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Technical barriers to entry in the telecommunications equipment sector

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Technical barriers to entry in the telecommunications equipment sector

Chiel Albers
Technical barriers to entry in the telecommunications equipment sector
Executive summary

This thesis focused on the influence of modularization and technological discontinuity on the innovative behaviour of firms.

The innovative behaviour of firms, especially new entrants, can be seriously hampered by technical entry barriers. Technological entry barriers determine, according to Bains, the possibility for established firms to maintain a "supra-competitive" advantage, using knowledge, with respect to potential entrants from outside an industry. Theory identifies two phenomena, modularization and technological discontinuity, that reduce the technical knowledge barrier in a given moment. Modularization reduces the complexity of the technology by breaking up a complex system into pieces, modules. An example of this is the change from an integrated telephone system to a more modular telephone system. This makes it easier for new companies to be active and innovate in the sector, because there is no need for a complete knowledge of the technology, with all its complexities. Instead a company can focus on a particular module that fits its knowledge base. The second reason can be technological discontinuity. This renders the old technology non-competitive, and many of the barriers that firms have erected around them in the previous paradigm become useless as the old technology is supplanted by the new technology. This reduces the competitive advantage the incumbents have over new companies that enter the market.

Two cases were studied to describe the innovative behaviour of firms in different technologies. The first case focuses on modularity and compares two switching technologies: Intelligent Network (IN) and Private Branch Exchange (PBX). The second case is on technological discontinuity and compares two transmission technologies: coaxial cable and optical fibre. To describe the innovative behaviour of firms, in the different cases, patents data was used. From the dataset the Weighted Patent Count (WPC) was constructed for every patent. On the basis of the WPC and the changes in WPC for the patents of a certain company the innovative behaviour in the cases was described and analysed.

In the case of IN (with modularity) and PBX (without modularity) the effect of modularization on the innovative behaviour of firms has been minimal. It appears there is no real difference in the trends both switching technologies follow, albeit there is a difference in the intensity of the behaviour. The technical discontinuity in the transmission technology that was caused by the transition from coaxial cable to optical fibre resulted in new companies entering the market. The lowering of the technical entry barriers changed the entire structure of the industry. However, as the new technology progressed, the barriers rose again and optical fibre became a more closed technology in the same way as coaxial cable. This happened even before the technology was completely developed and focus changed from product innovations to mainly process innovations. It is however clear that a technical discontinuity can change an industry significantly, although the effect on the old technology was limited in this case.

Modularization did not affect the innovative behaviour of the firms and it therefore did not change the structure of the market. Technological discontinuity did have an effect on the innovative behaviour, although it only influenced the new technology (optical fibre) and to a lesser extent the old technology (coaxial cable).
Preface

After 21 years this is the final step of my education. This thesis is the culmination of all that I have learned in those years.

I started with this thesis over a year ago without really knowing what I wanted to research. Therefore the first few months were spent in a search through the wonderful world of telecommunications and related economic issues. What I did know from the start was the methodology I wanted to use, a patent citation analysis. At the end of the summer of 2006 it was finally clear what I wanted to research and the theoretical framework was more or less standing. The next autumn was spent trying to make the patent citation analysis work, unfortunately I didn't succeed and at the end of the autumn I decided to change my methodology. I ditched the patent citation analysis and came the weighted patent count. From then on the empirical part went rather well, and now I am finally ready.

I want to thank both my supervisors, Bert Sadowski and Arianna Martinelli. They were very helpful in giving discerning comments and keeping me sharp. I further want to thanks Rudi Bekkers for giving my advice on the case studies that I conducted.

Chiel Albers
Eindhoven, June 2007
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1 Introduction

1.1 Background

In the post-war period the majority of the telecommunication companies were government controlled monopolies, corporate R&D was organized in central research laboratories that had an arm's-length relationship with the company's businesses, the most famous of these laboratories was Bell Labs. In the past there were always strong links between national Public Telecom Operators (PTOs), and their R&D facilities, and national equipment makers, for example between Deutsche Telekom and Siemens, Swedish Telecom and Ericsson and France Telecom and Alcatel. The equipment makers provided the PTOs with the equipment and the PTOs gave the equipment makers a guarantee that they could recuperate their investments. This vertical integration enabled both parties to recover their investments easily. Since the telecommunication monopolies operated on cost basis, and the R&D was regarded as one of the costs, there was little pressure on the laboratories to prove that it was paying its way.

This changed dramatically in the period between the mid 1980's and 2000, due to the liberalization of the telecommunications markets in many countries (more on this later). During this period, new entry and competition became increasingly important. KPN sold its R&D department to TNO in 2003, AT&T spun off its R&D department, Lucent, in 1996 and many other companies made similar moves. They made it their policy to buy their technology from independent R&D companies or manufacturers. The new service based competition, such as DDI and Japan Telecom in Japan, Mercury in the UK, and MCI and Sprint in the US, tried to avoid R&D all together and outsource it to specialist equipment companies. This choice had the advantage of keeping entry costs lower than they would have been with internal R&D.

In the period described above two important points emerged. First the R&D-intensive activities moved from the incumbent telecommunication companies to the specialist telecommunications equipment manufacturers. This is true in absolute terms (in terms of total R&D spending), in terms of R&D intensity (R&D as a percentage of sales), and in terms of R&D per employee (Figure 1). NTT remains the most R&D committed of the 'Big five' incumbents. However, its R&D intensity is far below that of the telecommunications equipment manufacturers as is its R&D per employee. Even in absolute terms its R&D spend is not much different from many of the equipment makers, even tough NTT has much larger sales (Fransman, 2002). The second point is that the telecommunications sector as a whole, that excludes equipment manufactures, is not very R&D intensive when compared with other sectors. Indeed sectors that are normally not thought of as 'high-tech', such as personal care and beverages, have the same R&D intensity. It can be said that the industry changed from vertically integrated into vertically specialized.

These two points reveal how the process of vertical specialization has produced specialist telecommunications equipment and technology suppliers who are capable of providing most of the equipment and technology required by the companies that operate the networks and provide telecommunication services. It is precisely for this reason that new entrants have been able to successfully enter the telecommunications services sector without having substantial internal R&D capabilities, something that would be impossible in other sectors such as pharmaceuticals or semiconductors (Fransman, 2002).
<table>
<thead>
<tr>
<th>Telecoms operators</th>
<th>1999 R&amp;D spend ($'000)</th>
<th>Sales ($m)</th>
<th>R&amp;D % sales</th>
<th>R&amp;D per employee ($'000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT&amp;T</td>
<td>550,000</td>
<td>62,391</td>
<td>0.9</td>
<td>2.3</td>
</tr>
<tr>
<td>BT</td>
<td>556,037</td>
<td>30,163</td>
<td>1.8</td>
<td>2.6</td>
</tr>
<tr>
<td>Deutsche Telekom</td>
<td>701,611</td>
<td>35,552</td>
<td>2.0</td>
<td>2.2</td>
</tr>
<tr>
<td>FT</td>
<td>594,572</td>
<td>27,297</td>
<td>2.2</td>
<td>2.1</td>
</tr>
<tr>
<td>NTT</td>
<td>3,729,910</td>
<td>95,061</td>
<td>3.9</td>
<td>10.3</td>
</tr>
<tr>
<td>Specialist telecoms suppliers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cisco</td>
<td>1,594,000</td>
<td>12,154</td>
<td>13.1</td>
<td>47.1</td>
</tr>
<tr>
<td>Ericsson</td>
<td>3,877,196</td>
<td>25,214</td>
<td>15.4</td>
<td>22.9</td>
</tr>
<tr>
<td>Fujitsu</td>
<td>3,659,723</td>
<td>51,224</td>
<td>7.5</td>
<td>12.7</td>
</tr>
<tr>
<td>Lucent</td>
<td>4,510,000</td>
<td>38,303</td>
<td>11.8</td>
<td>18.3</td>
</tr>
<tr>
<td>NEC</td>
<td>3,382,463</td>
<td>46,495</td>
<td>7.3</td>
<td>13.3</td>
</tr>
<tr>
<td>Nokia</td>
<td>2,030,662</td>
<td>19,817</td>
<td>10.2</td>
<td>22.6</td>
</tr>
<tr>
<td>Nortel</td>
<td>2,908,000</td>
<td>22,217</td>
<td>13.1</td>
<td>23.5</td>
</tr>
</tbody>
</table>

Figure 1: Telecoms R&D 1999 (Fransman, 2002)

The reason that is usually given for this change from a vertically integrated industry into a vertically specialized industry is the liberalization of the telecommunications market (Fransman, 2002). During the last decades the United States and the European Union have embarked on ambitious programs of liberalization of their telecommunications sectors. The United States led this effort by opening its long-distance market to competition in the 1970s, but it was the enactment of the Telecommunications Act of 1996 that forced open the market for local and intrastate telecommunications. The European Union ordered all Member States to begin opening markets to competition on January 1, 1998, but the process started in eleven years earlier (1987) with the exception of the U.K. (1984).

The goal of the governments was a market that evolves to a sustained pro-competitive market structure in which companies conduct in a competitive way, as to reap the benefits of competition, i.e. lower prices, better quality and a more extensive array of services.

In the United States AT&T had held the monopoly on telecommunications since the beginning of the twentieth century, because of the assumption that it was a natural monopoly. In the 1950s and 1960s there had been some small challenges to this monopoly, but in the 1970s new technologies opened the market up. The rise of cheap microwave communications equipment in the 1960s and 1970s opened a window of opportunity for competitors—no longer was the acquisition of expensive rights-of-way necessary for the construction of a long-distance telephone network. In light of this, the FCC (federal communications committee) permitted MCI (Microwave Communications, 1996)

---

1 A natural monopoly is said to occur when production technology, with relatively high fixed costs, causes long-run average total costs to decline as output expands. In such industries, according to theory, a single producer will eventually be able to produce at a lower cost than any two other producers, thereby creating a "natural" monopoly. Higher prices will result if more than one producer supplies the market. (DiLorenzo, 1996)
Inc) to sell communication services in the long distance market. This techno-economic argument against the necessity of AT&T's monopoly position would hold for a mere fifteen years until the beginning of the fibre-optics revolution sounded the end of microwave-based long distance communication.

The rest of the telephone monopoly lasted until final settlement of a 1974 United States Department of Justice antitrust suit against AT&T on January 8, 1982, under which AT&T agreed to divest its local exchange service operating companies, in return for a chance to go into the computer business. AT&T was broken up effective on January first 1984, AT&T's local operations were split into seven independent Regional Bell Operating Companies (RBOC); also known as “Baby Bells”. AT&T, reduced in value by about 70%, continued to run all its long distance services through AT&T Communications (the new name of AT&T Long Lines), although it lost some market share in the ensuing years to competitors MCI and Sprint Corporation (Massey, 1997).

The European telecommunications sector was historically characterized by a strong public service monopoly tradition together with an industrial policy of creating 'national champions', often run in conjunction with postal services. This environment began to change in the early 1980s, with privatization and the introduction of limited competition in some Member States, mainly United Kingdom. This process was accelerated through the European Community's internal market program which since the mid 1980s has provided a firm basis for the development of a common regulatory framework for the telecommunications sector. The Maastricht Treaty, which entered into force in November 1993, added an important new element to the legal basis for European integration in the area of telecommunications by means of its Title XII on Trans-European networks. This meant that in the course of the 1990s the markets for telecommunications in all Member States have been liberalized and privatized (European Union, 2005).

The liberalization and the free procurement of equipment by telecom operators have led to a competitive market for telecommunications equipment. One of the hallmarks of a competitive market is the relative ease of entering the market. With the removal of legal barriers to entry, the only barriers that remain are capital barriers and technical barriers. This thesis focuses on the influence of the change of technical entry barriers on the innovative behaviour of companies in the telecommunications.

Complexity of the technology generally increases the barriers to enter a certain market (i.e. technical entry barriers). New companies will have more difficulties in adapting the required technology; therefore incumbent companies mastering the technology have a greater competitive advantage. In the past the telecom equipment sector was dominated by this phenomenon and only few companies entered the market. However, recent developments have seriously decreased the technical knowledge barriers and new companies are entering the market (Fransman, 2002).

Theory identifies two reasons for the reducing of the technical knowledge barrier to enter a market in a given moment. The first reason is modularization. The complexity of the technology can be reduced by breaking up a complex system into pieces, modules. An example of this is the change from an integrated telephone system to a more modular telephone system. This makes it easier for new companies to be active and innovate in the sector, because there is no need for a complete knowledge of the technology, with all
its complexities. Instead a company can focus on a particular module that fits its knowledge base hereby reducing, in theory, the competitive advantage of the incumbents. The second reason can be technological discontinuity. This happens when a new technology is not compatible with the knowledgebase of the previous generation of technology and thus makes the pre-existing competencies of the incumbent firm obsolete or not relevant. An example of this is the change from copper wire to optical fibre. This reduced the competitive advantage the incumbents had over new companies that entered the market for physical transmission technology.

1.2 Aim of the research project

From the preceding follows the practical aim of this research project, namely;

1. Giving an understanding of innovative behaviour of firms in different technology areas
2. Giving an insight in the increase or decrease of the amount of companies entering a specific technology area that is influenced by one of the aforementioned phenomena.

From the theoretical perspective it is interesting to see what the real influence is of a number of potential phenomena lowering the technological entry barrier, such as modularization and a technological discontinuity. These phenomena could, according to theory, have a substantial effect on the rate of entry in a certain technology. The influence of these phenomena is however ceteris paribus.

This leads to the scientific goal of the research;

Providing an insight in the effect of lowering technical barriers on the innovative behaviour of firms in the telecom equipment sector

1.3 Research question

From the research aim the following research questions can be distilled:

Main question:

What is the influence of modularization and technological discontinuity on the innovative behaviour of firms?

From the research question the following sub questions are derived:

1. What is the effect of modularization on the innovative behaviour of firms?
2. What is the effect of technological discontinuity on the innovative behaviour of firms?
3. How can these phenomena affect the strategy of firms and regulators?
4. How does this research give a new supplement to the existing theory?
1.4 Research boundaries

Determining to what extent modularization and technological discontinuity affects the innovative behaviour of firms is of interest to several parties. First of all, it is interesting for the academic community to test theoretical models with real data to establish their validity. Secondly, it is of interest for regulators, like the Onafhankelijke Post en Telecommunicatie Autoriteit (OPTA) and Nederlandse Mededings Autoriteit (NMA). If it turns out that modularization and technological discontinuity significantly influence the innovative behaviour of firms these phenomena can be transformed into policy tools. Finally, this research is relevant for companies. They can use the outcomes to establish long term strategies in changing markets.

This paper takes the perspective of the telecommunications equipment industry. This includes all companies involved in the production and development of products that can be physically used to transmit signals over a distance for the purpose of communication. It explicitly excludes the telecommunications services industry, although it is possible that companies are active in both industries and those companies are of course part of this research. The focus is on innovative behaviour, this means the conduct of companies to develop new technologies and production methods.

1.5 Report outline

This report is divided in three sections; theory, methodology, empirical section.

The theory section can be divided in three parts. The first part deals with entry barriers while the second and third part deal with phenomena that can theoretically lower these barriers; modularization and technological discontinuity.

The methodology section will explain how the questions asked in the theory section can be answered.

In the empirical section two case studies are conducted. Every case in the empirical section exists of two parts. First it is a descriptive research; several cases will be studied to describe the innovative behaviour of firms in different technologies. The research focuses on two cases, each with two technologies.

Secondly an empirical analysis of the results of the descriptive research is conducted. Several sub questions were formulated and these will be answered with the empirical evidence gathered from the cases.
A schematic overview of the report structure is given below:

Figure 2: Report Structure
2 Theory

In the introduction the idea that technical entry barriers could have been an influential factor was put forward. But what are these entry barriers? The first part of this chapter will be dedicated to the theory surrounding entry barriers. The next step is to answer how these barriers can be lowered. The second and third part will focus on possible solutions for this problem. It will discuss the theory surrounding modularity and technical discontinuity and how these phenomena can influence the structure of a market.

2.1 Barriers to Entry

2.1.1 What are entry barriers?

J.S. Bain was one of the first to write about the existence of barriers to entry. In his 1956 book "Barriers to new competition: their character and consequences in manufacturing industries" he describes that in the years previous to his book there had never been a systematically undertaken measurement of the height and nature of barriers to entry. The focus of research in the field of economic theory had always been on the established firms (and the role the market leader played in eliminating or manipulating competition among established sellers) and there had been less attention to the extent to which established firms shaped price policies in the light of their anticipation of new entry, by deciding whether or not to try to prevent new entry (Bain, 1956).

The concept Bain introduces is "condition of entry". He says about this concept the following (Bain, 1956, p. 3):

"Let us understand the term "condition of entry" to an industry to mean something equivalent to the "state of potential competition" from possible new sellers. Let us view it moreover as evaluated roughly by the advantages of established sellers in an industry over potential entrant sellers, these advantages being reflected in the extent to which established sellers can persistently raise their prices above a competitive level without attracting new firms to enter the industry. As such, the condition of entry is then primarily a structural condition, determining in any industry the intra-industry adjustments which will and will not induce entry. Its reference to market conduct is primarily to potential rather then actual conduct, since basically it describes only the circumstances in which the potentiality of competition from new firms will or will not become actual."

