still find an expression for $P(IP)$. In order to compare the outside alternative to the IP PBX, one must first find the expected utility when the customer chooses an IP PBX. This expected utility, U^e_{IP} must then be compared to the expected utility from the outsite alternative U^e_0. This can be done by introducing another error term ϵ_{IP}, which indicates the error consumers make in their choice between an IP product and the outside alternative. It turns out that differentiable profit functions can be derived, while those functions cannot be solved for equilibrium prices.

To reengineer this result, consider the expected utility when choosing an IP PBX,

$$U^e_{IP} = u_{IP} + \epsilon_{IP}. \tag{A.6}$$

The term u_{IP} can be found by use of figure A.1. Note that without loss of generality, figure A.1 assumes that $p_1 < p_2$.

When integrating over all areas in figure A.1 and adding $a\phi + y$, one gets

$$u_{IP} = y + a\phi + \frac{8L^3 + 6L(p_1 - p_2)^2 + (p_1 - p_2)^3 - 12L^2(p_1 + p_2)}{24L^2}. \tag{A.7}$$

From this result, $P(IP)$ can be derived as described above, leading to the profit function

$$\pi_i = (p_1 - c)\left(\frac{1}{2} + \frac{p_2 - p_1}{2L}\right) \text{ continues...}$$

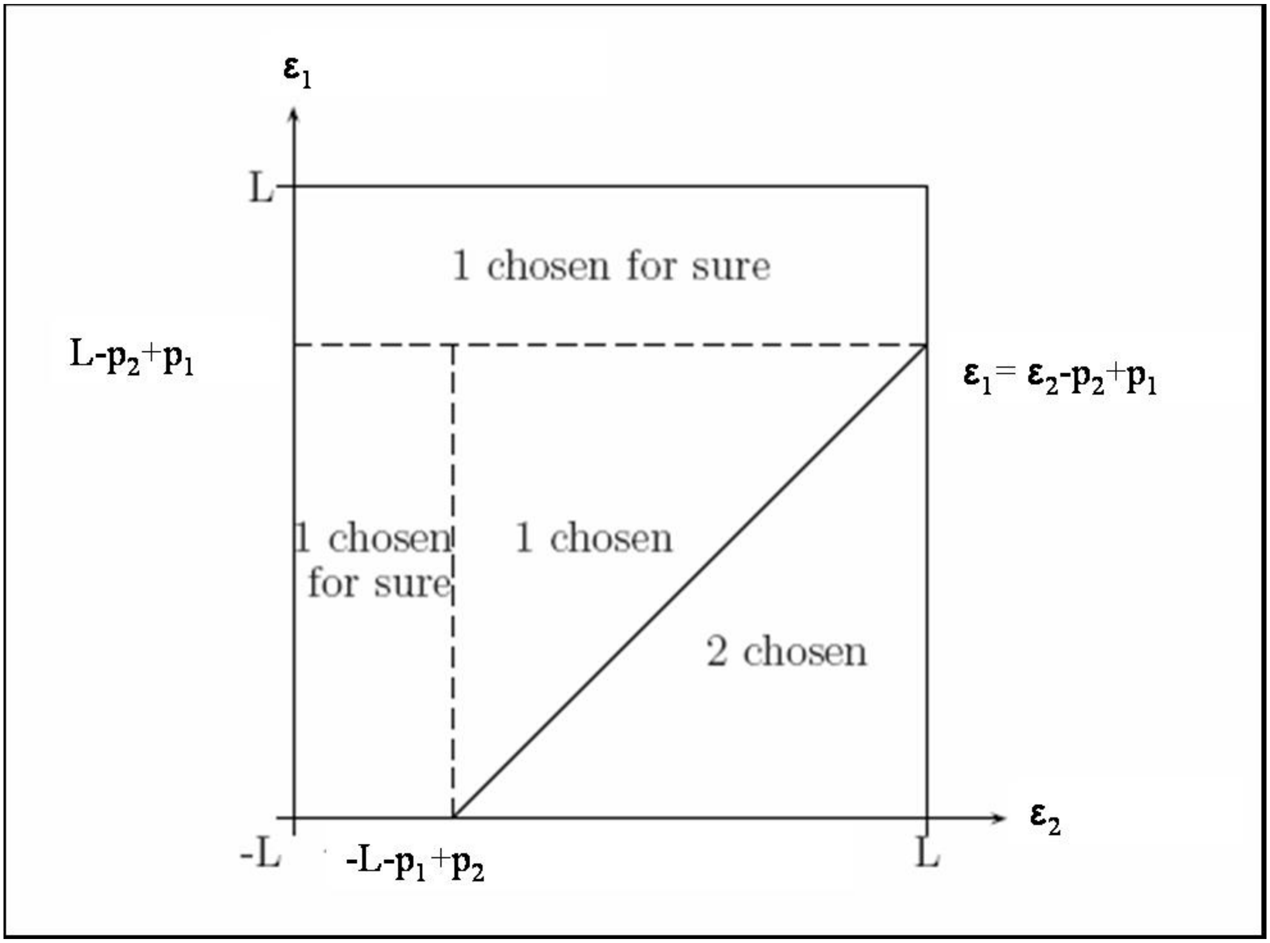

Figure A.3: Deriving expected probabilities, figure based on work by Kasper Leufkens

$$\frac{32L^3 + 6L(p_1 - p_2)^2 + (p_1 - p_2)^3 - 12L^2(p_1 + p_2 + 2u_0 - 2y - 2a\phi)}{48L^3} \tag{A.8}$$

where $i, j \in \{1, 2\}$ and i. When differentiating π_i with respect to p_i and trying to solve for p_i and p_j simultaneously, Mathematica returns no result. Given this, it is highly unlikely that an optimal degree of compatibility can be found after substituting $L(\phi)$ into the profit function. Leaving out the outside alternative would simplify the matter. Unfortunately, the simplification goes to far in the sense that the network externality term $a\phi$ drops out. Hence, it can be concluded that a linear probability model as depicted above is not feasible to be extended for continuous compatibility.

A.2 The Multinomial Logit

In a first attempt to model continuous compatibility, Jonard and Schenk's (2003) duopoly logit model with price competition and strategic compatibility was extended. When taking a look at the resulting equations, it quickly becomes clear that the model becomes unsolvable and many attempts to simplify result in the relevant variables dropping out.

Again imagine a two stage game, in which two firms first choose whether to make their PBX compatible and then set their prices. Customer choice is also represented by a two-stage process, in which customers first choose whether to buy an IP PBX or an outside alternative in form of a hybrid or regular PBX. If they decide for an IP PBX, they choose product 1 or 2 in the second stage.

Like the linear probability model, the multinomial logit is a probabilistic discrete choice model. Let us define the following utility functions

$$U_1 \equiv y + a(1-\phi) - p_i + \epsilon_i \text{ and} \tag{A.9}$$

$$U_0 \equiv y + u_0 + \epsilon_0, \tag{A.10}$$

for buying product i where $i \in \{1, 2\}$ and for buying the outside alternative respectively. y represents a customer's basic utility from buying a good or can alternatively function as the consumer's income (Jonard & Schenk, 2003). u_0 is the additional utility for buying the outside alternative while a is the maximum possible amount of additional utility from network externalities. Unlike in the linear probability model, $\phi = 1$ denotes incompatibility while $\phi = 0$ stands for complete compatibility and $\phi \in [0; 1]$.

The main difference to the linear probability model lies in the fact that the error terms are not distributed uniformly, but follow a double exponential distribution (Anderson et al., 1992). From this, the cumulative probability function, with the well-known shape of the multinomial logit results as depicted in figure A.4.

From this, the following profit function, analogously to the linear probability model results:

$$\pi_i = NP(i)(p_i - c) = N(p_i - c)P(IP)P_{IP}(i), \tag{A.11}$$

where $i \in \{1, 2\}$, $P(i)$ is the overall probability that product i is chosen, $P(IP)$ is the probability that the customer goes for an IP PBX and $P_{IP}(i)$ is the cumulative probability that product i is chosen given the customer has decided for an IP PBX. From Jonard and

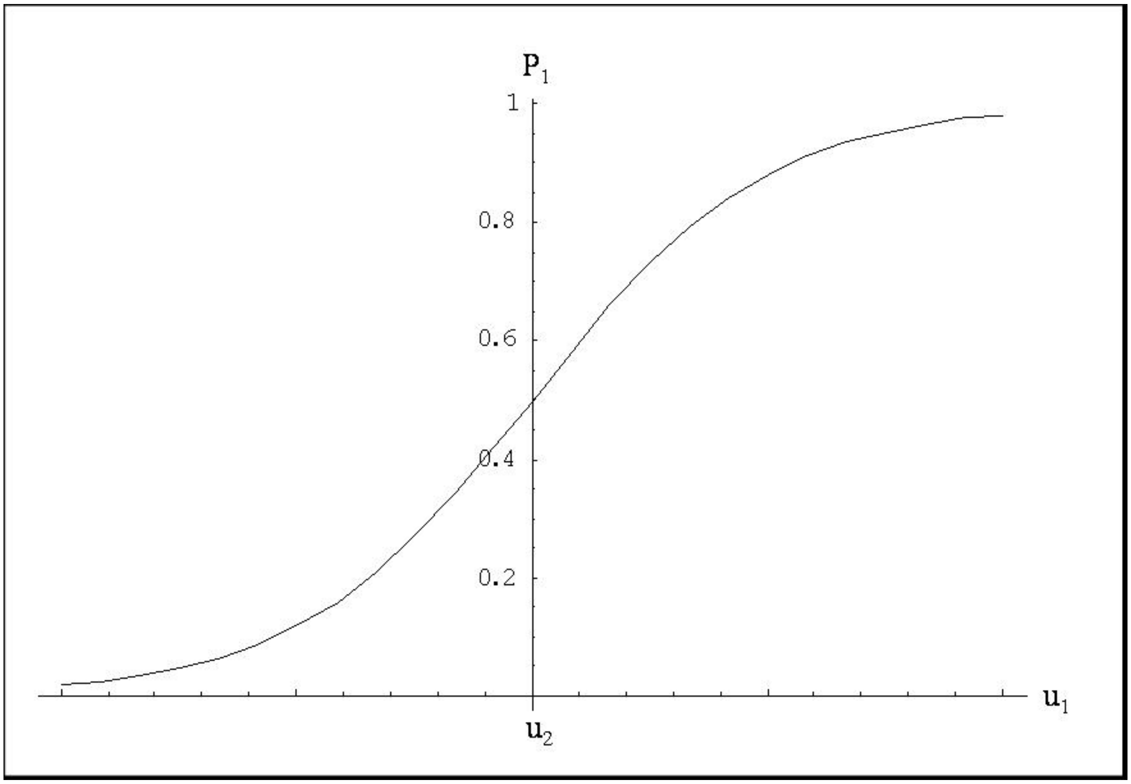

Figure A.4: Logit demand for product 1

Schenk (2003) it also becomes clear that

$$P_{IP}(i) = \frac{\exp \frac{-p_i}{\mu}}{\exp \frac{-p_i}{\mu} + \exp \frac{-p_j}{\mu}} \text{ and} \tag{A.12}$$

$$P(IP) = \frac{\exp \frac{u_{IP}}{\mu}}{\exp \frac{u_{IP}}{\mu} + \exp \frac{u_0}{\mu}}, \text{ where} \tag{A.13}$$

$$U_{IP} = \mu ln2 + y + a - a\phi - p_i. \tag{A.14}$$

In order to find the equilibrium amount of compatibility, one must first find the equilibrium price.