The concept for barriers to entry is defined as factors that enable established firms to earn supra-competitive profits without threat of entry. The new entrants are firms that were not active in the industry before, this excludes companies that have taken over a player in the industry (Bain, 1956).
There are three determinants of the condition to entry. The first one is the effect of absolute cost advantages. This could mean the control of techniques and patents by incumbents, limitations on raw materials for new entrants, money-market conditions imposing higher interest rates on new entrants. The second determinant is product differentiation. This means the accumulative preference of buyers for an established brand, control of superior designs and control of distribution channels by the incumbents. The third and last determinant is the economies of scale for large firms. This means real economies (i.e. in terms of quantities of factors used per unit of output) of large-scale production and distribution such that an optimal firm will supply a significant share of the market and other economies of scale. (Bain, 1956, p. 11-16)

Michael Porter (Porter, 1980) elaborates on these determinants and examples and identifies six main factors that impede entry; some are already identified by Bain (1956):

- Cost disadvantages independent of scale; incumbents can have benefits that can never be equalled by entrants. These benefits can be the ownership of essential technologies, favourable access to raw materials, a head start in the learning curve, a greater accumulation of know-how, etcetera.
- Product differentiation; the advantage incumbents have because their name is known by consumers and they have had the time to create some brand loyalty.
- Advantages of scale; the cost for the production of a good can decrease as the quantity that can be sold increases (dropping long range average cost).
- Capital requirements; money-market conditions imposing higher interest rates on new entrants
- Transformation costs; these are one-off costs that can include the retraining of personnel, new equipment, etcetera.
- Access to distribution channels; if the logical distribution channels are controlled by the incumbent it can be expensive for the new entrants to set up new channels.
- Government policy; state monopolies can rule out entering a market all together. Another forms of government policy working as a barrier can be health and safety regulations, etcetera. The telecommunications industry was dominated by state monopolies until the 1990s.

Both Bain and Porter name advantages of scale as an entry barrier. This is however disputed by a number of economists, such as George Stigler. His definition of entry barriers is as follows; "costs that must be incurred by an entrant that were not incurred by established firms" (Stigler, 1968). The barriers to entry from cost advantages by incumbent firms and by product differentiation are consistent with Stigler's view that a barrier is due to a cost asymmetry. Economies of scale, by itself, are not a barrier according to Stigler. The 1982 and 1984 Department of Justice Merger Guidelines and the participants in the 1987 Journal of Economic Perspectives "Symposia on Horizontal Mergers and Antitrust" have adopted the definition by Bain (Nahata & Olson, 1989). This is also the definition adopted in this thesis.
2.1.2 What are technical entry barriers?

The factor of cost disadvantages dependent and independent of scale also include technical entry barriers. Technological entry barriers determine the possibility for established firms to maintain a supra-competitive advantage, as the result of innovation, with respect of potential entrants from outside an industry. In other words, it means that technology/knowledge, its creation and all its attributes can be considered as barriers to entry (Marsili, 2001).

Different types of entry barriers related to the nature of the knowledge base and to the properties of the learning processes can be distinguished in different technologies. Sources of entry barriers to innovation can be identified in the characteristics of costs, competencies, complexity and sources of knowledge (Marsili, 2001).

The first type of knowledge entry barrier is the high cost of production of a technology. It increases the advantages of larger producers and, therefore, increases the barrier to entry in that area (Freeman & Soete, 1997). There are various factors that are considered to work to the advantage of larger firms in innovation, such as static scale economies in R&D activities (for example, high fixed costs), dynamic scale economies along learning curves, ease of access to internal funding for risky research projects and so on. High costs of production of a technology may not only arise from scale requirements in the innovation process but also from requirements of in-house technical competencies and complementary assets in the innovation process (Teece, 1986) (Marsilli, 2001).

Secondly, the source of technological entry barriers refers to the nature of the technological competencies that are developed and applied in the innovation process. In this respect an important characteristic is represented by the degree of specificity (or symmetrical pervasiveness) of the knowledge base, mainly in production. This property reflects the fact that in some technologies, new knowledge can be applied to a variety of products and processes and in other technologies it can not. This means that sectors that use technology with a broad scope/pervasiveness have a higher chance of new entrants, because that knowledge is also used in other sectors. Companies that produce frames for the car industry can also make bicycle frames or iron fences, because it all draws from a knowledgebase regarding metalworking (Marsilli, 2001).

A third source of technical entry barriers is complexity. A technology can be complex along a number of dimensions: the number of components and subsystems in products (product complexity), the number of modules/operations in production processes (process complexity), and the number of items of knowledge necessary to master production and use (knowledge complexity). If all these different components or processes use different competencies, it becomes more difficult for a company to enter the market because it is required to master all these competencies. All these aspects contribute to increasing the level of technological entry barriers (Winter, 1984) (Pavitt et al, 1987)(Marsilli, 2001).

Finally, the characteristics of the sources of knowledge that contributes to innovation are seen as important in defining technological entry barriers. Innovative entry is facilitated to the extent that many individuals are exposed to the same knowledge base underlying the innovative process. In particular, the role of suppliers and users of external sources of knowledge and, therefore, as threats of technology based entry in an industry, is
emphasised. In addition, other sources of knowledge and potential entry in an industry are represented by firms in horizontally-related industries and employees of competing firms and institutions that have carried out similar research activities. So if there are many sources for the knowledge used in a certain sector, the entry barriers are lower as it is easier to access the specific knowledge (Winter, 1984) (Pavitt et al, 1987) (Marsilli, 2001).

2.1.3 Conclusion

So all in all, what are barriers to entry? All barriers to entry, technical and economic, are factors that enable incumbents to earn supra-competitive profits without the threat of new entry. These barriers can originate from a lot of different sources. One of these sources is knowledge (technical barriers to entry).

The reason why, amongst others, knowledge can be a barrier to entry is the complexity of technology. Due to the network nature of telecommunication the technology tends to be very complex. This means a company has to be able to grasp the entire network. Another form of technical entry barriers is the high cost of production of a technology, mainly dynamic scale economies along learning curves. Because of the sheltered position traditional equipment makers enjoyed in the past they have accumulated a lot of specific know-how. This is something new entrants lack. These two technical entry barriers are the focus of this thesis.

Actually both barriers boil down to the same point; to gather the knowledge that is necessary to enter the market time and capital is needed. This time and capital acts as a barrier to entry. How can this barrier be lowered? The solution for this problem is to change the nature of the knowledge. Make knowledge simpler or irrelevant. How can this be achieved?
2.2 Modularity

One of the ways the technical entry barrier can be diminished is by reducing the complexity of the technology. If the technology is less complicated it takes less money to master the technology involved. The reducing of complexity can be achieved by a design/architecture principle called modularization. This section will explain what modularization is. Secondly the origin of modularization (history) is discussed. Thirdly the influence of modularity on the industry structure is researched.

2.2.1 What is modularity?

In the case of telecommunications networks modularity can be seen as the following:

Modularity is a general set of principles for managing complexity. By breaking up a complex system into discrete pieces, modules, which can then communicate with one another through standardized interfaces within a standardized architecture, one can eliminate what would otherwise be an unmanageable spaghetti tangle of systemic interconnection (Langois, 2002).

According to Baldwin and Clark (2000) the system as a whole must therefore provide a framework, an architecture, which allows for the independence of structure and integration of function. This framework is constructed by an architect; this can be a single company, a group of companies or a standardization body. All of this is captured by three terms: abstraction, information hiding and interface.

A complex system can be managed by dividing it up into smaller pieces and looking at each one separately. When the complexity of one of the elements crosses a certain threshold, that complexity can be isolated by defining a separate abstraction that has a simple interface. The abstraction hides the complexity of the element; the interface indicates how the element interacts with the larger system (Baldwin & Clark, 2000).

In order to modularize a design and its corresponding task structure, the architects of the design must have as their goal the creation of set of independent blocks at the core of the design process. They must set about systematically to sever all dependencies known to exist across the initial modules. This is the abstraction of the system. It divides the complex system into simple elements with simple tasks. However in the beginning, the complete set of dependencies between the elements may not be known. To solve this problem of unforeseen interdependencies and to tie up loose ends the architects must always provide for integration and testing of the system at the end of the design process (Baldwin & Clark, 2000).

The architect determines what information in the system has to be visible and what information has to be hidden. The principle of information hiding can be applied to any complex system. The benefit of information hiding is that if the information hidden in a module is changed this does not affect the rest of the system because this information was not known to the rest of the system. The fewer points of interaction between modules, the easier it will be for further designers to come in and change certain features of the system (Baldwin & Clark, 2000).
Information hiding starts as an abstraction, but to achieve information hiding in the real world, the initial segregation of the designs has to be maintained throughout the design. This means that at points of interaction between modules clearly defined interfaces are needed.

Interfaces are a pre-established way to resolve potential conflicts between interacting parts of a design. It is like a treaty between two or more sub elements. To minimize conflict, the terms of these treaties need to be set in advance and known to all affected parties. Thus interfaces are part of common information set that those working on the design need to assimilate. Interfaces are visible information.

The abstraction and the interfaces are known as the design rules. A complete set of design rules fully addresses the following categories of design information (Baldwin & Clark, 2000):

- Architecture, in other words, what modules will be part of the system, and what their roles will be;
- Interfaces, that is, the detailed descriptions of how the different modules will interact, including how they will fit together, connect, communicate, and so forth;
- Integration protocols and testing standards, because the modules can be manufactured by different parties it is necessary to determine how well it works and how well one version of an element works relative to another.

In the telecommunications equipment world modularity is often used to manage complexity. But in other circumstances, it may be used to obtain scale and scope advantages in production. For example, if all items in a product line use common parts, one-size screws can be used. Economies in parts sourcing lead to a reduction of costs.

But regardless of the goal, modularization does three basic things (Baldwin & Clark, 2000):

- Modularity increases the range of manageable complexity. It does this by limiting the scope of interaction between elements or tasks, thereby reducing the amount and range of cycling that occurs in a design or production process.
- Modularity allows different parts of a large design to be worked on simultaneously.
- Modularity accommodates uncertainty. Modular designs are flexible. If new knowledge later yields a better solution, it will be relatively easy to accommodate these changes without changing much to the overall system.

Innovation that takes place through changes in the modules is called modular innovation. This in contrast to what Henderson and Clark call architectural innovation, in which the parts remain the same but the architecture is changed. A successful example of the modular innovation is the IBM 360, the architecture of this computer remained the same for many years while the development of the modules, i.e. hard disks, graphical cards etc., moved forward in a very fast pace. They can differentiate themselves in relation to their competitors with the way they develop the hidden information of the modules (Henderson & Clark, 1990). In the telecommunications industry modularization is often a form of standardization, but this does not have to be the case. The modularisation that companies use can be done externally, by competitors or standard setting organisations, or internally.
2.2.2 Origin of modularization

In the period from 1890 till 1970 the design process for telecommunication equipment was strictly non-modular, the only interfaces that existed were for international voice traffic. The origin of the modular design principles can be found in the 1960s. The CCITT, from the French name “Comité consultatif international téléphonique et télégraphique” and known as ITU-T, was born of an amalgamation of the CCIF (telephony) and CCIT (telegraphy). It held its first meeting in New Delhi (India) in 1960. The opening of transatlantic submarine cables, the plans for a cable across the Pacific and the prospect of satellite communications, thus increasing international voice traffic, made it imperative for the CCITT to define the operational and signalling characteristics of an intercontinental telephone services. This resulted in some of the first real international standards, SS5 and SS6.

When SS7 was developed in the 1970s there was the first real spill over from the CCIT to the CCIF. The study group of the CCIT had flung themselves into the unexplored but promising field of data transmission. At the CCITT meeting of 1972 in Paris the two mainstreams were finally merging. The concept of a common data and telephone network was introduced. The modularity of the OSI model was quickly adopted by the CCITT data transmission study group and looked promising for telephone signalling as well as data communication. The CCITT research on digital technologies, which from 1965 to 1968 had been confined to transmission system applications, broke out of that narrow framework and was instructed to define the structures of a digital network and setting the interface standards for future networks (Chapuis and Joel, 1990).

2.2.3 Influence of modularization on market structure

There has been a lot of literature on the link between modularity and market structure. Does the product architecture affect the firm structure or is it the other way around. With firm structure is meant the way the firm conducts its production and research, in house or outside the organization. The structure of the firms, active in a market, will eventually shape the structure of that market.

The general idea that a firm's organizational structure over time mimics the structure of the products it produces has been extensively investigated. With respect to a firm's internal organizational structure this phenomenon has been identified as representing an advantage in stable environments, and being a disadvantage if competitors introduce products with different product architecture (Henderson and Clark, 1990).

The assumption that is made is that a product's architecture determines the processes required to make the product, and in turn, contributes to the definition of the firm's organizational structure including its boundaries (i.e. the structure of the market). The classic example is IBM's decision to introduce the System/360 with a modular structure. Once IBM had designed the system with modular product architecture, it became possible for independent manufacturers to provide individual components to customers. Market forces led to driving down prices for individual components, such as hard drives and operating systems, which could be mixed and matched and eventually became commodities. This development changed the structure of the market from a closed to an open structure. It first starts with defining a product's architecture, second, establishing
firm boundaries of certain types and at certain locations, and third changing the way firms interact within the market. The conclusion in general terms is that a modularization of the product architecture results in outsourcing of components and processes. And therefore changes a market with oligopoly characteristics to an open and competitive market (Baldwin and Clark, 2000).

Baldwin and Clark provide the underlying reason for this interpretation. They understand every production system as a network of tasks and transfers. Transfers are necessary in every system that is beyond the cognitive limitation of a single individual, i.e. very complex. Only a subset of the transfers, however, falls in the category of what economists call ‘transactions.’ Baldwin and Clark argue that for a transfer to become a transaction it needs to be standardized, countable, and evaluated. The actions that make it possible to agree upon the content of the transfer (standardized), that make it possible to count whatever is to be transferred (countable), and that make it possible to measure the quality of what is transferred (evaluable) are design decisions. These design decision can be captured by a single company, but can also be open to everybody’s use, hence lowering technical barriers to entry.

However, some argue that the firm boundary, i.e. market structure, influences the product architecture. It has been proposed that systems try to adapt to external forces to increase their level of competitiveness with respect to demands from their environment. For example, Schilling suggests that systems migrate toward or away from increasing product modularity as a reaction of factors such as heterogeneity in inputs and demands, in addition to inherent system characteristics (Schilling, 2000). As external forces she defines the degree of heterogeneity of input and demand. If a multitude of suppliers exists and offers a wide variety of technologies, the product architecture will migrate to higher levels of modularity to take advantage of the situation. To the extent to which the firm boundary choice represents the available capabilities, and this is precisely the situation in a supply chain, it is the location (and type) of firm boundary that translates into a force that drives the product architecture toward or away from higher levels of modularity. So if there is an open and competitive industry with many sources of innovation there will be a modular architecture and if there is a closed industry with few sources of innovation there will be an integrated architecture.

The third and final category of interactions assumes that both the industry product architecture and firm boundary affect each other simultaneously. For automotive cases, researchers have argued that there exist a reciprocal relationship between product architectures and organizational structures (Takeishi and Fujimoto, 2001). A model has been suggested that describes product architectures and firm boundaries complementing each other. The model incorporates a feedback mechanism that ensures that the entire system oscillates between modular products in horizontal supply chains and integral products in vertically integrated supply chains (Fine, 1998).

In his model, labelled ‘the Double-Helix of Business,’ Fine explains this joint oscillation between integral and modular stages is driven by three forces from each side. According to this model, relentless entry of niche competitors, the challenge of keeping ahead of the competition across many dimensions of technology and markets required by an integral system, and the bureaucratic and organizational rigidities that often settle upon large, established companies, all drive an industry to a horizontal stage with modular products and a market that has a high level of new entries.
On the other hand, if technical advances in one subsystem make that subsystem the scarce commodity in the chain, if market power in one subsystem encourages bundling with other subsystems, or if market power in one subsystem encourages engineering integration with other subsystems to develop proprietary integral solutions, then the system moves to products with an integral architecture in a vertically integrated industry structure. All forces exhibit first increasing and then decreasing strength the closer they achieve their goal. As a result, neither state of product architecture and associated industry structure is permanently sustainable. This effect keeps the oscillation alive. Fine argues that entire industries evolve through this double helix. To the extent that most industry participants' ability to shape their industry is limited, they are required to 'swim with the stream' (Fine, 1998). Not adjusting to this ever changing environment, a firm may find itself in a trap represented by a misfit between product structure and industry structure (Chesbrough and Kusunoki, 1999).

2.2.4 Conclusion

The technical entry barrier can be diminished by reducing the complexity of the technology. The reduction can be achieved by a design/architecture principle called modularization. What is modularization?

On balance, modularity is a general set of principles for managing complexity. By breaking up a complex system into discrete pieces, modules, which can then communicate with one another through standardized interfaces within a standardized architecture, one can eliminate what would otherwise be an unmanageable spaghetti tangle of systemic interconnections (Langois, 2002). This standardization of interfaces, architecture, integration protocols and testing standards is done by an architect. This can be a single firm, a consortium of firms or a standardization body. The first use of modularization was in the 1960s with the construction of more and more submarine cables made standardizing interfaces a necessity. This development continues to this day. What is the influence of this development on the market structure?