$$\frac{d\pi_i}{dp_i} = NP(IP)P_{IP}(i) + N(p_i - c)\left[\frac{dP(IP)}{dp_i}P_{IP}(i) + \frac{dP_{IP}(i)}{dp_i}P(IP)\right] = 0 \tag{A.15}$$

$$\Leftrightarrow 0 = P(IP)P_{IP}(i) + (p_i - c)\left[\frac{P(IP)^2 - P(IP)}{\mu}\right]P_{IP}(i)^2 \tag{A.16}$$

$$+\frac{P_{IP}(i)^2 - P_{IP}(i)}{\mu}P(IP)$$

$$\Leftrightarrow -1 = (p_i - c)\left(\frac{P(IP)P_{IP}(i) - 1}{\mu}\right) \tag{A.17}$$

$$\Leftrightarrow p_i \quad = \quad p_i^* = c + \frac{\mu}{1 - P(IP)P_{IP}(i)} \tag{A.18}$$

In order to move to the next stage and derive the optimal degree of compatibility, one would have to introduce $\mu(\phi)$ as μ represents the degree of differentiation. Afterwards, one has to find $\frac{d\pi_i}{d\phi}$. The problem is that the probability $P(i)$ is a function of the price. Hence, unless one can solve for the price and probabilities simultaneously, finding $\frac{d\pi_i}{d\phi}$ is impossible. The problem thus boils down to finding the simultaneous solution to the following two equations with respect to the equilibrium price p_i^* and the probability $P^*(i)$,

$$p_i^* \quad = \quad c + \frac{\mu}{1 - P^*(i)} \text{ and} \tag{A.19}$$

$$P^*(i) \quad = \quad \frac{\exp \frac{u_{IP} - p_i^*}{\mu}}{(\exp \frac{u_0}{\mu} + \exp \frac{u_{IP}}{\mu})(\exp \frac{-p_j}{\mu} + \exp \frac{-p_i^*}{\mu})}, \tag{A.20}$$

where $i, j \in \{1, 2\}$ and i. When attempting to solve the equation, Mathematica answers that "The equations appear to involve the variables to be solved for in an essentially non-algebraic way." As it turns out, the exponential function to be solved is transcendental and its solution can therefore not be expressed with any algebraic means. When trying to simplify the model by leaving out the outside alternative or using a non-nested multinomial logit, the relevant variables drop out.

One can conclude that the multinomial logit is particularly sensitive to extensions as it involves exponential functions which quickly become unsolvable.

A.3 Hotelling Models

Hotelling models are some of the most simple models of horizontal differentiation (Tirole, 1988). In the original model of 1929 (Hotelling in Tirole), customers have heterogeneous tastes regarding one aspect of the product, namely location. Hotelling assumes that customers are evenly distributed along a linear city of length one, while there are two stores located at each end of the city. Further details have been left out so as to keep this appendix to a minimum. More information on Hotelling models can, for example, be found in Tirole (1988).

The following two sections depict a symmetric as well as an asymmetric Hotelling model. In the asymmetric model, products come with different potential gains from network externalities. Finally, the sections show that neither the symmetric nor the asymmetric models allow for partial compatibility. A corner solution is always optimal.

A.3.1 Symmetric Models

Imagine a Hotelling model, where two firms are located at $x = 0$ and $x = 1$ respectively while $x \in [0; 1]$. Consumers are uniformly distributed over this interval with density 1 and all have a unit demand. Next to the products of the two firms, there is an outside alternative available with a net value of u_0 for those customers who buy it. Thus, customters face the following utilities depending on their choice:

$$U \equiv \begin{cases} y + a\phi - p_1 - tx & \text{if a consumer buys product 1} \\ y + a\phi - p_2 - t(1-x) & \text{if a consumer buys product 2} \\ u_0 & \text{if a consumer chooses the outside alternative,} \end{cases} \tag{A.21}$$

where $y > 0$ represents the gross utility from buying a PBX system and $a\phi$ represents the utility from compatibility with $0 \leq \phi \leq 1$. At $\phi = 0$, products are incompatible. If $\phi = 1$, products are fully compatible. t represents transportation costs to the shops at the end of the city and is a proxy for product differentiation. If the city has N citizens, at least two different profit levels are possible for the firms:

Case I:

$$\pi_1 = N\overline{x}(p_1 - c) \text{ and} \tag{A.22}$$

$$\pi_2 = N(1 - \overline{x})(p_2 - c), \tag{A.23}$$

if $-p_1 - tx = -p_2 - t(1-x) > u_0$ and $\overline{x}$ is defined as depicted in figure A.5.

In this case, the equilibrium is

$$p_1^* = p_2^* = c + t \text{ and} \tag{A.24}$$

$$\pi_1^* = \pi_2^* = \frac{1}{2}tN. \tag{A.25}$$

This equilibrium is independent of $a\phi$ and hence independent of network externalities. Since this does not correspond with the professional VoIP market, this case cannot be used to derive an equilibrium with possibly partial compatibility. Network externalities actually drop out from different models since the models are symmetric.