There is a lot of theory regarding the link between the modularization of products and the structure of firms and markets. Henderson and Clark (1990) argue that the modular architecture of the products will lead to a modular industry, because the production will be modular and a company organizes itself around the production process. The modular products lead to more market entry, lower prices and thus more specialization or separate modules.

On the other hand, Schilling (2000) argues that the structure of the industry shapes the architecture of the products. If there are many sources of innovation, this will lead to a modular architecture and if there are not many sources an integrated architecture will originate. This means that in the case of the telecommunications equipment industry it is not the changing of the technical entry barriers that led to the spin-off of all those research arms, but the spin-off will lead to a lowering of entry barriers.

The third category of interactions assumes that both product architecture and firm boundary affect each other simultaneously. If all modules can be obtained relatively easy this will lead to an open (modular) industry structure, but if this is not the case and one module becomes a rare commodity the industry moves towards a more closed structure.
This thesis focuses primarily on the first model, as proposed by Henderson and Clark (1990). The second and third models are not as relevant, because the telecommunications industry has a modular system. However it can still contribute to the discussion of which of these three theoretical models is relevant for the telecommunication equipment industry. To understand this it is important to find out what kind of influence a modular architecture has on the amount of new companies entering, the stability of companies as sources of innovation and the concentration of innovation activity. This will show if an industry has become more open and have lower barriers, after the introduction of a modular architecture.
2.3 Technical discontinuity

The second way to diminish the barrier to entry would be to lower the importance of the know-how accumulated by incumbents. This is the case when there is a technological discontinuity; this means the end of a technical paradigm and the emergence of a new technical paradigm. A technological discontinuity sometimes renders the old technology (paradigm) non-competitive, and many of the barriers that firms have erected around them in the specific phase may become useless.

This section will first explain what the concept of technical paradigm implies. Secondly it will discuss the change of paradigm that the telecommunications industry is currently undergoing. The result of this shift in paradigm is a technical discontinuity and this will be discussed in the third part. Finally the concept of technological discontinuity and its possible effects on a market structure will be discussed.

2.3.1 What is a paradigm?

The concept of paradigms stems from the work of philosopher of science Thomas Kuhn who gave this word its contemporary meaning when he adopted it to refer to the set of practices that define a scientific discipline during a particular period of time. In his book *The Structure of Scientific Revolutions* Kuhn defines a scientific paradigm as (Kuhn, 1970):

- what is to be observed and scrutinized,
- the kind of questions that are supposed to be asked and probed for answers in relation to this subject,
- how these questions are to be structured,
- how the results of scientific investigations should be interpreted.

Dosi used this concept for his work on the relationship between growth and technological progresses, with the concept of technology paradigms Dosi (1982) meant the following:

*A set of procedures, a definition of the “relevant” problems and of the specific knowledge related to their solution. We shall argue also that each “technological paradigm” defines its own concept of “progress” based on its specific technological and economic trade-off.*

The idea of technological paradigm is based on a view of technology grounded on the following three fundamental concepts (Dosi, 2002).

At first, it suggests that any satisfactory description of 'what is technology' and how it changes must also embody the representation of the specific forms of knowledge on which a particular activity is based and can not be reduced to a set of well-defined blueprints. It primarily concerns problem-solving activities involving also tacit forms of knowledge embodied in individuals and organizational procedures.

Second, paradigms entail specific heuristic and visions on “how to do things” and how to improve them, often shared by the community of practitioners in each particular activity (engineers, firms, technical society, etc.), i.e. they entail collectively shared cognitive frames (Constant 1980).
Third, paradigms often also define basic templates of artefacts and systems, which over time are progressively modified and improved. These basic artefacts can also be described in terms of some fundamental technological and economic characteristics. For example, in the case of an airplane, their basic attributes are described not only and obviously in terms of inputs and production costs, but also on the basis of some salient technological features such as wing-load, take-off weight, speed, distance it can cover, etc. (Sahal 1981; Grupp 1992; Saviotti 1996).

Each "technological paradigm" defines its own concept of "progress" based on its specific technological and economic trade-offs. We will call this a "technological trajectory" the direction of advance within a technological paradigm. A technology shift means usually a shift in trajectory, but not a shift in paradigm.

The core ideas involved in this notion of trajectories are the following.

- First, each particular body of knowledge (each paradigm) shapes and constraints the rates and direction of technical change, in a first rough approximation, irrespectively of market inducements.
- Second, technical change is partly driven by repeated attempts to cope with technological imbalances which it creates.
- Third, as a consequence, one should be able to observe regularities and invariances in the pattern of technical change which hold under different market conditions (e.g. under different relative prices) and whose disruption is mainly correlated with radical changes in knowledge bases (in paradigms).

2.3.2 Convergence: What does it mean?

Although technological paradigms may be very strong for a considerable period of time, technologies do not follow the same technological path forever. A change in regime may arise whenever there are diminishing returns in improving the basic technological characteristics over time or when other technological developments give way to a change of the characteristics of the design. Change can, however also be induced when there are significant changes in the nature of selection environment, which favours other technological alternatives (Sadowski et al, 2003). The telecommunications industry is currently undergoing a change in paradigm. This change is sometimes called convergence but unfortunately this concept is used in a variety of different situations. This part will explain the different meanings and will establish the definition used in this thesis.

There are five forms of convergence; these forms are not totalities, however they cover to a large extent the noticeable forms of convergence:

- Functional convergence
- Technical convergence
- Network convergence
- Economic convergence
- Paradigm convergence
**Functional convergence** implies that technology today offers more functions and services more that they were initially designed to. Convergence is when, for instance, radio and television and other communication systems simultaneously provide service to the consumers. Convergence makes it possible for one element to provide multi-service. An illustrated example of this is in the mobile phone, which was initially designed for voice communications. These days cell phones offer more functions: They offer print and text media as in the Short Message Service (SMS); they provide reception links to radio stations and access to broadcast information, they provide links to access the web, they capture, send and receive pictures and so forth. New generation of mobile phones are designed to capture video images (Katz & Woroch, 1997).

**Technological convergence** points to the way technologies are increasingly converging into one. The availability of carrier technology with high bandwidth means that, transmission is not limited to voice only, now data, picture and other multimedia and interactive media can be transported in one single carrier technology like the fibre optic cable and satellite technology. Some see this convergence as the emergence of the Swiss army network: a single integrated infrastructure capable of delivering voice, video and data services. The technological driver of this form of convergence is the continuous stream of advances in digital transmission technologies (Katz, 1997).

**Economic convergence** occurs when the individuality of organization yields to a more collective form due to a networking relationship. There is a blurring of industrial lines. For instance telecom companies are converging through series of mergers and acquisition deals, telecom companies are moving into new telecom market in addition to their traditional markets. For example, a telephone company converging Internet service provision into its operation, the extensive vertical integration that exists between cable programming and cable television system operators and between content providing companies and content distributing companies, i.e. telecommunication companies (Katz, 1997). An example of this is the takeover of TimeWarner by AOL in 2000.

**Paradigm convergence** is a process that cuts across the telecommunications and computer industries, and refers to the melding of communications and computers; the fusion of the telecommunications and computer paradigms. Computer/communications convergence materializes in the form of networked computing (the seamless interconnection of otherwise isolated computers, e.g. the Internet) or intelligent networks (the integration of large amounts of intelligence in the fabric of communications networks). In this thesis the last definition, the paradigm convergence, is used.

The most basic technological example of this paradigm convergence, and the subsequent new paradigm that is formed, is the shift from circuit-switched routing to packet-switched routing. Telecommunications are used to communicate between two places. The main concept to set up the connection between these two places for the last 100 years has been circuit-switched routing. In telecommunications, a circuit switching network is one that establishes a dedicated circuit between nodes and terminals before the users may communicate. Each circuit that is dedicated cannot be used for other users until the circuit is released and a new connection is set up. If no actual communication is taking place in a dedicated circuit then that channel still remains unavailable to other users. Channels that are available for new calls to be set up are said to be idle. Packet-switched networks are the dominant communications paradigm in computer networks, in which packets (units of information carriage) are individually routed between nodes over data links which might be shared by many other nodes, so there is
no need to establish a dedicated connection (as is the case with circuit-switching). Historically circuit-switching has mainly been used in telephone networks, while packet switching has been used in computer networks, but telephone networks are now shifting towards packet-switched routing. This paradigm convergence is a significant change in the nature of the selection environment and establishes a completely new way of solving problems and achieving certain goals in the telecommunications industry, rendering some of the incumbents' established knowledge obsolete.

2.3.3 Technical discontinuity and its effect on market structure

What is the effect of this 'confluence' of paradigms, and the related technical discontinuity, on the market structure?

When two paradigms meet, this enables new innovations. Clearly all technological innovation imposes some kind of change, but change does not have to affect market entry. Some changes, such as process innovations, may require new procedures in handling information, but utilize existing labour skills in a more effective way. Such changes conserve the established competence of the firm, and if the enhancement or refinement of those skills is considerable may actually entrench those skills to achieve an advantage. Such innovation may have an effect on competition by raising the barriers to entry, reducing the threat of substitution, and making competing technologies (and perhaps firms) less attractive.

On the other end of the spectrum, the effect of innovation is quite the opposite. Instead of enhancing and strengthening, innovation of this sort disrupts and destroys. It changes the technology of process or product in a way that imposes requirements that the existing resources, skills and knowledge satisfy poorly or not at all. The effect is thus to reduce the value of existing competence, and in the extreme case render it obsolete. This kind of change is at the heart of Schumpeter's theory of innovation and economic development in which "creative destruction" is the vehicle of growth (Schumpeter, 1934). Its effect on competition works through a redefinition of what is required to achieve a competitive advantage. In strong form, where disruption is both deep and extensive, such innovation creates new industries.

Foster (1986) calls this a technological discontinuity. This discontinuity sometimes renders the old technology non-competitive, and many of the barriers that firms have erected around them in the previous paradigm may become useless. Irreversible investments in plant capacity and R&D, special licenses, contracts for special materials or services may become obsolete. This concept can be seen as linked to the work of Mueller and Tilton (Mueller & Tilton, 1969). A technological discontinuity is externally driven; companies can not control these events. They can only anticipate.

Mueller and Tilton (Mueller & Tilton, 1969) contended that a new industry is created by the occurrence of a major process or product innovation and develops technologically as less radical innovations are introduced. They further argue that the large corporation seldom provides its people with incentives to initiate a development of radical importance. Thus, these changes tend to be developed by new entrants without an established stake in a product market segment. In their words, neither large absolute size nor market power appears to be a necessary condition for successful development of most major innovations.
Mueller and Tilton contend that once a major innovation is established, there will be a rush of firms entering the newly formed industry, or adopting a new process innovation. They hold that during the early period of entry and experimentation immediately following a major innovation, the science and technology upon which it depends is often only crudely understood, and that this reduces the advantage of large firms over others. However, the authors suggest that as the number of firms entering the industry increases and more and more R&D is undertaken on the innovation, research becomes increasingly specialized and innovations tend to focus on improvements in small elements of the technology. This clearly works to the advantage of larger firms in the expanding industry and to the disadvantage of smaller entrants. Product differentiation will be increasingly centred on the technical strengths and R&D organization of the existing firms. Strong patent positions may have been established by earlier entering firms that are difficult for later entrants to completely circumvent (Utterback, 1993).

In evolutionary economics the occurrence of a technical discontinuity leads to a rise in technological opportunities. These technical opportunities reflect the likelihood of innovating for any given amount of money invested in search. High opportunities provide powerful incentives to the undertaking of innovative activities and denote an economic environment that is not functionally constraint by scarcity of the set of possibilities for technological advance (Breschi et al, 2000). However this reflects only part of the story, as it omits the incumbents.

Afuah and Utterback (1997) combine the concept of technical discontinuity with the Porters' five forces (Porter, 1980) and the model of dynamic innovation (Utterback & Abernathy, 1975) (Abernathy, 1978) (Utterback, 1994). They state that an industry goes through a cycle. It starts with the fluid phase. In this phase there is a lot of product and market uncertainty. Manufacturers are not quite sure of what should go into the product. Customers may not know what they want in the product either. There is competition between the new and old technologies as well as between different designs using the new technology. Manufacturers interact with their local environment of suppliers, customers, complementary innovators and competitors to resolve both technological and market uncertainties.

This phase is succeeded by the transitional phase when some standardization of components, market needs and product design features takes place, and a dominant design emerges, signalling a substantial reduction in uncertainty, experimentation and major design changes. A dominant design is one whose major components and underlying core concepts do not vary substantially from one product model to the other, and the design commands a high percentage of the market share. The rate of major product innovations decreases and emphasis shifts to process innovation and incremental innovation. Competition is based largely on differentiated products.

The third phase is the specific phase, products built around the dominant design proliferate, and there is more and more emphasis on process innovation with product innovations being largely incremental. Products are highly defined with differences between competitors' products often fewer than similarities. The pattern described above repeats itself when a new technology with the potential to render the old one non-competitive is introduced, often by a competitor from outside the established industry. This results in a discontinuity, plunging the innovation cycle back to the fluid phase with another wave of entering firms.
The result of this technical discontinuity is the move from the specific phase of one technological evolution cycle to the fluid phase of the next cycle. Technological discontinuities normally level the playing ground since incumbent's existing capabilities may be rendered obsolete (Foster, 1986; Utterback, 1994). The impact of a technical discontinuity on industry attractiveness, according to Porter's five forces, is summarized in the following table. The threat of new entrants is high since the playing ground has been levelled and incumbent existing capabilities may not only be useless, they may actually become a handicap. The threat of substitutes, from the new technology is now very high.

*Rivalry* among incumbents gets higher as the new technology invades the old and incumbents who have not switched to the new technology are increasingly squeezed. As manufacturers leave specialized materials and equipment of the specific state to turn to the general-purpose equipment of the emergent fluid phase, the bargaining power of suppliers drops. The impending discontinuity further increases the bargaining power of customers.

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<th>Force</th>
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<td>Rivalry among existing</td>
<td>Low or high depending on the reaction of incumbents</td>
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<td>competitors</td>
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<tr>
<td>Threat of new entrants</td>
<td>High, since the competitive advantages of the incumbents have</td>
</tr>
<tr>
<td></td>
<td>been diminished</td>
</tr>
<tr>
<td>Bargaining power suppliers</td>
<td>Low since their specialized materials and equipment may be</td>
</tr>
<tr>
<td></td>
<td>replaced soon by general purpose materials and equipment</td>
</tr>
<tr>
<td>Bargaining power customers</td>
<td>High since discontinuity leads to fluid phase with its unique</td>
</tr>
<tr>
<td></td>
<td>products</td>
</tr>
<tr>
<td>Threat of substitutes</td>
<td>High</td>
</tr>
</tbody>
</table>

*Table 1: Industry attractiveness at the discontinuity phase (Afuah & Utterback, 1997)*

2.3.4 Conclusion

The high cost to produce a technology, mainly due to dynamic scale economies along learning curves, is an important barrier to entry. Because of the sheltered position traditional equipment makers enjoyed in the past, they have accumulated a lot of specific know-how. How can this technical entry barrier be lowered? One way to diminish this barrier would be to lower the importance of know-how accumulated in a certain technological paradigm.

A paradigm means a set of procedures, a definition of the "relevant" problems and of the specific knowledge related to their solution. Each "technological paradigm" defines its own concept of "progress" based on its specific technological and economic trade-offs. It is a way of thinking and of fixing certain problems accordingly. The change of paradigm in the telecommunications equipment industry is called convergence. The word convergence has a lot of different meanings, but the definition central in this thesis is paradigm convergence.

When a paradigm changes, like in the telecommunications equipment industry, this can lead to a technical discontinuity. This is when a paradigm is changed in such a way that it renders the old technology non-competitive, and many of the barriers that firms have
erected around them in the previous paradigm may become useless. Irreversible investments in plant capacity and R&D, special licenses, contracts for special materials or services may become obsolete.

Mueller, Tilton and Utterback among others argued that every industry goes through different life cycles and that the changes brought forth by a technical discontinuity usher in a new stage in the life cycle. The major innovation that triggers this change can be developed by any kind of company; neither large absolute size nor market power appears to be a necessary condition for successful development of most major innovations.

When the new innovation and the subsequent new industry develop it is very open; it attracts new entrants who become new sources of innovation for the new technology. Afterwards the technology matures and becomes more and more closed again. Is this theoretical answer to the effects of a technological discontinuity on the market in accordance with reality? And is it as such a way to explain a lowering of technical entry barriers. Will a technology which had recently a technological discontinuity have more new companies entering then technologies with a matured paradigm? Will such a technology have less stability in its sources of innovation? And will such a technology have a lower concentration of innovation?
3 Methodology

This whole thesis evolves around the importance of knowledge as a barrier to entry. So to answer the questions asked in the last chapter, formalized knowledge in the form of patents will be studied. If there is a significant change in the sources of the knowledge and their behaviour, this can indicate a change of technical entry barrier. The patents are researched in two case studies. These case studies will examine the innovative behaviour of firms.

The chapter will discuss five topics. The first topic is the cases; why were these cases chosen? The second topic that is discussed is the construction of the dataset and the strategies that were used to achieve that goal. The third part deals with the first method that was chosen to analyze the dataset. This analyse did eventually not bear the results that were expected, reasons why this could be the case will be discussed. The fourth part discusses the final method chosen for analyzing the dataset; weighted patent count (WPC). Finally the concepts that are investigated are discussed.

3.1 Cases

In order to answer the questions that are raised by the theory, several case studies are conducted. These cases studies can be seen as an embedded, multiple-case design. The cases are embedded, because there are multiple units of analysis. The different technologies that were researched in each case were interlinked, embedded. To research several possible phenomena, the multiple-case design was chosen, hence the embedded, multiple-case design (Yin, 1994). Each case is chosen on the grounds of numerous factors, among others the period a certain network was developed and the underlying technological features:

- The first case deals with the effects of modularity of the architecture on innovative behaviour. This case consists of two circuit switching technologies. In telecommunications, a circuit switching network is one that establishes a dedicated circuit (or channel) between nodes and terminals before the users may communicate. Each circuit that is dedicated cannot be used by other callers until the circuit is released and a new connection is set up. The first technology, Private Branch Exchange (PBX), was chosen as an example of a technology without a universal standard (i.e. modularization). The automated version of the PBX has been around since the end of the 1960s. The second technology is Intelligent Network (IN). This is a technology with its roots in the old telephone industry and a modular design structure with a formalisation/architecture by one of the standardization bodies. Both technologies went through the shift from electric switching to digital switching and the introduction of functionalities as voicemail and the automatic call attendant.

- In the second case the shift from coaxial cable to optical fibre is discussed. This case was chosen as an example of a technological discontinuity. Both technologies can be regarded as transmission technologies. This means technologies used for the propagation of a signal by any means and via any
medium. The first technology is coaxial cable. This is an electrical cable consisting of a round conducting wire, surrounded by an insulating spacer, surrounded by a cylindrical conducting sheath, usually surrounded by a final insulating layer (jacket). It is used as a high-frequency transmission line to carry a high-frequency signal. It was used in trunk lines during the period from 1950 to 1990. The second technology is optical fibre, i.e. a glass or plastic fibre designed to guide light along its length by confining as much light as possible in a propagating form. This technology replaced the coaxial cables in the trunk lines and is now slowly replacing the coaxial cable in the local loop. This discontinuity made knowledge about how to send an electrical signal through a copper wire less valuable and gave more emphasis on the knowledge of sending a light signal through glass.

3.2 Creating the dataset

For each case study a collection of patents that reflect the technology and its development is used, this collection is called a dataset. A dataset can be found with the help of several different patent offices around the world. The United States Patent and Trademark Office (USPTO) is the oldest patent office of the world and the online available information on the full-text patents goes back until 1976, actual patent records go back to 1970 but the are not available full-text. On the site of USPTO a patent search can be done via queries that search for different terms in the patents and via the different patent classifications. With the patent numbers that are found on this site, databases can be constructed that can be used to find the citations that these patents make to other patents. These citations are found in the NBER (National Bureau of Economic Research) database, this is a database that contains the citation data of the USPTO patents in the period between 1976 and 2002.

In order to construct the dataset, mentioned above, several different strategies were used. The strategies used for the first case (IN) will be discussed in this section. The other datasets were constructed in a rather similar fashion. The first strategy was to make a very broad dataset that included all relevant information regarding the technology. This dataset consisted of the results from a very broad query and all patents that were cited by those patents. All in all this resulted in a dataset of over 11.000 patents. The size of this dataset was too big for the software, in combination with the available hardware, to compute.

The next strategy was to split up the technology according to the structure of IN as mentioned in the ITU recommendations (Q.1200-Q.1205). In these recommendations the IN conceptual model (INCM) is described. The INCM, which is solely a tool for describing IN capabilities and characteristics, is composed of four "planes" that represent different aspects of implementing IN services. These planes include the service plane, the global functional plane, the distributed functional plane, and the physical plane. More on this in the part regarding the Technology of Private Branch Exchange and Intelligent Network.
A dataset with patents for analysis has been constructed for every plane. The databases were built up using several queries regarding the entities and functionalities of the plane in question. For instance the queries that formed the database for the physical plane were:

- \((\text{ABST/"service switching point" OR ABST/ssp}) \text{ AND ISD/1972}$$ -> 2002$$)\)
- \((\text{ABST/"service control point" OR ABST/scp}) \text{ AND ISD/1972}$$ -> 2002$$)\)
- \((\text{ABST/"service data point" OR ABST/sdp}) \text{ AND ISD/1972}$$ -> 2002$$)\)
- \((\text{ABST/"intelligent peripheral") AND ISD/1972}$$ -> 2002$$)\)
- \((\text{ABST/"service node") AND ISD/1972}$$ -> 2002$$)\)

These queries are all specific for certain entities in the functional plane. They may contain duplicates because certain patents mention more than one entity. The first query relates to the service switching point entity. This query resulted in 118 patents. These patents and the patents they cited were put together in a dataset that consisted of 635 patents. The database was thus extended with the patents cited by the queried patents, this was done to make the dataset more inclusive and to eliminate to a certain extend the strictness of the search query.

### 3.3 Patent citation analysis

The initial method for analyzing the patent data was the method developed by Hummon, Doreian (1989) and Verspagen (2005); Patent citation network analysis. This method analyzes the network of citations between patents and the changes that correlated with it. In order to get an insight in, the main flow of ideas through, a field of technological development. This would give an indication of changes in the paradigm when the modularization or technological discontinuity occurred. This analysis rests on a number of basic assumptions from the field of network analysis. A network consists of a number of vertices (patents) and connections between them, the edges (citations).

The citation network is represented by means of a matrix \(C\), in which the element \(C_{ij}\) is equal to 1 if patent \(j\) cites patent \(i\), and zero otherwise. Define the matrix \(C'\) as the matrix in which the elements are formed by taking the maximum value (in \(C\)) of below and above diagonal elements. We define a (weak) component in the network \(C\) as a subset of patents in which for every patent \(i\) and \(j\), a path from \(i\) to \(j\) exists in the network represented by \(C'\). The concept of a (weak) component is used to represent a subset of the network that is somehow connected by a complex set of relations.

In the network matrix \(C\), vertices may be distinguished into three categories; sources, sinks and intermediate points. Sources are vertices that make no citations, but are cited. Sinks are the opposite, they cite but are not cited themselves, and intermediate points both cite and are cited. Below, the term start point will be used to refer to a node that is a source but not an isolate, and the term endpoint to a node that is a sink but not an isolate.
The simplest analysis is the so-called search path link count (SPLC) measure. This simply enumerates all possible paths in the network and counts how often an edge lies on such a path. A different measure is the search path node pair (SPNP) indicator. This accounts for all connected node pairs along the search path. First, count all nodes in $C$ for which a path to $i$ exists, and include $i$ itself in this count. We denote this count by $n_i$. Then, count the number of patents to which a path exists from $j$, and include $j$ itself in this count. Call this number $m_j$. Now the SPNP value for $e_{ij}$ is defined as $n_i \times m_j$. Thus, SPNP represents the number of pairs of patents that can be formed by taking one patent that lies "upstream" the edge $e_{ij}$ and one patent that lies "downstream" this edge.

The next step is to create a main path using the data from the SPLC or SPNP. In our analysis the SPNP was used, because of the fact that it has more detail. The main path represents at each step (edge) the option that has attracted most weight in the SPNP procedure, i.e., it represents the largest flow of ideas in the network. So from every start point a main path can be constructed.

A network of main paths is constructed $C_t$ for every sub-network $C_{t-1}$ where $C_t$ is defined as the subset of $C$ that includes only rows and columns corresponding to patents granted in a year smaller than or equal to $t$. Hence $C_{t-1}$ corresponds to the network of main paths that reflects the flow of ideas up to and including the year $t$.

Next, the single main path in the network on which the sum of all edges is maximal is identified, and called path $p_t$. Now the merging together the paths $p_t$ for all values of $t=T_0+a...T_n$ where $T_0$ is the earliest patent (latest) in the dataset, and $a$ is some non-negative number. The matrix that corresponds denotes to the resulting network $P$, this as a temporal evolution of the main paths in the original network $C$.

These main paths were made graphically visible using the Ucinet and NetDraw software; this led to the following network of the citations in the development of the service switching point (see Figure 3).

Figure 3: citation network of Service Switching Point
This is the main network and it consists of six sub paths. When each of these sub paths is analyzed individually, this gives the following paths (see appendix). These networks give an insight in the network, but a very limited one. This is because of the fact that the lengths of the paths are very short. The longest path in any of the paths is only 3 to 4 patents. These paths are therefore too small to give any indications to the trajectories of the technologies.

What were the reasons that this way of analyzing the patents was falling short? One explanation could be the relatively short time span of the technology, especially in comparison with the case of the fuel cells (Verspagen, 2005). In this case the network is so young that the network consists of a number of small networks. Over time continuing citing will lead to a main network because some patents become more cited than others.

Another reason this method wasn't successful could be because the modularization/standardization gives enough to hold on to; therefore there is no need for citing other patents. The outlines of the technology are explained in the recommendations.

### 3.4 Weighted patent count

So, how could the patent dataset be analyzed without the aforementioned problems occurring? Keeping the patent dataset as the central empirical research tool is imperative because of its quantitative nature and the fruitful source of information about technology innovation. The goal of discovering innovation behaviour trends en how these trends explain the theoretical analysis regarding convergence remained the same.

The simplest method to achieve this is the simple patent count (SPC), which is the number of patents assigned over a certain period of time to firms, industries, countries, etc. The body of evidence that has accumulated since Schmookler (1966) indicates fairly clearly that SPC are closely associated with the input side of the innovative process, primarily with the contemporaneous R&D expenditures in the cross-sectional dimensions (Griliches, 1984). So SPC’s are only indicative of the input side, as reflected in the R&D outlays.

One option for further analysis was the "key patents" method. This method is a much simpler way of analysing patents and their citations than the method used by Verspagen. This straightforward possibility is to weight each patent by the actual number of citations it received. This linear weighting scheme then assigns a value to all patents. This method was first proposed by Trajtenberg in 1990 in his article "A penny for your quotes: patent citations and the value of innovations". In this article Trajtenberg also showed that patent counts weighted by a citation-based index are found to be highly correlated (over time) with independent social gains from innovations in Computed Tomography, the case Trajtenberg studied.
How to construct a sensible weighting scheme? Trajtenberg answered this with the simple answer of weighing each patent \( i \) by the actual number of citations it received, denoted by \( C_i \). Thus, if we were to compute an index of weighted patent counts (WPC) for, say, a given product class in a given year, \( t \), we would have,

\[
WPC_t = \sum_{i=1}^{n_t} (1 + C_i),
\]

where \( n_t \) is the number of patents issued during year \( t \) in that product class. This linear weighting scheme then assigns a value of one to all citations and all patents.

It is normal to see a decline in WPC at the end of time scale of the data set, because of truncation of assigned patents and of the citing of patents. There is a lag time as the time moves closer to the last date in the data set, patent data timed according to the application date will increasingly suffer from missing observations consisting of patents filed in recent years that have not yet been granted. Overall, the lags have shortened significantly, from an average of 2.4 years in the late 1960's to 1.8 years in the early 1990's (Jaffe, 2002).

The second problem is the lag time of citations, if a patent is 20 years old it has had a lot more chance to be cited then a relatively new patent. Figure 4, shows the frequencies of citation lags up to 50 years back, and separately the remaining tail for lags higher than 50 years. A striking fact that emerges is that citations go back very far into the past. There is some indication that the lags have been shortening recently, as evidenced by Table 2. At average the lag time has a mean of 12.66 years, but the majority of citations are made after 5-6 years. These numbers are for all fields of technology and it can be expected that these numbers are smaller for the field of ICT, due to the relative newness and the fast development rate of this field (Jaffe, 2002).
To counter this truncation the fixed-effects approach was used. This method assumes that all sources of systematic variation should be removed before comparing the citation intensity of patents from different cohorts. That is, we rescale all citation intensities and express them as ratios to the mean citation intensity for patents in the same cohort. If we want to compare a 1990 patent with two citations to a 1985 patent with four citations, we divide each by the average number of citations received by its own cohort. In this thesis the size of the cohort will be one year. This rescaling purges the data of any systematic movements over time in the propensity to cite, and effects due to changes in the number of patents making citations (Jaffe, 2002).

### Concepts

The questions asked in the previous chapter can be translated into three concepts. These three concepts are (Breschi et al, 2000):

- **ENTRY** is the percentage share of WPC scored by firms applying for the first time in a given technology, during a specific period, over the total WPC scored in the same period. It measures innovative birth and not entrepreneurial birth; a new innovator may be in fact a company that has been operating for quite some time.

- **STABILITY** is measured by the spearman rank correlation coefficient between the hierarchies of firms' WPC scoring during different time periods.

- **CONCENTRATION** represents the concentration of WPC scores, using the Herfindahl-Hirschman Index, during a certain period. This does not refer to the market concentration but to the concentration of innovative behaviour.

Each concept is used for both cases. The adjusted WPC scores for every case are put in to cohorts of five years. This means for instance that all the adjusted WPC scores for the Siemens Company in those five years are aggregated and can be compared to other cohorts.
3.5.1 Entry

The companies that are present in the previous cohorts are compared with the companies in the cohort that is researched. The companies that are not present in the previous cohorts, only in the new cohort, are the new entrants. The adjusted WPC scores for all the new entrants in the cohort are accumulated and compared with the accumulated adjusted WPC score for all companies. This percentage is entry rate.

3.5.2 Stability

There will be for each cohort a ranking of the companies, according to their accumulated adjusted WPC score (highest score gets rank 1). This ranking of companies will be compared with the ranking of companies in the other time frame. The rank order relationship will be determined through the Spearman rank order correlation Analysis ($\rho$). The $\rho$ will have a value between 1 (completely the same ranking) and -1 (completely reverse ranking).

3.5.3 Concentration

The concentration of innovative, calculated for every five year cohort, is done using the Herfindahl-Hirschman Index (HHI). This index is calculated by squaring a companies' percentage of the total adjusted WPC score for the cohort and then aggregating all these scores. For a set of adjusted WPC scores aggregated by $J$ companies, with a score of $N_j$ for each company ($N_j \geq 0, j = 1, \ldots, J$)

$$HHI = \sum_{j=1}^{J} \left( \frac{N_j}{N} \right)^2$$

A HHI-score of less than 1,000 is a competitive concentration of innovative behaviour; a result of 1,000-1,800 to be a moderate concentration of innovative behaviour; and a result of 1,800 or greater to be a high concentration of innovative behaviour (Rhoades, 1993).
4 Empirical section

This part will bring answers to the questions that were raised in the theory chapter. These questions regarded the entering of new companies, the stability of innovative sources and the concentration of innovative sources.

The empirical part consists of two case studies, as was described in the methodology chapter.

4.1 Case 1: Private Branch Exchange and Intelligent Network

So, which of the three theoretical models regarding the influence of modularity on industry structure is relevant for the telecommunication equipment industry? To understand this it is important to research the influence a modular architecture has on the amount of new companies entering, the stability of companies as sources of innovation and the concentration of innovation.

This first case consists of two circuit switching technologies. In telecommunications, a circuit switching network is one that establishes a dedicated circuit (or channel) between nodes and terminals before the users may communicate. Each circuit that is dedicated cannot be used by other callers until the circuit is released and a new connection is set up. Even if no actual communication is taking place in a dedicated circuit then, that channel still remains unavailable to other users. Channels that are available for new calls to be set up are said to be idle.

The Private Branch Exchange (PBX) case was chosen as an example of a technology without a universal standard on modules and interfaces (i.e. modularization), except a standard connection to the PSTN. The automated version of the PBX has been around since the end of the 1960s. There have been major innovations regarding switching of telephone lines and some new functionality. This started with the shift from electric switching to digital switching and the introduction of functionalities as voicemail and the automatic call attendant, more on this latter. However the basic function of the PBX (i.e. a telephone switching system on the users' premise with access to the Public Switched Telephone Network) did not change.

The Intelligent Network (IN) case was chosen as an example of a technology with a modular architecture. This modularity was designed as a response to the divesture of AT&T and the need for the Regional Bell Operating Companies (RBOCs) to have open access to the network an to provide flexibility in switching and in introducing new services. The architecture is developed by the International Telecommunication Union (ITU) and it became official when the ITU approved the Q.1200 recommendations regarding IN in 1993.

This case consists of two datasets. How these two sets were constructed will be explained below. The dataset for PBX case was constructed using the USPTO search engine to identify all patents with a reference to "private branch exchange" in their abstract. This pool was further augmented with patents that were found using queries that looked for key words, regarding to PBX, in the abstract of patents. These key words are mentioned
in the appendix. The second enlargement of the patent pool was the addition of all patents that cite the patents that were identified after the first two steps. This led to a dataset of 4269 patents.