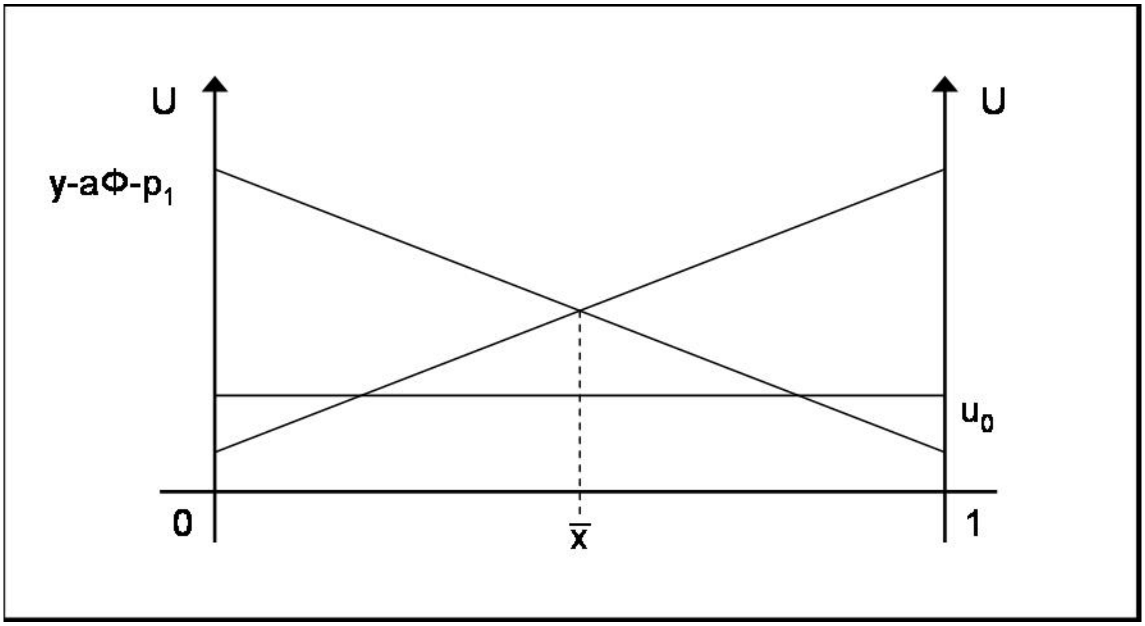

Figure A.5: Case I

Case II: In the current market, non-IP and hybrid PBX actually comprise an outside alternative which is still the most attractive option for many companies (EITO, 2005). In this case, the following profit function results:

$$\pi_i = (p_i - c)N\frac{y + a\phi - u_0 - p_i}{t}, \tag{A.26}$$

$$\begin{aligned} \text{if } y + a\phi - p_1 - tx &= u_0 \text{ and} && \text{(A.27)}\\ y + a\phi - p_2 - t(1-x) &= u_0 \text{ and if} && \text{(A.28)}\\ -p_1 - tx &= -p_2 - t(1-x) < u_0 && \text{(A.29)} \end{aligned}$$

In case II, the equilibrium is defined by the following equations:

$$\begin{aligned} p_1^* = p_2^* &= \frac{y + a\phi - u_0 + c}{2} \text{ and} && \text{(A.30)}\\ \pi_1^* = \pi_2^* &= \frac{N}{4t}(y + a\phi - u_0 - c)^2 && \text{(A.31)} \end{aligned}$$

Before optimizing profits for compatibility ϕ, $t(\phi)$ must be defined. The function must satisfy $\frac{dt}{d\phi} < 0$ since transportation or distaste costs decrease as products become more compatible. One simple function which fulfills this requirement is

$$t(\phi) = \frac{1}{\phi} - 1. \tag{A.32}$$

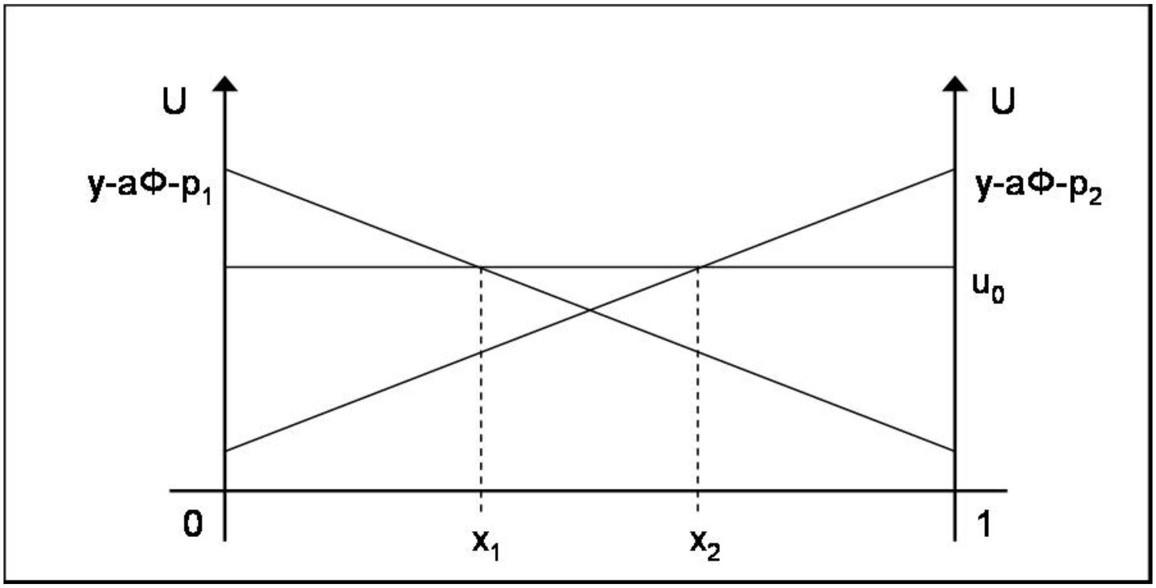

Figure A.6: Case II

When plugging $t(\phi)$ into equation A.31 and differentiating with respect to ϕ, one gets

$$\frac{d\pi^*}{d\phi} = \frac{aN(y + a\phi - u_0 - c)}{2(\frac{1}{\phi} - 1)} + \frac{N(y + a\phi - u_0 - c)^2}{(\frac{1}{\phi} - 1)^2\phi^2}, \tag{A.33}$$

where $\pi^* = \pi_1^* = \pi_2^*$. Solving for ϕ, one gets

$$\phi = \frac{c + u_0 - y}{a} \vee \phi = \frac{3}{4} + \frac{\sqrt{9a^2 - 8a(c + u_0 - y)}}{4a} \vee \phi = \frac{3}{4} - \frac{\sqrt{9a^2 - 8a(c + u_0 - y)}}{4a} \tag{A.34}$$