The dataset for IN was constructed by using a strategy to split up the technology according to the structure of IN as mentioned in the ITU recommendations (Q.1200-Q.1205). IN is composed of four "planes" that represent different aspects of implementing IN services. These planes include the service plane, the global functional plane, the distributed functional plane, and the physical plane. This in combination with the presence of the name "Intelligent Network" in the abstract became the basis for the dataset. The second enlargement of the patent pool was the addition of all patents that cite the patents that were identified after the first step. This resulted in a dataset of 8251 patents.

4.1.1 Technology of Private Branch Exchange and Intelligent Network

Before we can discuss the results of the analysis of the patent pools it is important to understand how both technologies, PBX and IN, work.

4.1.1.1 Private Branch Exchange

A PBX is an on-premise facility that interconnects internal telephones and provides access to the Public Switched Telephone Network (PSTN). Initially, PBXs were smaller versions of the same equipment that was installed in the phone company's central office (CO) sites. Accordingly, they were viewed as branches of the CO installed in private locations. The term exchange refers to the PBX's primary task of switching voice from an input device to an output device.

Originally, these systems required manual switchboard operators to make connections between input and output devices. In the 1920s, automatic systems began to replace the manual operators. These first automatic systems were called private automatic branch exchanges (PABX) since they did not require an attendant to perform the switching. These systems used electromagnetic technology and analogue signalling.

In the 1970s a new generation of digital PBXs was introduced that used electronic technology and digital switching. The PBX of today, although improved and enhanced since the 1970s, is based on the digital architecture.

The primary task of a PBX is to create a voice circuit between a user of the PBX and the PSTN. Additionally, a PBX can facilitate internal voice communication by creating a voice circuit between PBX users. A PBX provides a range of basic and advanced services. The basic services of a PBX include:

- Allowing multiple users to share a limited number of connections to the PSTN to place and receive telephone calls.
- Allowing users to call one another without using the PSTN.
- Allowing users to perform simple call control activities, such as transferring calls and placing calls on hold.
The advanced services were developed from the end of the 1970s until the 1980s and are often delivered as optional and/or completely separate components. Some of the more common advances include:

- **Auto-Attendant** – An auto-attendant consists of the prompts and menus that a caller hears when a PBX answers an incoming call. The menus usually allow the caller to select a specific person or department. The auto-attendant then transfers the phone call based on the caller's selection. Most auto-attendants sound something like this...

  "Hello and thank you for calling XYZ Corporation. If you know the extension of the person you like to speak with, enter it now. For sales, press 1. For technical support, press 2. To speak with an operator, press 0"

- **Voice-mail** – The ability for a caller to leave a recorded voice message when the called party is not available is an optional feature on most PBXs.

- **Automatic Call Distribution (ACD)** – An ACD system allows calls to be distributed amongst a defined group of users. If all of the users in a group are unavailable, incoming calls will be queued. ACD systems are used by most large call centres. Most of us are familiar with the following message provided by an ACD system...

  "Thank you for calling XYZ Corporation. All of our agents are currently assisting other customers. Your call will be handled in the order that it was received."

- **Least Cost Routing (LCR)** – LCR service can be used to route outbound calls to different local or long distance providers based on a variety of factors, such as time or day or the destination of the call. LCR is designed to take advantage of discounted calling rates offered by service providers.

Today you will find a PBX installed in almost every office with more than a few employees. Since voice communication is critical to the success of most business, the office PBX is an extremely important business tool.

The traditional PBX has been designed around the characteristics of the PSTN. The PSTN is a circuit switched network that provides a dedicated 64 Kbps circuit for every point-to-point connection, when you place a call from Eindhoven to Amsterdam over the PSTN; you reserve a 64 Kbps path between the two locations. The PBX is simply an
extension of this concept. When making a call through a PBX, you are given a dedicated circuit from your telephone through the PBX to the party you are calling.

Figure 6: Traditional digital PBX architecture based on TDM switching (Krupinski et al, 2001)

It is important to note that there is no standard reference architecture for PBXs. Every PBX manufacturer has designed their system to their own proprietary specifications. Accordingly, a telephone designed by one PBX manufacturer will not work with another manufacturer's system, nor will the voice mail unit, the ACD unit, or any other component. In fact, the only standard interface on a traditional PBX is the interface to the PSTN; as a result, the selection of a PBX has traditionally been viewed as the selection of a long-term business partner (Krupinski et al, 2001).

In the 1990s the PBX was influenced by new technologies, like mobile telephony. This led to the development of the mobile PBX. A mobile PBX is a hosted or virtual PBX service that extends fixed-line PBX functionality to mobile devices such as cellular handsets, smart phones and PDA phones by provisioning them as extensions. Mobile PBX services also can include fixed-line phones. Mobile PBX systems are different from other virtual PBX systems that simply forward data or calls to mobile phones by allowing the mobile phone itself, through the use of buttons, keys and other input devices, to control PBX phone functions and to manage communications without having to call into the system first.

One of the latest trends in PBX development is the VoIP PBX, also known as an IPBX, which uses the Internet Protocol to carry calls. Most modern PBXs support VoIP. ISDN PBX systems also replaced some traditional PBXs in the 1990s, as ISDN offers features such as conference calling, call forwarding, programmable caller ID, etc (Krupinski et al, 2001).

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Technological development</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970-1984</td>
<td>Development electric switching</td>
</tr>
<tr>
<td>1980-1994</td>
<td>Functionalities like voicemail and automatic call attendant</td>
</tr>
<tr>
<td>1990-1995</td>
<td>Mobile PBX</td>
</tr>
<tr>
<td>1995-now</td>
<td>VoIP PBX</td>
</tr>
</tbody>
</table>

Table 3: Summary technological development PBX
4.1.1.2 Intelligent Network

After the divesture of AT&T, the Regional Bell Operating Companies (RBOCs) requested Bellcore to pioneer a new switching network; the Intelligent Network (IN). This was done with the following objectives in mind: to support the rapid introduction of new services in the network; to help establish equipment and interface standards to give the RBOCs the widest possible choice of products; and to create opportunities for non-RBOC providers to offer services that would stimulate network usage. They chose for a flexible, open and modularized standard. Designed to permit open access to the network, the RBOCs claimed that the new architecture would help their responsiveness to customers.

IN was first announced by Bellcore (now Telcordia) as a conceptual model called Intelligent Network-1 (IN/1). It became a generic term for networks characterized by distributed intelligence and the definition of interfaces and services in ways that departed from the current practice. Bellcore's objectives for the IN were described as falling into three categories: the development of flexible network architecture, the implementation of standard network interfaces and increased speed in advanced services introduction (Mansell, 1993).

This flexibility was introduced because within traditional public switched telephone networks, the hierarchy of switching equipment and software had to be upgraded each time a new service was added to the network. This is a complex and costly process. Further, network switches could not provide new number translation, routing, and charging capabilities. As telecommunications services evolved, the need to reduce the overhead for service use had increased along with the need to simplify maintenance and service upgrades or additions.

The IN essentially separated these services from switching equipment and organizes a centralized system so that providers do not need to perform major modifications on multiple switches when they introduce new services. The first step in IN development was to create separate service data in a centralized database outside the switching nodes. The second step was to separate the service programs, or service logic, and to define a protocol that would permit interaction between switching systems and intelligent nodes containing the service logic and data. These are normal steps in the development of a modular architecture.

The core of the networks became the center of power, not only were telephones made dumb, the primary local telephone exchanges did not even know how to route certain types of phone calls, such as toll-free numbers or local competitors' calls, without assistance from a central routing database.

All of these basic elements form the infrastructure in IN, which supports the notion of separating service-control functions from service switching-functions, to realize more rapid-services development and deployment. Another equally important concept in IN has been the notion of service independence. Here, the primary goal has been to identify and create generic sets of reusable service components that could be used to build new services and loaded into switching control points (SCPs) to generate new services rapidly. These service components are also known as service independent building blocks (SIBs).
To provide a framework that would lead toward IN engineering standardization, the IN conceptual model (INCM) was developed. The INCM, which is solely a tool for describing IN capabilities and characteristics, is composed of four "planes" that represent different aspects of implementing IN services. This model depicts the relationship among services and service features, global service logic (SIBs), distributed service logic, and the physical network entities such as SCP and service switching points (SSP). These planes include the service plane, the global functional plane, the distributed functional plane, and the physical plane as shown in Figure 7 (IEC, 2007).

Figure 7: IN conceptual model (IEC, 2007)

The service plane describes services from a user's perspective, where a service consists of generic blocks or service features that make up part or all of a service (e.g., Freephone, an audio tool for the Internet). The global functional plane deals with service creation and is comprised of the SIBs that will be used to create service features. Global service logic defines how SIBs are linked together to form features and how these SIBs interact with another basic SIB known as the basic call process (BCP). The BCP is the process that optimally supports services that do not require special features and is basic to the processing of all services.

The distributed functional plane defines a set of functional entities that perform specific actions. SIBs are implemented through a specific sequence of functional-entity actions performed by those functional entities.

The physical plane consists of the physical entities (switches) that coincide with the functional entities (e.g. switching control function and switching control point)

The physical entities that control and function on these different planes are (ITU Telecom, 1993):

- The Service Switching Point (SSP) is co-located with the telephone exchange itself, and acts as the trigger point for further services to be invoked during a call. The SSP implements the Basic Call State Machine (BCSM) which is a Finite state machine that represents an abstract view of a call from beginning to end (off hook; dialling; answer; no answer; busy; hang up etc). As each state is traversed, the exchange encounters Detection Points (DPs) at which the SSP may invoke a query to the Service control Point (SCP) to wait for further instructions on how to proceed. This query is usually called a trigger. Trigger criteria are defined by the operator and might include the subscriber calling number or the dialled number.
• The Service Control Point (SCP) is a separate set of platforms that receive queries from the SSP. The SCP contains service logic which implements the behaviour desired by the operator. During service logic processing, additional data required to process the call may be obtained from the Service Data Function. The logic on the SCP is created using the Service Creation Environment.

• The Service Data Function (SDF) is a database that contains additional subscriber data, or other data required to process a call. For example, the subscriber’s prepaid credit which is remaining may be an item stored in the SDF to be queried in real time during the call. The SDF may be a separate platform, or is sometimes co-located with the SCP.

• Service Creation Environment (SCE) is the development environment used to create the services present on the SCP. Although the standards permit any type of environment, it is fairly rare to see low level languages like C used. Instead, proprietary graphical languages have been used to enable telecom engineers to create services directly.

• Specialized Resource Function (SRF) or Intelligent Peripheral (IP) is a node which can connect to both the SSP and the SCP and delivers additional special resources into the call. For example play voice announcements or collect DTMF tones from the user.

Figure 8: Intelligent Network schematic diagram (Clark, 1997)

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Technological development</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965-1984</td>
<td>Development digital switching</td>
</tr>
<tr>
<td>1965-1980</td>
<td>Database technology</td>
</tr>
<tr>
<td>1965-1980</td>
<td>Computer technology</td>
</tr>
<tr>
<td>1975-1980</td>
<td>Interface database&lt;-&gt;PSTN</td>
</tr>
<tr>
<td>1980-1995</td>
<td>IN architecture</td>
</tr>
<tr>
<td>1985-2002</td>
<td>Service Blocks</td>
</tr>
</tbody>
</table>

Table 4: Summary technological development IN
4.1.2 Innovative behaviour in Private Branch Exchange and Intelligent Network

To understand the innovative developments of the technologies and the companies who were involved it is important to get a description of the innovative behaviour in both technologies. This will help to put the development of the three concepts, as discussed in the methodology, into perspective. The first part is a general discussion of trends in both technologies, while the second and third parts go into the innovative behaviour of both technologies in great detail.

The PBX is a technology that started in the 1930s, but really picked up with the change to electrical switching. This technology was developed by several major telecommunications equipment manufacturers and some smaller innovative firms. The entire innovative behaviour in the business changed in the beginning of the 1980s. A big acceleration occurred and this acceleration continues until this day. However there are some downswings and upswings in this trend, these are caused by the changing economic climate. At the end of the graph there is a steep decline, this is caused by citation lag as described in the methodology section.

The development of the technology, mainly computer and database technology, related to IN started in the 1960's. It picked up speed midway through the 1980's, due to the initiatives from the RBOCs and Telcordia. After 1984 there was a strong growth in the end of the 1980's and in the early 1990's. In 1993 the ITU approved the Q.1200 recommendations regarding IN, this caused a depression in the growth in the years leading up to 1993, due to the uncertainty involved in the standardization process. The technology had its peak in the mid 1990's, although it is not completely clear if this is the real peak, the peak could have occurred a little later. The reason for this is that due to the citation lag the WPC score is slightly skewed to the left side of Figure 9. It is however clear that the technology development has declined in recent years.

![WPC score over time](image)

Figure 9: Development of annual WPC score
If the WPC score is adjusted for truncation, because older patents have had more time to collect citations and have therefore a relatively higher WPC score. The difference in intensity becomes smaller due to the fact that this adjustment uses yearly averages to factor out the truncation (Jaffe, 2002).

It becomes clear that the extreme growth in innovative behaviour for both technologies started a little later (compared with Figure 9), with the highest growth in the end of the 1990s. This increase in patenting can be seen as a general trend across sectors (Jaffe, 2002). Both technologies have a growth in WPC score since the 1980s. The PBX mimics the trend in IN, but lags it with several years.

![Adjusted WPC score over time](image)

**Figure 10: Development of annual WPC score adjusted for truncation**
4.1.2.1 Private Branch Exchange

The development of PBX innovation can be told on the basis of the companies that were involved in these innovations. In the 1970s development was done by established communication equipment makers like AT&T, Stromberg-Carlson, Siemens, ITT, NCIC (later NEC) and Bell Canada (Nortel). These companies combined their knowledge of the PSTN with the emerging technology of electric PBX technology. On the other end there were small entrepreneurial companies like Lorain Products and San/Bar Corporation, these companies came with innovations like line-card technology. Both large and small companies had a stake in the development of that period.

<table>
<thead>
<tr>
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<tbody>
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<td>NON-CORPORATE</td>
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<td>SAN/BAR CORPORATION</td>
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<tr>
<td>LORAIN PRODUCTS CORPORATION</td>
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<tr>
<td>ITT CORPORATION</td>
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</tr>
<tr>
<td>BELL CANADA</td>
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</tr>
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</table>

Table 5: Top ten adjusted WPC scores for PBX during the period 1970-1974

In the second half of the 1970s the distinction between the established communication equipment makers and the small entrepreneurial companies remained. The developments centred mainly on the use of electronic technology and digital switching. Many of these innovations were conducted by the major firms. The smaller firms' innovations focussed on innovations like automatic telephone diallers and automatic queuing of telephone calls. Generally speaking one can say that the innovation of the major companies came from a fundamental research background, i.e. micro-electronics, whereas the innovations of the smaller firms were changes at the application level.

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<td>NIPPON COMMUNICATION INDUSTRIAL COMPANY LIMITED</td>
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<td>NON-CORPORATE</td>
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<td>MITRONICS INC.</td>
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<td>NEC CORPORATION</td>
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<tr>
<td>SIEMENS AKTIENGESELLSCHAFT</td>
<td>3,4</td>
</tr>
</tbody>
</table>

Table 6: Top ten adjusted WPC scores for PBX during the period 1975-1979
During the first half of the 1980s the development and use of micro-electronics gained more and more momentum. This is clearly visible in the adjusted WPC scores for that period with companies that are maybe more known for their achievements in the field of micro-electronics than in the field of telecommunications (Rockwell, Toshiba and Philips), but also smaller companies that specialized in the use of micro-electronics in switching and PBX like Mitel and Wescom Switching.

Mitel was a company specialized in PBX technology and more precisely in the application of microprocessor technology in PBXs. Early on Mitel realized the possibilities of the then new technology of microprocessors to change how office telephone equipment was built. With this insight, they introduced the SX200 PBX to an astonishing success. In 1976, the company expanded into the semiconductor field with the acquisition of Siltex an ISO-CMOS foundry in Bromont, Québec, Canada. This evolved into a semiconductor division that specialized in mixed signal and thick film hybrid devices. The next major product was a large digital PBX called the SX2000. This was an early attempt to integrate the voice and data functions of office systems (Zarlink, 2007).

Jayem Dialer Corporation is the exception in this; they innovated on automatic caller techniques and can be seen as from the same mould as companies like Lorain Products and San/Bar Corporation.