When testing the second order condition, it turns out that $\frac{d^2\pi^*}{d\phi^2} > 0$ for all ϕ where $\frac{d\pi^*}{d\phi} = 0$ and $0 \leq \phi \leq 1$. This implies that the three critical points above are actually minima and it would thus not be optimal to choose any degree of partial compatibility. Rather, firms would choose to be fully compatible as $\pi^*(1) > \pi^*(0)$.

One could argue that this finding is due to the functional form of $t(\phi)$. The trial of linear functional forms like $t(\phi) = 1 - \frac{9}{10}\phi$, logarithmic functions like $t(\phi) = -ln\phi$ or root functions, however, yields convex functions in the relevant domain, $0 \leq \phi \leq 1$, as well. Hence, it is possible that no Hotelling profit function exists, which is concave in ϕ, while at the same time satisfying $\frac{da}{d\phi} > 0$ and $\frac{dt}{d\phi} < 0$.

Two different conclusions can be drawn from the fact that symmetric Hotelling models as depicted here do not seem to allow for partial compatibility. On the one hand, one can conclude that partial compatibility is simply not the optimal choice for firms, even when it is technically available. On the other hand, this thesis has shown that there are models which do allow for partial compatibility. Hence, Hotelling models might not be the best-fitting tool to analyse markets like the professional VoIP market. A closer analysis of the fit between market characteristics and model parameters can shed light on this issue.

A.3.2 Asymmetric Models

This section shows that Hotelling models which are asymmetric in the degree of experienced network externalities suffer from similar complications when it comes to partial compatibility like the symmetric models. This does at least hold when one assumes that consent between the two companies is necessary to achieve compatibility. For the professional VoIP market, this is a realistic assumption. The reason is that the vast majority of proprietary protocols is closed. This implies that unless the owner of the proprietary protocol allows it, other companies are neither able to nor allowed to make their products one-way compatible. Hence, it is safe to assume that compatibility only comes to exist when both firms in the market have an incentive to be compatible.

For a closer understanding of why no partial compatibility results from models with asymmetric network externalities, imagine a Hotelling model like the one described in the previous section. The difference is that now companies have individual strengths of network externalities a_1 and a_2. The utility function of the N customers hence looks like the following:

$$U \equiv \begin{cases} y + a_1\phi - p_1 - tx & \text{if a consumer buys product 1} \\ y + a_2\phi - p_2 - t(1-x) & \text{if a consumer buys product 2} \\ u_0 & \text{if a consumer chooses the outside alternative,} \end{cases} \tag{A.35}$$

Consider the case where

$$a_1\phi - p_1 - t\overline{x} = a_2\phi - p_2 - t(1-\overline{x}) \geq u_0 \text{ as depicted in figure A.7.} \tag{A.36}$$

Then,

$$\overline{x} = \frac{\phi(a_1 - a_2) + p_2 - p_1 + t}{2t} \tag{A.37}$$

Consequently,

$$\pi_1 = N(p_1 - c)\frac{\phi(a_1 - a_2) + p_2 - p_1 + t}{2t} \text{ and} \tag{A.38}$$

$$\pi_2 = N(p_2 - c)\frac{-\phi(a_1 - a_2) + p_1 - p_2 + t}{2t}. \tag{A.39}$$

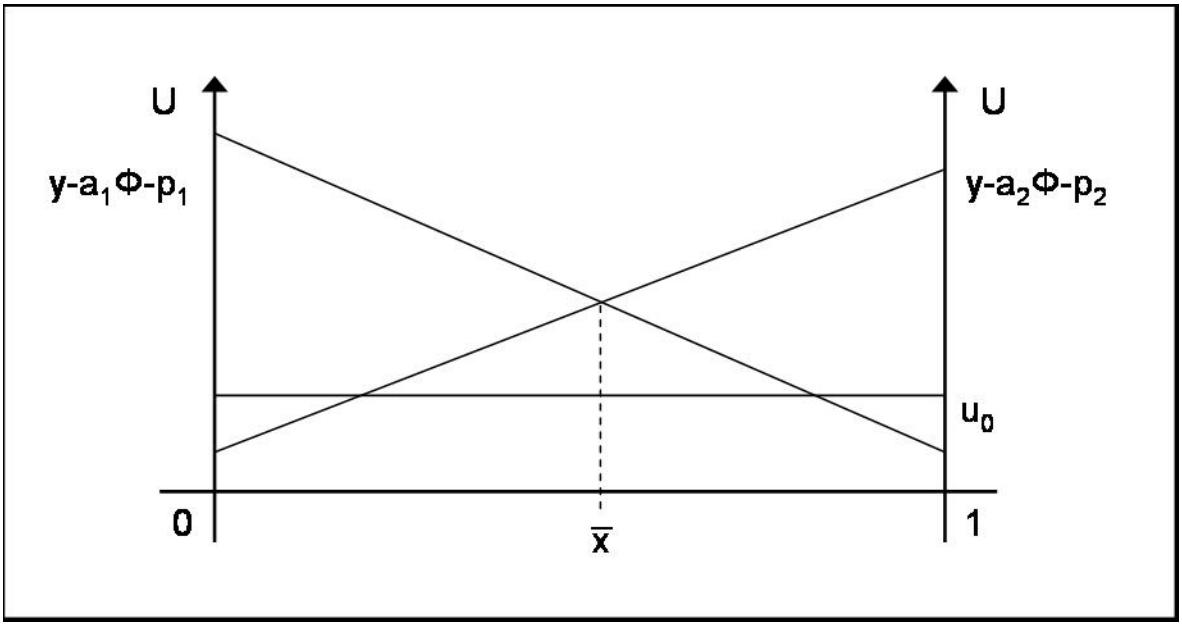

Figure A.7: Asymmetric Network Externalities

By setting

$$\frac{d\pi_1}{dp_1} = \frac{N}{2t}\left(\phi(a_1 - a_2) + p_2 - 2p_1 + t + c\right) \tag{A.40}$$

equal to 0 and doing the same for π_2, one can solve for the equilibrium prices and profits:

$$p_1^* = t + c + \phi\frac{(a_1 - a_2)}{3}, \tag{A.41}$$

$$p_2^* = t + c + \phi\frac{(a_2 - a_1)}{3} \text{ and} \tag{A.42}$$

$$\pi_1^* = \frac{N}{2t}\left(t + \phi\frac{(a_1 - a_2)}{3}\right)^2, \tag{A.43}$$

$$\pi_2^* = \frac{N}{2t}\left(t + \phi\frac{(a_2 - a_1)}{3}\right)^2. \tag{A.44}$$

Again, one has to substitute $t(\phi)$ before solving for the optimal level of compatibility. One simple linear function fulfilling the criteria outlined above is $t = 10 - \frac{99}{10}\phi$. Furthermore, make the change of variable $z = \frac{a_1 - a_2}{3}$. Then

$$\frac{d\pi_1^*}{d\phi} = N\left[\frac{2(z - \frac{99}{10})(10 + \phi(z - \frac{99}{10}))}{20 - \frac{99}{5}\phi} + \frac{99(10 + \phi(z - \frac{99}{10}))^2}{5(20 - \frac{99}{5}\phi)^2}\right] \tag{A.45}$$

Just as with the symmetric models, the profit function is convex in ϕ, see figure A.8. Again, this implies that one of the corner solutions is optimal and not any degree of partial compatibility in between.

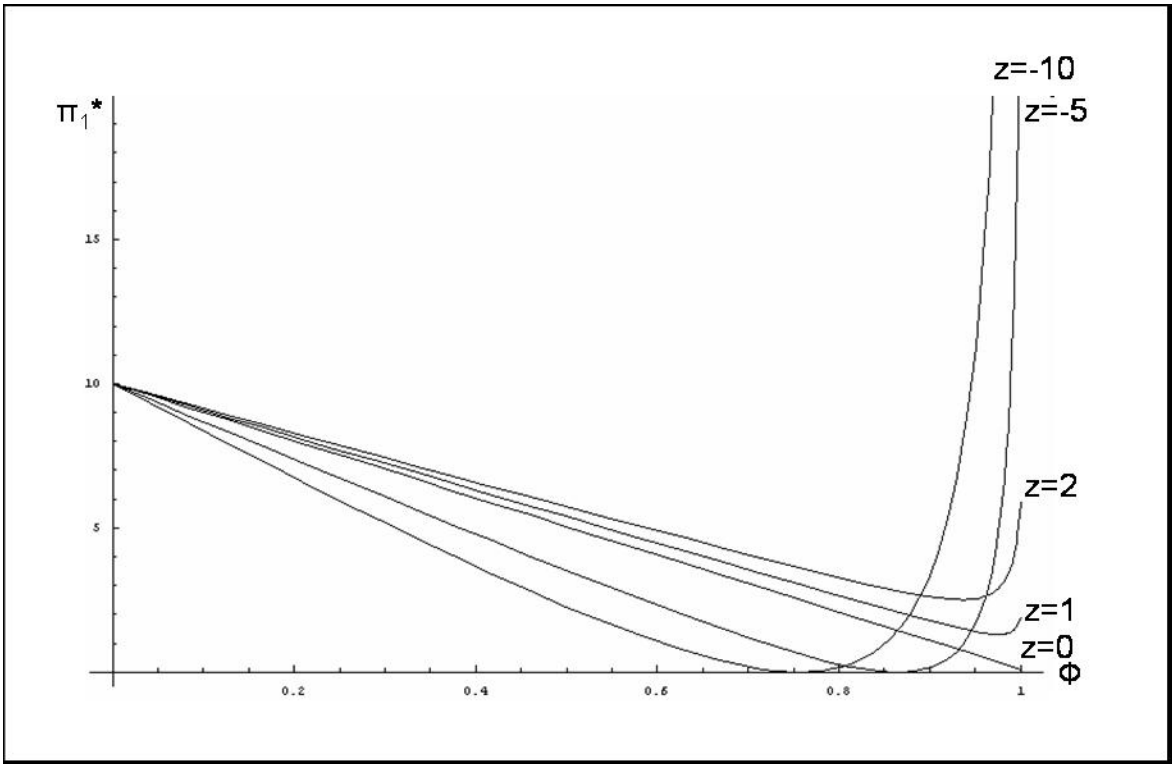

Figure A.8: Profit for different degrees of asymmetry, z

When retreating to alternative functional forms for $t(\phi)$ to arrive at a concave profit function, different problems occur. With functions quadratic in ϕ like $t(\phi) = (a_1 - a_2)\phi^2$, many solutions become infeasible for certain domains of z. Furthermore, $\pi^*(\phi^*)$ easily becomes intractable in Mathematica. The most important hurdle to compatibility, however, stems from the assumption of necessary mutual agreement. For root functions of $t(\phi)$, domains of z exist, in which partial compatibility represents the optimal solution for one company. It turns out, however, that whereever this applies, the other company would prefer incompatibility. Hence, no partial compatibility can be agreed on.