<table>
<thead>
<tr>
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<td>MITEL CORPORATION</td>
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<td>ROCKWELL INTERNATIONAL CORPORATION</td>
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<td>JAYEM DIALER CORP.</td>
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<td>NORTEL NETWORKS CORPORATION</td>
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<tr>
<td>TOSHIBA CORPORATION</td>
<td>3,7</td>
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<tr>
<td>U.S. PHILIPS CORPORATION</td>
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<tr>
<td>WESCOM SWITCHING, INC.</td>
<td>2,9</td>
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</table>

Table 7: Top ten adjusted WPC scores for PBX during the period 1980-1984

The final half of the 1980s saw the introduction of a number of features that were added to the capabilities of the PBX, mainly automatic voice functions like voice mail and the automated attendant. These functions were mainly developed by smaller companies. One of these companies was Dytel, it was founded in 1982 and founded by the "father of call processing", Sandy Morganstein. It became an acclaimed leader in the voice processing industry, credited with innovations like the automated attendant (CommuniTech Services, 2007). Other companies that were involved in these call processing innovations were Opcom and MessagePhone. The latter was responsible for implementing automated message delivery in to the PBX.
The call processing innovations that were introduced in the final half of the 1980s continued in the beginning of the 1990s with companies like Dytel and Unifi Communications. However, a new wave of innovations, that would change telecommunications, was entering the scene; mobile telephony. This wave of innovations is clearly illustrated by the high ranking of Omnipoint (U.S. subsidiary of T-Mobile) and Qualcomm. Especially Qualcomm has many key patents in the field of mobile telephony. These patents were essential for the development of the mobile PBX, whose functionalities have been discussed earlier. Other sources of mobile technologies integrated in PBX were the relatively small companies; Cylink and Interdigital Technology. Cylink innovated on secure wireless transmission, especially spread spectrum coding. Interdigital Technology has been a recognized pioneer in the design, development and delivery of advanced wireless technology platforms.

The call processing innovations that were introduced in the final half of the 1980s continued in the beginning of the 1990s with companies like Dytel and Unifi Communications. However, a new wave of innovations, that would change telecommunications, was entering the scene; mobile telephony. This wave of innovations is clearly illustrated by the high ranking of Omnipoint (U.S. subsidiary of T-Mobile) and Qualcomm. Especially Qualcomm has many key patents in the field of mobile telephony. These patents were essential for the development of the mobile PBX, whose functionalities have been discussed earlier. Other sources of mobile technologies integrated in PBX were the relatively small companies; Cylink and Interdigital Technology. Cylink innovated on secure wireless transmission, especially spread spectrum coding. Interdigital Technology has been a recognized pioneer in the design, development and delivery of advanced wireless technology platforms.
In the second half of the 1990s the intensity of innovative behaviour increased rapidly, as can be seen by the spectacular rise of the adjusted WPC scores for the top ten companies. In the end of the 1990s smaller companies disappear from the top ten and the list becomes dominated by large telecommunications equipment manufacturers. The majority of the innovations in this period can be seen as incremental. The development of the mobile PBX continues, albeit with a relatively lower intensity. In 10th place is Nortel, this company started in the end of the 1990s with network access in a multi-service environment; convergence of transmission on different media. An early form of convergence and this can therefore be seen as a stepping stone for IPBX.

<table>
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<td>TELEFONAKTIEBOLAGET LM ERICSSON</td>
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<td>OMNIPONT CORPORATION</td>
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<td>QUALCOMM, INC.</td>
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<td>MOTOROLA, INC.</td>
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<tr>
<td>NORTEL NETWORKS CORPORATION</td>
<td>38,0</td>
</tr>
</tbody>
</table>

Table 10: Top ten adjusted WPC scores for PBX during the period 1995-1999

The trend of convergence that was started in the 1990s continues in the first years of the 2000s. The number one spot for Nortel is a clear indication for this. This shift from circuit switched networks (PSTN) towards packet switched networks (IP) is also shown by the inclusion of Sun Micro Systems in the top ten and Cisco Systems being just outside the top ten at place eleven. These companies score high in the list with innovations like multi-layer network elements for forwarding received packets. The other striking companies are the telecommunications service providers, like Bell Atlantic and Sprint. The technologies were their patents are focusing on are mainly focussing on the connection of the PBX on to the different network technologies. The demise of AT&T is mainly due to the spinning of Lucent. AT&T and Lucent put together still dominated the R&D conducted in this field.

<table>
<thead>
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<td>AT&amp;T CORP.</td>
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<tr>
<td>SUN MICROSYSTEMS, INC.</td>
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</table>

Table 11: Top ten adjusted WPC scores for PBX during the period 2000-2002
The PBX technology starts with innovations regarding electric switching. These innovations where based on developments regarding micro-electronics and were conducted by traditional equipment makers (TEM), like Siemens, that had dominated the telecommunications industry for ages and the research departments of the incumbent telephone operators (ITO), such as AT&T. These developments were later backed by innovations by big electronics firms, like Philips. However smaller firms were also important sources for innovation in those early years. They were particularly instrumental in the developments of functionalities such as voice mail and automatic call attendants.

Generally speaking one can say that the innovation of the major companies came from a fundamental research background, i.e. micro-electronics, whereas the innovations of the smaller firms were changes in the application level and came from practical problems.

In the beginning of the 1990s new waves of innovation started to change the PBX technology. The first innovation was the development of the Mobile PBX, based mainly on technology by new equipment manufacturers (NEM), like Qualcomm, who rose to prominence with the development of the mobile phone technology. This was combined with the practical knowledge of the new telecom operators (NTO), like Omnipoint. This contradicts the assumption Fransman (2002) makes that the NTO did not perform their own R&D but relied on the telecommunication equipment manufacturers for R&D. The second innovation, and a much more important one, was the start of the development of VoIP PBX. This technology was developed by NEM, like Cisco, and TEM, like Nortel. This heralded the shift from circuit switched networks (PSTN) towards packet switched networks (IP) and was based on new technologies coming from the computer industry.

The last two waves of innovation were completely dominated by large companies. The smaller companies that had played an important role lost all there significance. PBX is now dominated by large corporations.

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Technological development</th>
<th>Dominant types of companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970-1984</td>
<td>Development electric switching</td>
<td>Electronics firms, TEM and ITO</td>
</tr>
<tr>
<td>1970-1994</td>
<td>Functionalities like voicemail and automatic call attendant</td>
<td>Small firms</td>
</tr>
<tr>
<td>1990-1995</td>
<td>Mobile PBX</td>
<td>NEM and NTO</td>
</tr>
<tr>
<td>1995-now</td>
<td>VoIP PBX</td>
<td>NEM and TEM</td>
</tr>
</tbody>
</table>

Table 12: Technological development PBX and the companies involved
4.1.2.2 Intelligent Network

The technology sources that eventually led to the creation of IN were during the end of the 1960s in the hands of electronics firms and the new fledgling computer industry.

However the biggest chunk of the WPC score was controlled by AT&T, with its huge research facilities. Their research focused mainly on telephone switching, especially the change from electro-mechanical switching technologies to electric switching technologies.

The mainframe manufacturers supplied the technology that would later lead to the separate service data in a centralized database outside the switching nodes. Companies like IBM, GE, Burroughs and RCA were part of the eight major United States computer companies (together with Honeywell, NCR Corporation, Control Data Corporation, and UNIVAC) through most of the 1960s. IBM's share of the market at the time was so much larger than all of the others that this group was often sarcastically referred to as "IBM and the Seven Dwarfs" (Pugh, 1996).

But also other companies, that contributed to the technology for the centralized database, like General Dynamics, General Signal and Giannini Scientific contributed to the technology for the centralized database and the computing of this database as those technologies were intertwined with there field of expertise, respectively defence contracting, railway signalling and aerospace. Another company that came originally from the aerospace industry was Bunker-Ramo; a company with expertise in data processing, retrieval and display. They made the telequote terminals for the securities industry and worked for the defence department. They developed a data processing system (NYT, 1985).

<table>
<thead>
<tr>
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<td>BURROUGHS CORPORATION</td>
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<td>GIANNINI SCIENTIFIC CORPORATION</td>
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<tr>
<td>Bunker Ramo Corporation</td>
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</table>

Table 13: Top ten adjusted WPC scores for IN during the period 1963-1969

In the 1970's IN technology followed the trend that was visible in the 1960s. Albeit that traditional telecommunication equipment makers, other than AT&T, came in the top ten of highest WPC scores. They supplied the technology for the communication between the PSTN and the databases, as well as integrating all the separate technologies. Examples of this are Stromberg-Carlson and Ericsson.

The majority of innovations were on electric switching and on improvements on mainframe technology and database technology. For instance the Nanodata Corp., introduced a computer called QM-1 that allowed users to use the "innermost secrets" of the computer; creating new instructions, modifying others, etc. It actually used nano
programming (the lowest level of microprogramming) as the primary machine instructions, with the micro-memory in which they reside, as the main memory (American University, 2007). This technology was later used for creating new SIBs.

<table>
<thead>
<tr>
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<td>TELEFONAKTIEBOLAGET LM ERICSSON</td>
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<td>NANODATA CORPORATION</td>
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<tr>
<td>DIGITAL EQUIPMENT CORPORATION</td>
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</table>

Table 14: Top ten adjusted WPC scores for IN during the period 1970-1974

In the last half of the 1970s technology regarding data transmission and utilizing two-way channels came from the Martin Marietta Corporation. The company was a leader in aggregates, cement, chemicals, aerospace, and electronics. This company typified the conglomerates as they were formed in the 1960s.

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<td>GTE</td>
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<tr>
<td>MOTOROLA, INC.</td>
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<td>SIEMENS AKTIENGESELLSCHAFT</td>
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<td>MARTIN-MARIETTA CORPORATION</td>
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</tbody>
</table>

Table 15: Top ten adjusted WPC scores for IN during the period 1975-1979

During the beginning of the 1980s there was a significant change in the development of the IN technology. The technology regarding computers and electric switching technologies became more mature. But the biggest changes happened on the regulatory side. In 1984 the break-up of AT&T into seven independent Regional Bell Operating Companies (RBOCs) was ordered and the RBOC gave the order to Telcordia to develop the official IN technology. This change became completely clear in the later half of the 1980s.

In the top ten of WPC scores from the early 1980s there are two institutes that standout because they are no corporation; Standford University and Massachusetts Institute of Technology. Both universities developed technologies relating to cryptographic communication systems. This technology is essential for the operations of IN. The system depends on the secure interaction between switching systems and intelligent nodes containing the service logic and data.
The official development of the IN architecture started half way through the 1980s and this is shown by the emergence of Telcordia in the top ten of WPC scores and the spectacular rise of the absolute WPC scores.

Another new company was VMX. This company was a large contributor to the knowledge base of IN in the 1980’s. VMX (voice message exchange) was the company that produced the world’s first commercial voicemail system. The occurrence of patents from this firm is no surprise, because voicemail is one of the most popular service independent building blocks. This is the first start of the serious development of the service plane. A second important feature is the emergence of Asian companies in the field of IN technology, namely NEC and Hitachi.

The chain of events that was started in the mid-1980s continued in the beginning of the 1990s. The rise in the intensity of innovative behaviour continued and so did the rise of the Asian telecommunication equipment manufacturers.

Technology was developed so that IN could make the link between mobile and fixed line networks; research on this field was done by Bell Atlantic and Qualcomm.

AT&T contributed a lot of knowledge regarding the programming of the software and they developed the patent on providing personalized telephone subscriber features at remote locations.
In the mid-1990's a big shift can be observed in the dwindling of the importance of the computer manufacturers and the rise of the importance of RBOCs (AT&T and Bell Atlantic) and even more vertically integrated telecommunication equipment manufacturers. Only IBM managed to remain relevant in this field of technology.

### Table 18: Top ten adjusted WPC scores for IN during the period 1990-1994

<table>
<thead>
<tr>
<th>COMPNAME</th>
<th>SumOfScore</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT&amp;T CORP.</td>
<td>278,1</td>
</tr>
<tr>
<td>NON-CORPORATE</td>
<td>177,8</td>
</tr>
<tr>
<td>MOTOROLA, INC.</td>
<td>122,2</td>
</tr>
<tr>
<td>INTERNATIONAL BUSINESS MACHINES CORPORATION</td>
<td>110,2</td>
</tr>
<tr>
<td>FUJITSU LIMITED</td>
<td>50,8</td>
</tr>
<tr>
<td>HITACHI, LTD</td>
<td>46,8</td>
</tr>
<tr>
<td>TELEFONAKTIEBOLaget LM ERICSSON</td>
<td>38,8</td>
</tr>
<tr>
<td>DIGITAL EQUIPMENT CORPORATION</td>
<td>37,0</td>
</tr>
<tr>
<td>TOSHIBA CORPORATION</td>
<td>35,4</td>
</tr>
<tr>
<td>TELCORDIA TECHNOLOGIES, INC.</td>
<td>34,5</td>
</tr>
</tbody>
</table>

### Table 19: Top ten adjusted WPC scores for IN during the period 1995-1999

During the first years of the 2000's it is clear that the technology has become mature. The main developments are done on the service plane, hence the importance of service providers (Bell Atlantic, Sprint, AT&T and BT) and small improvements by vertical integrated telecommunications equipment providers.

<table>
<thead>
<tr>
<th>COMPNAME</th>
<th>SumOfScore</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT&amp;T CORP.</td>
<td>287,0</td>
</tr>
<tr>
<td>NON-CORPORATE</td>
<td>209,8</td>
</tr>
<tr>
<td>TELEFONAKTIEBOLaget LM ERICSSON</td>
<td>191,0</td>
</tr>
<tr>
<td>INTERNATIONAL BUSINESS MACHINES CORPORATION</td>
<td>178,6</td>
</tr>
<tr>
<td>BELL ATLANTIC</td>
<td>174,0</td>
</tr>
<tr>
<td>LUCENT TECHNOLOGIES INC.</td>
<td>123,8</td>
</tr>
<tr>
<td>MOTOROLA, INC.</td>
<td>102,1</td>
</tr>
<tr>
<td>NORTEL NETWORKS CORPORATION</td>
<td>68,5</td>
</tr>
<tr>
<td>TELCORDIA TECHNOLOGIES, INC.</td>
<td>65,2</td>
</tr>
<tr>
<td>MCI COMMUNICATIONS CORP.</td>
<td>52,5</td>
</tr>
</tbody>
</table>

### Table 20: Top ten adjusted WPC scores for IN during the period 2000-2002
Although IN as we know it was developed during the 1980s, the technology incorporated in IN was first developed in the 1960s. It is built on two technologies; database technology and electric switching. The database technology and the server technology to run the databases on were developed in the 1960s and 1970s by the then fledgling computer industry, companies like IBM. This was augmented by companies from the aerospace industry, like Martin Marietta Corporation. The aerospace industry innovated substantially in computer technology; this was developed for the space program and missile systems but could also be applied in the telecommunications equipment industry. The integration of these "foreign" technologies with the PSTN and the electrical switching technology was done by traditional equipment makers (TEM) and incumbent telephone operators (ITO).

When the official development of IN started in the 1980s this was done by TEM, like Telcordia and AT&T. Although many of the application innovations were invented by smaller companies, just as with PBX, and the essential cryptographic communication systems were developed by universities, like Stanford and MIT, the majority of innovations came from TEM.

After 1993, the finalizations of the architecture by the ITU, main developments were only done on the service plane. The importance of service providers, ITO and new telephone operators (NTO) grew as they were the only ones building new SIBs for the service plain. This importance is a great indicator that the IN technology is mature and to a large extent entirely developed.

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Technological development</th>
<th>Dominant types of companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965-1984</td>
<td>Development digital switching</td>
<td>Electronics firms, TEM and ITO</td>
</tr>
<tr>
<td>1965-1980</td>
<td>Database technology</td>
<td>Computer industry</td>
</tr>
<tr>
<td>1965-1980</td>
<td>Computer technology</td>
<td>Computer and aviation industry</td>
</tr>
<tr>
<td>1975-1980</td>
<td>Interface database&lt;&gt;PSTN</td>
<td>TEM</td>
</tr>
<tr>
<td>1980-1995</td>
<td>IN architecture</td>
<td>TEM</td>
</tr>
<tr>
<td>1985-2002</td>
<td>Service Blocks</td>
<td>NTO, ITO and small companies</td>
</tr>
</tbody>
</table>

Table 21: Technological development IN and the companies involved
4.1.3 Results concepts

Now that we have a better insight in the development of both technologies we can come to answering the questions that were raised in the theory part.

What is the influence of modularity on new companies entering a technology?

This question was researched with the use of the concept of entry. Entry is the percentage share of WPC (weighted patent count) by firms applying for the first time in a given technology, during a specific period, over the total WPC in the same period. It measures innovative birth and not entrepreneurial birth; a new innovator may be in fact a company that has been operating for quite some time.

The entry rate for PBX is structurally higher than that for IN. Even tough PBX is based on technology that was mainly developed by AT&T, a lot of small firms provided technology that was incorporated in PBX. The beginning of the 1990s led to an increase of the WPC score of new entries. This was due to mobile technology, developed mainly by new entrant Qualcomm. After this brief surge the entry rates for PBX, but also for IN, dropped significantly. Both technologies matured in this period and the new development in these technologies (packet switching) did not yet make a significant impact on the data.

![ENTRY](image)

Figure 11: Development of the ENTRY-score for PBX and IN over the years

After the publication of the Q.1200 recommendations in 1993 regarding IN, there was a decrease in the percentage of new entries. However this was also the case for PBX, therefore it is unclear if there is a relation between the decrease and modularity.
The second question was related to stability. What is the influence of modularity on the stability of a company as a source of innovation?

The concept of stability shows the relation between the rankings of companies' WPC scores over the years. This means that if the Spearman Correlation is one the ranking is exactly the same as it was in the previous period, if the score is 0 there is no relation.