These results allow conclusions analogously to those that can be drawn from symmetric Hotelling models.

Appendix B

Interview Protocols

This chapter provides the protocols of two in-depth interviews that the author conducted with experts in the field of VoIP. Three employees of the Computacenter AG were interviewed in two sessions. Computacenter is a vendor-independent IT infrastructure service provider. In Germany, the UK-based company employs more than 3,500 people. Next to unified communication solutions, Computacenter offers full-fledged individual IT solutions, from client computing to network solutions. The interview protocols below have been approved by the interviewees.

B.1 Interview Hartmut Leyendecker and Guido Thater

Hartmut Leyendecker is currently employed as a Sales Consultant for Unified Communication Solutions. Guido Thater works as a Product Manager at the Consulting Services. The interview was conducted on May 12, 2006, at the Computacenter office in Cologne.

1) For what parts of the PBX is compatibility an issue? Is there anything beyond phones and applications?
Apart from phones and applications, the upcoming standardization through IP and SIP may also play a role in organizational compatibility as well as security issues. In terms of internal organization, one can talk about a current incompatibility between data and telephone network employees. Cultural differences and lack of knowledge of the respective other domain can lead to misunderstandings and frictions. With the introduction of IP telephony, compatibility or even merger between data network and voice administration will come about. Similarly for future security structures: Because of the industry-wide standardized platforms that are used in IP telephony, existing security structures can be adopted without much further integration. A multitude of open (Linux) as well as closed

(Windows) standards can be employed with the standardized platforms. Open interfaces even enable the so-called "Appliance Model", in which software is installed somewhere in the network, not necessarily on the IP telephony server. Nevertheless, one must carefully assess the meaning of compatibility in the telephony area compared to the PC market. A crucial difference is the ratio of licence to hardware costs. The share of licence costs is relatively lower in the VoIP field.

2) Particularities regarding compatibility in the German professional VoIP market

Germany is lagging behind in the adoption of VoIP compared to many other industrialized nations. This is due to several particularities of the German market, which need to be kept in mind during any analysis. First of all, IP technologies have been underrepresented in general because of Germany's very well developed ISDN. This network provides many call features, and the Germans' preference for many such features holds true for the professional telephony market as well. Consequently, products developed for the less feature-rich American market have been less successful than specialized German developments. Companies like Siemens had developed advanced products early on, so that development costs remained low during the 1980's and 1990's. During this time the German market developed into an oligopoly. With the introduction of VoIP, a time of change has begun for this rather stable market. During this change, new entrants face a large challenge because of missing definitions for common features. Each customer defines features according to past experience. As this makes it somewhat unclear what exactly the "chief secretary" function must include, new, and especially foreign, entrants have a hard time to improve and adapt their products. On top, the propensity to innovate is very ambivalent among German companies. Some firms do not anticipate an added value of VoIP, while others may struggle to have their plans approved by the works council.

Last but not least, the German market might switch from the past direct sales system to indirect marketing strategies with the adoption of VoIP, as is common in other countries.

3) Technology: SIP and comparable protocols

The Session Initiation Protocol has undergone a remarkable development within the past few years, but it still lacks many features compared to the proprietary protocols. Nevertheless, its power is steadily increasing and it has bypassed competitor H.323. Main success factors have been its simplicity, its standardization and the fact that it has become an important marketing term. Features beyond basics like automatic call-back, number submission and path replacement are implemented in proprietary protocols on top of SIP.

[Path replacement as such is not a real issue in pure IP based environments as transport is always based on the IP protocol. IP by definition always uses the shortest path. The issue may come up however, where an intermediate system like an IVR terminates two half circuits and then is not needed any more for the communication.] Cisco, for example, employs Cisco SIP or the Skinny protocol, for even more features. Those extra features are still incompatible with phones from other companies. A similar relation between compatibility and feature richness exists in the classic world of telephony; analogue technology is traditionally compatible while digital technology is not. Again, the strict definition of call features is important for the future development of SIP and thus standardization and compatibility.

4) The compatibility decision by vendors

In general, the compatibility decision is regarded as a strategic decision by vendors. Several choice patterns seem possible in the future. Compatibility decisions could be made according to strategic partnerships with providers of phones and applications. Such partnerships can play a vital role in reducing adjustment and testing costs, since testing of all components of the PBX must be done even under compatibility. "Incompatibility - Compatibility" cycles seem equally likely. Important innovative features might initially be incompatible, but become standardized later on.

The exact choices of compatibility will depend on the development of standards like SIP to a large degree. Currently, companies like Cisco, Avaya-Tenovis, Alcatel and Siemens support SIP, but proprietary protocols are still prevalent. Sometimes SIP is only used as a vehicle for vendor specific protocols, so that incompatibility between different brands remains. Furthermore, vendor support of SIP varies to a large degree. The quick advancement of SIP is much more crucial for the challengers of the PBX market than for the "defenders". Challengers include new entrants from the network technology market, i.e. mainly Cisco, as well as traditional vendors with very advanced IP PBX systems. Companies with a large installed base and less advanced IP technology, on the other hand, have an interest in collecting high licensing fees for proprietary applications etc. for as long as possible.

5) From your experience, what are the most important factors determining customer choice?