The Spearman correlation between the ranking of companies in cohorts did not change much for IN in the period from 1970 till 2000. It hovered around the 0.6 mark in that period what meant that there was not a lot of change in the importance of the sources for innovative behaviour. In the period during the early 2000s the correlation got even stronger at almost 0.8.

This is in sharp contrast with the development of the Spearman correlation for PBX. In the end of the 1970s there was almost no stability in the ranking of the WPC score for innovative sources. This reinforces the view that, although heavily dominated by AT&T, here was a lot of change in the importance of the sources of innovation for PBX. This could have to do with the fact AT&T (at least until 1984) was liberally giving out licences. However, over the years this changed and the correlation became stronger and stronger. The stable trend for IN in the correlation changed after the introduction of the Q.1200 recommendations by the ITU in 1993. This change was reflected in a drop in correlation between the period 1990-1994 and the period 1995-1999. The correlation restored however to previous highs in the period after 2000. This indicates that the ranking has become stable again.

![Stability](image-url)

**Figure 12: Development of the STABILITY-score for PBX and IN over the years**

The introduction of modularity led to an increase in the Spearman correlation. Again this trend is mimicked by PBX. So there is no direct evidence of a link between modularity and stability.
The third and final question was related to the concentration of innovation. What is the influence of modularity in the concentration of innovative behaviour?

The concentration was measured using Herfindahl-Hirschman Index (HHI). The HHI gives an indication of the concentration of innovative behaviour as illustrated by the WPC scores. A HHI-score of less than 1,000 is a competitive concentration of innovative behaviour; a result of 1,000-1,800 to be a moderate concentration of innovative behaviour; and a result of 1,800 or greater to be a high concentration of innovative behaviour (Rhoades, 1993).

The first data entry for PBX (1970-1974) has a high concentration rate. This is due to the fact that this cohort has only a small amount of patents (34). Therefore it is better to discard this data entry.

All in all the two technologies have a competitive concentration of innovative behaviour. In the 1980s PBX had a higher concentration rate than IN. This is due to the dominance of AT&T; to a lesser extent AT&T also dominated IN. This dominance diminished in the 1990s and this led to a drop in the concentration rate for both technologies. Around 1995 the concentration rate for PBX drops even below the rate for IN, this is the period when the modular architecture for IN came into effect.

There does not seem to be a relation between an influence of modularity on the concentration of innovative behaviour in IN.
4.2 Case 2: Coaxial Cable to Optical Fibre

Is the theoretical answer to the effects of a technological discontinuity on the market in accordance with reality? And is it as such a way to explain a lowering of technical entry barriers. Will a technology which had recently a technological discontinuity have more new companies entering then technologies with a matured paradigm? Will such a technology have less stability in its sources of innovation? And will such a technology have a lower concentration of innovation?

In the second and final case the shift from coaxial cable to optical fibre is discussed. This case was chosen as an example of a technological discontinuity. This discontinuity made knowledge about how to send an electrical signal through a copper wire less valuable and gave more emphasis on the knowledge of sending a light signal through glass.

This case handles two separate technologies, albeit both technologies perform the same task (i.e. the transmission of data). Therefore two datasets were created, one for coaxial cable and one for optical fibre.

The dataset for both technologies was constructed using the following query strategy. The query contained a keyword (coaxial cable, optical fibre and optical fibre). The difference between these technologies and previous cases is in the fact that these keywords are ubiquitous. So the query was further detailed by some technology classes that were relevant for the technology in question. In the case of coaxial cable it was 8 classes and for the optical fibre it was 10 classes (the exact classes are mentioned in the appendix A). This led to a database that contained 2302 patents regarding coaxial cable technology and a dataset of 4567 patents regarding optical fibre.

4.2.1 Technology coaxial cable and optical fibre

Before we can discuss the results of the analysis of the patent pools it is important to understand how both technologies work. The first part will discuss the technological issues that surround coaxial cable. The second part will focus on optical fibre.

4.2.1.1 Coaxial cable

Open wire transmission lines have the property that the electromagnetic wave propagating down the line extends into the space surrounding the parallel wires. These lines have low loss, but also have undesirable characteristics. They cannot be bent, twisted or otherwise shaped without changing their characteristic impedance (a measure of opposition to an electric current). They also cannot be run along or attached to anything conductive, as the extended fields will induce currents in the nearby conductors causing unwanted radiation and detuning of the line.

Coaxial lines solve this problem by confining the electromagnetic wave to the area inside the cable, between the central conductor and the shield. The transmission of energy in the line occurs totally through the dielectric; inside the cable between the conductors.
Coaxial lines can therefore be bent and moderately twisted without negative effects, and they can be strapped to conductive supports without inducing unwanted currents in them.

A coaxial cable consists of two concentric conductors, made usually of aluminium or copper. The central wire, or pole, is separated from the cylindrical spacing layer of insulation, as shown in the picture below.

The outer conductor is a metal foil or mesh, wound spirally around the insulation layer, outside this is a layer of sheathing to provide external insulation and physical protection for the cable.

The weak points in any cable are the points where they are connected to a device or another cable. The shielding of the cable is interrupted and this can lead to a loss of signal and to interference of other magnetic fields. Therefore connectors are designed to maintain the shielding that the coaxial design offers. From the signal point of view, a connector can be viewed as a short, rigid cable. The connector usually has the same impedance as the related cable and probably has a similar cut-off frequency although its dielectric (non-conductivity) may be different. High-quality connectors are usually gold or rhodium plated, with lower-quality connectors using nickel or tin plating. Silver is occasionally used in some high-end connectors due to its excellent conductivity, but it usually requires extra plating of another metal since silver readily oxidizes in the presence of air. There is also much use of polymers that have conductive or non-conductive qualities (Clark, 1997).

Short coaxial cables are commonly used to connect home video equipment, in measurement electronics and in the consumer cable modem market for broadband Internet access. They used to be common for implementing computer networks; in particular Ethernet, but twisted pair cables have replaced them in most applications. Although coaxial cable needs less repeaters (to amplify the signal as it dies out due to impedance), Ethernet can run approximately 100 meters using twisted-pair cabling. Using coaxial cable increases this distance to 500m (Cisco, 2007).

Long distance coaxial cable is used to connect radio networks and television networks, though this has largely been superseded by fibre optics. It still carries cable television signals to the majority of television receivers, and this purpose consumes the majority of coaxial cable production. One increasing development has been the wider adoption of micro-miniature coaxial cable in the consumer electronics sector (for example mobile phones) in recent years.
Although modern optical fibre cable has meant that coaxial cabling has to some extent fallen out of fashion, the huge existing base of such cabling has caused recent development effort to be concentrated on seeking new methods of using coaxial cable networks.

A summary of all the technical developments in the coaxial cable technology is given in the table below.

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Technological development</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972-2002</td>
<td>Development new connectors</td>
</tr>
<tr>
<td>1980-1992</td>
<td>Use of polymers in connectors</td>
</tr>
<tr>
<td>1995-2002</td>
<td>Use of coaxial cable in broadband</td>
</tr>
</tbody>
</table>

Table 22: Summary technological developments coaxial cable

4.2.1.2 Optical fibre

The importance of optical fibres and their extensive use stems from their extremely high bit-rate capacity and their low costs. Optical fibres are a hair's breath in diameter and are made from a cheap raw material: glass. They are easy to install because they are small, and because they allow the repeaters to be relatively far apart (well over 100 km spacing is possible) they are easy to maintain.

An optical fibre conveys the bits of a digital pattern as either 'on' or an 'off' state of light. The light (of wavelength 1.3 or 1.5 µm) is generated at the transmitting end of the fibre, either a laser, or by a cheaper device called a light emitting diode (LED). A diode is used for detection. The light stays within the fibre (in other words is guided by the fibre) due to the reflective and refractive properties of the outer skin of the fibre, which is fabricated in a 'tunnel fashion'.

Fibre optical technology is already into its third generation. In the first generation, fibres had two cylindrical layers of glass, called the core and the cladding. In addition a cover or sheath of a different material (say plastic) provided protection. The core and the cladding were both made out of glass, but of a different refractive index. A step in the refractive index existed in the boundary of core and cladding, causing reflection of the light rays at this interface, so guiding the rays along the fibre. Unfortunately however, because of the relatively large diameter of the core, a number of different light ray paths could be produced, all reflecting off the cladding at different angles, an effect known as dispersion. The different overall ray paths would be different lengths and therefore take different amounts of time to reach the receiver. The received signal is therefore not as sharp; it is dispersed. It is most problematic when the user intends very high bit-rate operation. The different wave paths (or modes) explain the name step index multimode fibre which has been given to these fibres (see the Figure 15).

A refinement of step index multimode fibre was achieved by using a fibre with more gradual grading of the refractive index from the core to the cladding. A graded index multimode fibre is shown in Figure 15: Types of optical fibre. This has a slightly improved high bit-rate performance over step index multimode fibres. Finally, monomode fibres are the third generation in the development of optical fibres, and have the best performance. In monomode fibre, more advanced fibre production techniques have produced a very narrow core area in the fibre, surrounded by a cladding area; there is a step change in the
refractive index of the glass at the boundary of the core and the cladding. The narrow core of a monomode fibre allows only one of the ray paths (or modes) to exist. As a result there is very little light pulse dispersion in monomode fibre, and much higher bit-rates can be carried.

For in-building and campus cabling of office, industrial or university sites it is now commonplace to use optical fibre at least in the building risers (the conduits between floors or buildings). The cable generally contains multimode fibre, usually suited for transmission between relatively cheap, LED transmitting devices over distances up to 3 km or 15 km. Although the multimode fibre itself is nowadays more expensive than monomode fibre, this is usually compensated by the much cheaper end devices (Clark, 1997).

In contrast, monomode fibre is the preferred technology of network operators, and this is the cable mainly deployed for metropolitan, national or undersea usage. The high volumes of production brought the cost below that of multimode fibres, despite the more complex manufacture. The main benefit is the very high bit-rate achievable and the lengthy inter-repeater distances. The disadvantage is the need for expensive laser devices as transmitters to produce high quality single mode (single wavelength) light required.

The innovation that really kicked started the development and use of optical fibre technology was the amplifier. An optical amplifier is a device which receives some input signal and generates an output signal with higher optical power. Typically, inputs and outputs are laser beams. The amplification occurs in a so-called gain medium, which has to be "pumped" (i.e., provided with some energy) from an external source. Most optical amplifiers are either optically or electrically pumped. This innovation occurred in 1986 and marked breaking point of the technical discontinuity, because from that point onwards the optical fibre was a financially viable alternative for coaxial cable.

Most optical amplifiers are laser amplifiers, where the amplification is based on stimulated emission. Here, the gain medium contains some atoms, ions or molecules in an excited state, which can be stimulated by the signal light to emit more light into the same radiation modes. Such gain media are either an insulator doped with some laser-active ions, or semiconductors, which can be electrically or optically pumped. Doped insulators for laser amplification are laser crystals and glasses used in bulk form. The laser-active ions are usually either rare-earth ions or (less frequently) transition-metal ions. A particularly important type of laser amplifier is the erbium-doped fibre amplifier, which is used mostly for optical fibre communications (RP Photonics, 2007).
Another important factor in the design and installation of optical fibre networks is the careful joining or interconnection of fibre sections. The reflections caused at the joint, and the losses caused by slight misalignment of the two fibre cores and lead to major losses of signal strength. The latest generation of cabling splicing devices and cable connectors have improved real network performance dramatically in recent years. The ST-connector (a bayonet-type connector) now common for optical fibre patch frames and equipment connections, for example, has been designed to ensure correct alignment of the fibres.

Recent development in optical fibre technology has concentrated on achieving longer operation life of installed cable, without the need to replace 'active' components. One of the problems with the original systems was the use of optical signal regenerators specific to a given light wavelength and transmission bit-rate. This means that the early optical fibres cannot easily be upgraded in bit-rate without major reinvestment in regenerators and other 'active' devices. For this reason, considerable effort has been put into optical amplifiers and regenerators which work without re-converting the signal to electrical form and the re-creating a new light signal for onward transmission. Such amplifiers can be built to give greater range of optical wavelength and bit-rate. Wavelength, bit-rate and multiplexing upgrades can thus to some extent be limited to the end devices, giving scope for new developments.

A summary of all the technological developments in optical fibre technology is given below.

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Technological development</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975-1982</td>
<td>Multimode fibre</td>
</tr>
<tr>
<td>1982-1995</td>
<td>Monomode fibre</td>
</tr>
<tr>
<td>1986-...</td>
<td>Amplifiers</td>
</tr>
<tr>
<td>1990-...</td>
<td>Connectors</td>
</tr>
<tr>
<td>1998-...</td>
<td>Bragg grating</td>
</tr>
</tbody>
</table>

Table 23: Summary technological developments optical fibre
4.2.2 Innovative behaviour in coaxial cable and optical fibre

To understand the innovative developments of the technologies and the companies who were involved it is important to get a description of the innovative behaviour in both technologies. This will be done in the same fashion as in the first case.

The first modern coaxial cable was produced in 1929 by AT&T. From the 1940s onwards the coaxial cable was used for commercial purposes and the first transatlantic cable was constructed in 1956. The technology was therefore already matured in the 1970s and 1980s. The patenting intensity rose in the 1990s, even when adjusted for truncation, this was due to new applications for the coaxial cable. The most important new application was the use of coaxial cable in the last mile of the Internet.

The optical fibre was developed in the 1970s. In those first years the development was very composed, but this changed with the introduction of the erbium-doped fibre amplifier in 1986. This made optical fibre commercially attractive to use in the backbone of the network (trunk lines) of major telecommunication providers. The innovative intensity doubled sevenfold in the following year and this intensity continues to this day. The year 1986 can be seen as the break point for the technical discontinuity. However, the rise in optical technology did not lead to demise in coaxial technology. This was mainly due to the fact that when coaxial cable was replaced by optical fibre in the trunk lines, coaxial cable got new uses in the local loop. At this moment coaxial cable is also being replaced in the local loop by optical fibre. This change can not be seen in the data due to the fact that the dataset only runs until 2002.
4.2.2.1 Coaxial cable

In the period between 1970 and 1974 several companies were active in the field of coaxial cable technology. These companies can be split into two groups; a sector specific group and a material suppliers group. The first group uses coaxial cable technology in their respective sectors. These sectors are computer technology (Bunker Ramo Corporation), measurement and testing equipment (Tektronix Inc.) and aviation electronics (Bendix). The second group consists of material suppliers like AMP, Lindsay speciality, Gilbert Engineering, ITT (components), Anaconda and Andrew Corporation (wire producers). The majority of the patents coming from both groups were related to connectors and plugs for coaxial cable.

<table>
<thead>
<tr>
<th>COMPNAME</th>
<th>SumOfScore</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMP INCORPORATED</td>
<td>6,4</td>
</tr>
<tr>
<td>NON-CORPORATE</td>
<td>5,2</td>
</tr>
<tr>
<td>LINDSAY SPECIALTY PRODUCTS LIMITED</td>
<td>5,2</td>
</tr>
<tr>
<td>BUNKER RAMO CORPORATION</td>
<td>4,2</td>
</tr>
<tr>
<td>TEKTRONIX INC.</td>
<td>3,0</td>
</tr>
<tr>
<td>GILBERT ENGINEERING COMPANY, INC.</td>
<td>2,6</td>
</tr>
<tr>
<td>ANDREW CORPORATION</td>
<td>2,5</td>
</tr>
<tr>
<td>ITT CORPORATION</td>
<td>2,0</td>
</tr>
<tr>
<td>BENDIX CORPORATION (NOW ALLIED-SIGNAL INC.)</td>
<td>2,0</td>
</tr>
<tr>
<td>ANACONDA COMPANY</td>
<td>2,0</td>
</tr>
</tbody>
</table>

Table 24: Top ten adjusted WPC scores for coaxial cable during the period 1970-1974

The trend from the first half of the 1970s, with a focus on new connectors (i.e. different shielding materials and methods), continues in the second half of the decade. The dominance of AMP inc. is growing with a score almost 5 times greater then the numbers two and three. The introduction of Raychem signalled the beginning of a change in the innovative behaviour for coaxial cable that would take off in the 1980s. This change was the introduction of plastics and polymers as conductors and dielectric material.

<table>
<thead>
<tr>
<th>COMPNAME</th>
<th>SumOfScore</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMP INCORPORATED</td>
<td>35,3</td>
</tr>
<tr>
<td>NON-CORPORATE</td>
<td>7,7</td>
</tr>
<tr>
<td>BUNKER RAMO CORPORATION</td>
<td>7,7</td>
</tr>
<tr>
<td>RAYCHEM CORPORATION</td>
<td>5,4</td>
</tr>
<tr>
<td>AT&amp;T CORP.</td>
<td>5,1</td>
</tr>
<tr>
<td>ITT CORPORATION</td>
<td>3,4</td>
</tr>
<tr>
<td>ANDREW CORPORATION</td>
<td>3,2</td>
</tr>
<tr>
<td>GK TECHNOLOGIES, INC.</td>
<td>3,1</td>
</tr>
<tr>
<td>GAMCO INDUSTRIES, INC.</td>
<td>2,6</td>
</tr>
<tr>
<td>UNISYS CORPORATION</td>
<td>2,6</td>
</tr>
</tbody>
</table>

Table 25: Top ten adjusted WPC scores for coaxial cable during the period 1975-1979
As mentioned before, the 1980s saw the large-scale use of polymers in coaxial cable. Next to Raychem, companies like Du Pont started innovating in the technological field of coaxial cable. Du Pont is a chemical giant and one of the companies that led the polymer revolution with innovations like Nylon, Kevlar and Teflon. An example of these innovations is the patent that Du Pont was granted regarding a terminal for establishing electrical contact with a shielded cable (i.e. coaxial cable), using aluminized Mylar.