In general, customers are divided in their attitudes towards VoIP and the variety of features, but costs play the most important role for all. Once a request for proposal has been issued, price can determine the customer's choice up to 95%. One reason is that customers indeed have a strong bargaining position in this so-called "buyers market". Furthermore, systems have not differed greatly with regard to features, which is the second most important criterion for customers. A large variety of known as well as new features is especially appreciated by the most innovative customers. As with the variety of features, the attitudes towards VoIP are split between more open customers following the trend of VoIP and the traditionalists, who greatly value the reliability of their current systems and brands. Existing customer relations in this B2B market do play a minor role.

6) What is the share of phones in total cost and how have profit margins developed?

Compared to the traditional world of telephony, phones represent an ever larger part of costs. This is partly due to the extended functionality of each individual telephone but also to the higher complexity of IP technology in general. The higher cost for IP phones implies that profit margins on these devices are lower than in the old world as well. Price competition with traditional telephones is tough, which are often sold at 10 to 15% of list prices when a new system is purchased. Nevertheless, producers of phones are usually still able to achieve profit margins in excess of 50%. One reason is that devices from low price chains like Saturn or Mediamarkt are hardly ever adopted in the professional VoIP market.

7) Applications

The advent of VoIP has made an easier provision of various old and new applications possible. Among those are

- Voicemail
- Unified Messaging (including integration with email clients and faxing)
- Billing (often used at governmental agencies or for separate billing of private phone calls at the workplace)
- Presence Management, which is particularly valuable in connection with mobile devices.

Innovation is only at its outset. Further new developments and industry-specific applications are likely in the future for at least two reasons. Firstly, convergence becomes easier to implement with SIP on an IP platform. What is more, new and potential new entrants are keen to bring new developments forward and use them as their entry ticket into the market. Overall, SIP will be the foundation for further innovations in the area of VoIP and integrated applications.

Regarding compatibility with applications, the crucial identical interfaces are only likely to come about in the far future. In the meantime, XML allows for the skipping of the previous expensive middleware. The configuration investments, however, remain. After all, future applications will determine the future interfaces.

8) How could applications be partly compatible?
Vendors can make their PBX systems partly compatible with applications by only opening their systems to a certain extent. Thus open interfaces are the ultimate key to compatibility. Next to this, vendors can choose exactly with which systems, e.g. SAP, to make their products compatible. This is where strategic partnerships may come into play. In such partnerships, the telephone might simply become an extension of the computer as the main office device. Finally, PBX vendors can orchestrate different applications by extracting individual functions that match single business processes.

B.2 Interview Christian Louis

Christian Louis is a System Engineer at Consulting Services for Security Solutions with the Computacenter AG. The interview took place over the telephone on September 19, 2006.

What is the current role of SIP in the professional VoIP market? What will the future development look like?
The basic function of SIP is to connect telephones with a company's PBX system. Because of its heritage, however, it can do much more. By putting more intelligence from the PBX into phones and other terminal equipment, it cannot only reproduce many known features, but virtually connect any kind of multimedia. It is more multifunctional than the past technologies, e.g. it can incorporate functions like presence management or instant messaging rather easily.

On the other hand, as SIP was not born out of the telecommunications industry, it can currently reproduce many, but not all traditional features. The RFC standardization by the IETF still leaves some room for the interpretation of SIP. It is likely, that companies like Cisco, Avaya or the large telcos will advance the standard to include all traditional features in the medium term. This is because the fixed line networks are becoming entirely IP-based. Furthermore, producers without traditional PBX systems are heavy users of SIP and need the full list of features to not put themselves at a competitive disadvantage.

Because of the processes at the IETF, the advancement of the SIP standard will be dynamic, with new features being pushed forward by different companies every once in a while. The choice of enhancements that are put forward will be a strategic one. Furthermore, not all competitors might implement or accept new additions to the SIP standard. Strategic alliances will become important in this respect. Regarding individual phones then, the market will likely be split in two. Certain vendors will offer full-fledged phones that are updated regularly with the/their latest additions to SIP. Concerning the compatibility between the PBX and those phones, only the phones from a few different vendors will work with a certain PBX without further and possibly considerable adjustment costs. A second and larger set of phones will implement the most widely used subsets of SIP. When thinking about the future offer of phones, it is also important to keep in mind the demand side. In general, customers are much more interested in what terminal equipment can do than in how it does something in a technical sense. This leaves doubts about how many different terminal devices can be profitable.

How can phones still be differentiated once compatibility occurs?

First of all, vendors are likely to engage into two different types of strategies: cheap mass production or constant innovation. The innovators will differentiate their products via different channels. In case of standardization, functionality will become more alike, just like one can surf the internet with an Apple as well as a PC. Hence, other differentiation characteristics will play a bigger role. First, there will always be temporary diversification through development of new features and functions. Second, user interfaces and handling of phones and PBX systems will differ markedly, especially because ease of use is gaining more importance.

There are two technological developments in favour of the former means for differentiation. Both the multimedia features of SIP and the increasing intelligence of individual phones leave more room for innovation. Such innovation could e.g. happen through clever combination of multimedia-based communication tools. The combination of voice communication with instant messaging is a very promising one in this vein. Moreover, phones will be easier to update as they become more intelligent. Ultimately, they will only be another form of computer. Thus different PBX systems and phones might relate to each other like Mac and PC or Skype and ICQ.

As a result of the two generic strategies and technological developments, certain strategic moves are likely to gain more importance. Influencing the future development of the SIP standard bears potential benefits for producers. Moreover, first mover advantages regarding new features can be crucial in a dynamic market. Finally, even the cherry on top of the PBX can become decisive as differentiation opportunities diminish.

Throughout the discussion one should not forget, that the shift to IP telephony has not been completed, yet. In the long term, the wanted features as well as their total number are likely to change, also in the German market.