<table>
<thead>
<tr>
<th>COMPNAME</th>
<th>SumOfScore</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMP INCORPORATED</td>
<td>34,8</td>
</tr>
<tr>
<td>NON-CORPORATE</td>
<td>16,3</td>
</tr>
<tr>
<td>RAYCHEM CORPORATION</td>
<td>10,7</td>
</tr>
<tr>
<td>BENDIX CORPORATION (NOW ALLIED-SIGNAL INC.)</td>
<td>5,7</td>
</tr>
<tr>
<td>BUNKER RAMO CORPORATION</td>
<td>5,5</td>
</tr>
<tr>
<td>E. I. DU PONT DE NEMOURS AND COMPANY</td>
<td>4,2</td>
</tr>
<tr>
<td>SUMITOMO ELECTRIC INDUSTRIES CO., LTD.</td>
<td>3,9</td>
</tr>
<tr>
<td>AT&amp;T CORP.</td>
<td>3,8</td>
</tr>
<tr>
<td>VIRGINIA PATENT DEVELOPMENT CORP.</td>
<td>3,7</td>
</tr>
<tr>
<td>CHABIN CORPORATION</td>
<td>3,3</td>
</tr>
</tbody>
</table>

Table 26: Top ten adjusted WPC scores for coaxial cable during the period 1980-1984

In the end of the 1980s Raychem came up with the use of piezoelectric materials in connectors. Junkosha, a Japanese company specialized in high-performance products created with Fluor polymer application technologies, started using a porous plastic dielectric disposed around the outer periphery of the conductor. The preferred porous dielectric is expanded polytetrafluoroethylene (Teflon).

The contributions of companies that came from the sector specific group (as specified earlier) decreased significantly in the 1980s and in the top ten for the final half of the decade there are only two companies present. These companies are Allied-Signal (aerospace, automotive and engineering company) and Lockheed (aerospace) they use the coaxial technology for wiring inside airplanes. The other companies that make up the top ten can be classified as material suppliers, even AT&T can be put in this category because most of innovations were material related and it only divested its production arm in the 1990s. The list is still dominated by AMP.

<table>
<thead>
<tr>
<th>COMPNAME</th>
<th>SumOfScore</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMP INCORPORATED</td>
<td>90,8</td>
</tr>
<tr>
<td>NON-CORPORATE</td>
<td>27,5</td>
</tr>
<tr>
<td>RAYCHEM CORPORATION</td>
<td>20,1</td>
</tr>
<tr>
<td>ALLIED-SIGNAL INC.</td>
<td>12,3</td>
</tr>
<tr>
<td>AT&amp;T CORP.</td>
<td>10,4</td>
</tr>
<tr>
<td>LRC ELECTRONICS, INC.</td>
<td>7,2</td>
</tr>
<tr>
<td>KASEVICH ASSOCIATES, INC.</td>
<td>6,0</td>
</tr>
<tr>
<td>LOCKHEED CORPORATION</td>
<td>5,8</td>
</tr>
<tr>
<td>JUNKOSHA CO., LTD.</td>
<td>5,8</td>
</tr>
<tr>
<td>E. I. DU PONT DE NEMOURS AND COMPANY</td>
<td>5,7</td>
</tr>
</tbody>
</table>

Table 27: Top ten adjusted WPC scores for coaxial cable during the period 1985-1989
The focus for coaxial cable remained on the further developments of connectors and methods for shielding the cable. In the early 1990s W.L. Gore, a spin off from Du Pont and the inventor of Gore-Tex, came up with an improved version of the use of Polytetrafluoroethylene (Teflon) as an insulation material. The idea was first patented by Junkosha in the 1980s. This illustrates the continuing importance of chemical companies in the innovative behaviour regarding coaxial cable.

In the mid 1990s AMP shifted its patenting operations from AMP Incorporated to its subsidiary Whitaker Corporation. The reason for this shift is not completely clear. In the end of the 1990s both AMP Incorporated and Raychem Incorporated were taken over by Tyco. This affected the ranking substantially.

The most important shift in the end of the 1990s was the start of the use of coaxial networks for broadband Internet networks. Lucent Technologies developed in 1996 a method and apparatus enabling synchronous transfer mode and packet mode access for multiple services on a broadband communication network. This patent received over nine times the average amount of citations for that year.
In the early 2000s the intensity of corporate R&D for cable slowed down. This is shown by the importance of non-corporate patent holders compared to the corporate patent holders. The direction of development stayed the same with a main focus on coaxial connectors and other end devices. The coaxial cable technology did not see many innovations regarding its form or workings, but witnessed in the end of the 1990s a change in its use. This shift prolonged the relevancy of coaxial cable for several extra years.

Coaxial cable, first developed in the 1920s, was already a matured technology in the 1970s (when this case starts). This is why the majority of the innovations relate to the connectors and not to the actual cable. The sources of these innovations can be split into two groups; a sector specific group (SPG) and a material suppliers group (MSG). The first group uses coaxial cable technology in their respective sectors. These sectors are computer technology (Bunker Ramo Corporation), measurement and testing equipment (Tektronix Inc.) and aviation electronics (Bendix). The second group consists of material suppliers, like AMP, and wire producers, like Anaconda.

In the end of the 1970s and in the 1980s a new trend emerged. It was the use of plastic polymers as shielding material for the cable, but more importantly for the connectors. This change was mainly driven by chemical companies, like Du Pont.

In the late 1980s and in the 1990s the influence of the SPG began to wane and the MSG dominated the industry even more from then on. However, the most change in the 1990s was the start of the use of coaxial networks for broadband Internet networks. Lucent Technologies developed in 1996 a method and apparatus enabling synchronous transfer mode and packet mode access for multiple services on a broadband communication network. This development was carried by traditional equipment makers (TEM), such as Lucent and Alcatel. From 2000 onwards the technology is losing more and more of its importance as the local loop is slowly being over taken by optical fibre and other technologies.
The first serious research into optical fibre was started in the 1950s. This led to the work of researchers Robert D. Maurer, Frank Zimar and others working in the early 1970s for American glass maker Corning Glass Works, now Corning Inc. They demonstrated a fibre with 17 dB optic attenuation per kilometre by doping silica glass with titanium. This led the start into the applied research involved with fibre optics (Keck, 2000).

This research was mainly conducted by telecommunication equipment makers like Hitachi, ITT, Northern Telecom (later Nortel Networks) and Harris Corporation and by network operators like AT&T and NT&T. This research focussed on improving production methods for optical fibre and improving the laser used to generate the light signals that had to be transmitted by the fibre. This led to the first practical networks and on 22 April, 1977, General Telephone and Electronics (GTE) sent the first live telephone traffic through fibre optics, at 6 Mbit/s, in Long Beach, California, USA (Alwyn, 2004).

<table>
<thead>
<tr>
<th>COMPNAME</th>
<th>SumOfScore</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT&amp;T CORP.</td>
<td>11,8</td>
</tr>
<tr>
<td>HITACHI, LTD</td>
<td>6,0</td>
</tr>
<tr>
<td>ITT CORPORATION</td>
<td>5,5</td>
</tr>
<tr>
<td>NIPPON TELEGRAPH &amp; TELEPHONE CORP.</td>
<td>4,4</td>
</tr>
<tr>
<td>GTE LABORATORIES, INC.</td>
<td>1,9</td>
</tr>
<tr>
<td>NORTEL NETWORKS CORPORATION</td>
<td>1,9</td>
</tr>
<tr>
<td>HARRIS CORP.</td>
<td>1,6</td>
</tr>
<tr>
<td>NON-CORPORATE</td>
<td>1,4</td>
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<tr>
<td>CANADIAN PATENTS AND DEVELOPMENT LTD.</td>
<td>1,2</td>
</tr>
<tr>
<td>BATTELLE DEVELOPMENT CORPORATION</td>
<td>1,0</td>
</tr>
</tbody>
</table>

Table 32: Top ten adjusted WPC scores for optical fibre during the period 1975-1979

In the beginning of the 1980s the research and the patenting was still dominated by telecommunication equipment makers/ electronics firms, like ITT, Nortel, Philips, Thomson and RCA. These firms were supplemented by material suppliers like Corning and EOTEC. The odd one out in this case was Xerox; they developed laser technology that was later used in optical fibre networks. The early 1980s saw further breakthroughs like the invention of the monomode or single mode fibre by companies like Corning and ITT and the further improvement of laser technologies.

<table>
<thead>
<tr>
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<tbody>
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<tr>
<td>ITT CORPORATION</td>
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<tr>
<td>CORNING INCORPORATED</td>
<td>7,6</td>
</tr>
<tr>
<td>NIPPON TELEGRAPH &amp; TELEPHONE CORP.</td>
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</tr>
<tr>
<td>NORTEL NETWORKS CORPORATION</td>
<td>5,1</td>
</tr>
<tr>
<td>XEROX CORPORATION</td>
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</tr>
<tr>
<td>EOTEC CORPORATION</td>
<td>4,5</td>
</tr>
<tr>
<td>U.S. PHILIPS CORPORATION</td>
<td>3,8</td>
</tr>
<tr>
<td>THOMSON-CSF</td>
<td>3,2</td>
</tr>
<tr>
<td>RCA CORPORATION</td>
<td>3,0</td>
</tr>
</tbody>
</table>

Table 33: Top ten adjusted WPC scores for optical fibre during the period 1980-1984
The major breakthrough for optical fibre networks was the erbium-doped fibre amplifier, which reduced the cost of long-distance fibre systems by eliminating the need for optical-electrical-optical repeaters. The amplifier was invented by David Payne of the University of Southampton, and Emmanuel Desurvire at AT&T in 1986. The two pioneers were awarded the Benjamin Franklin Medal in Engineering in 1998. This started the acceleration of innovative activity in this technology and the amount of innovative activity, measured by WPC, almost increased tenfold in those years.

A large portion of the further development of the optical amplifier was conducted at Stanford University by people like Michel Digonnet. The Digonnet group performed research on WDM fibre couplers, amplifiers, single crystal fibres, and integrated optics for fibre sensors.

<table>
<thead>
<tr>
<th>COMPNAME</th>
<th>SumOfScore</th>
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<tbody>
<tr>
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<td>NON-CORPORATE</td>
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<tr>
<td>AMP INCORPORATED</td>
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<tr>
<td>POLAROID CORPORATION</td>
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<tr>
<td>RAYCHEM CORPORATION</td>
<td>22,6</td>
</tr>
<tr>
<td>HITACHI, LTD</td>
<td>22,5</td>
</tr>
<tr>
<td>STANFORD UNIVERSITY, LELAND JUNIOR, THE BOARD OF TRUSTEES OF</td>
<td>20,0</td>
</tr>
<tr>
<td>BRITISH TELECOMMUNICATION, PLC</td>
<td>19,9</td>
</tr>
<tr>
<td>CORNING INCORPORATED</td>
<td>18,7</td>
</tr>
</tbody>
</table>

Table 34: Top ten adjusted WPC scores for optical fibre during the period 1985-1989

The share of the telecommunication equipment makers diminished in the end of the 1980s and the share of the material suppliers rose sharply. This is illustrated by the presence of Sumitomo, AMP, Raychem and Corning in the top ten. These companies were mainly involved in innovation regarding the production of optical fibre and optical fibre connectors.

<table>
<thead>
<tr>
<th>COMPNAME</th>
<th>SumOfScore</th>
</tr>
</thead>
<tbody>
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<tr>
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<td>NON-CORPORATE</td>
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<tr>
<td>ALCATEL</td>
<td>35,9</td>
</tr>
<tr>
<td>HUGHES AIRCRAFT COMPANY</td>
<td>32,8</td>
</tr>
<tr>
<td>MINNESOTA MINING AND MANUFACTURING COMPANY</td>
<td>29,7</td>
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<tr>
<td>FUJITSU LIMITED</td>
<td>28,5</td>
</tr>
<tr>
<td>BRITISH TELECOMMUNICATION, PLC</td>
<td>27,2</td>
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<tr>
<td>NORTEL NETWORKS CORPORATION</td>
<td>26,3</td>
</tr>
</tbody>
</table>

Table 35: Top ten adjusted WPC scores for optical fibre during the period 1990-1994

The material suppliers continued to develop the technology regarding connectors and types of optical fibre. Many of these companies were active in the coaxial cable technology and became also active in optical fibre technology in the period between 1985 and 1995. One of these companies was Minnesota Mining and Manufacturing Company (now known as 3M Company) a company known for its adhesives and abrasives, like
post-it notes. This company manufactured connectors, but had the most success with a type of laminate for fibre couplers that maintains the polarization of the light. This patent received 5 times the average amount of citations.

<table>
<thead>
<tr>
<th>COMPNAME</th>
<th>SumOfScore</th>
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<tr>
<td>AT&amp;T CORP.</td>
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<tr>
<td>FUJITSU LIMITED</td>
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<td>NON-CORPORATE</td>
<td>65,6</td>
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<tr>
<td>ALCATEL</td>
<td>62,7</td>
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<tr>
<td>NEC CORPORATION</td>
<td>59,5</td>
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<tr>
<td>E-TEK DYNAMICS, INC.</td>
<td>42,1</td>
</tr>
<tr>
<td>NORTEL NETWORKS CORPORATION</td>
<td>31,2</td>
</tr>
<tr>
<td>MINNESOTA MINING AND MANUFACTURING COMPANY</td>
<td>30,3</td>
</tr>
</tbody>
</table>

Table 36: Top ten adjusted WPC scores for optical fibre during the period 1995-1999

AT&T spun off its R&D department, Lucent, in 1996 and this led to an end of the domination of innovative activities by AT&T. The sum of the adjusted score dropped from 262.4 in the period between 1990 and 1994 to almost 0 in the period after 2000. Alternatively Lucent became the major player in the technology.

One of the other significant developments was the use of fibre with Bragg grating. A fibre with Bragg grating is a type of distributed Bragg reflector constructed in a short segment of optical fibre that reflects particular wavelengths of light and transmits all others. This is achieved by adding a periodic variation to the refractive index of the fibre core. A fibre Bragg grating can therefore be used as an inline optical filter to block certain wavelengths, or as a wavelength-specific reflector. This technology was pioneered by Lucent/AT&T, Nortel and Alcatel.

<table>
<thead>
<tr>
<th>COMPNAME</th>
<th>SumOfScore</th>
</tr>
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<tr>
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<tr>
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<td>SAMSUNG ELECTRONICS CO., LTD.</td>
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<td>ALCATEL</td>
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<tr>
<td>CORNING INCORPORATED</td>
<td>10,9</td>
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<tr>
<td>NON-CORPORATE</td>
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<tr>
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<td>PIRELLI CAVI S.P.A.</td>
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<tr>
<td>SIECOR CORPORATION</td>
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</tbody>
</table>

Table 37: Top ten adjusted WPC scores for optical fibre during the period 2000-2002

By the beginning of the 2000s the top ten is dominated by material suppliers. This group can be subdivided in electronics firms and fibre producers. The first group produces and innovates in amplifiers and transceivers and dominates the first half of the list. They have an electronics background; Lucent, Fujitsu, Samsung, NEC and Alcatel. The latter group (Corning, Sumitomo, Pirelli and Sicor) are companies with their roots in the wire or glass business. They innovate mainly on new production methods, new types of fibre and connectors.
In the table below all the developments and the type of firms that were instrumental in these developments are mentioned.

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Technological development</th>
<th>Dominant types of companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975-1982</td>
<td>Multimode fibre</td>
<td>TEM and MSG</td>
</tr>
<tr>
<td>1982-1995</td>
<td>Monomode fibre</td>
<td>TEM and MSG</td>
</tr>
<tr>
<td>1986-...</td>
<td>Amplifiers</td>
<td>TEM</td>
</tr>
<tr>
<td>1990-...</td>
<td>Connectors</td>
<td>MSG</td>
</tr>
<tr>
<td>1998-...</td>
<td>Bragg grating</td>
<td>TEM and NEM</td>
</tr>
</tbody>
</table>

Table 38: Technological development optical fibre and the companies involved

The first research into optical fibre was conducted in the 1970s, mainly by traditional equipment makers (TEM), like GTE, and incumbent telephone operators, like AT&T. This research was mainly focused on improving production methods and the use of lasers to generate the transmission light.

In the 1980s these efforts were augmented by the activities of electronics firms, like RCA, in the development of laser technology. This period also saw the rise of the material supply group (MSG), like Corning, as an important source of innovation. They focused mainly on fibre, single mode fibre, and optical connectors.

The innovation that changed the economics of optical fibre, and therefore fire started the industry, was the erbium-doped fibre amplifier. This innovation instigated a huge rise in innovative activity in the industry and many new companies entered the industry. However, by the end of the 1980s the share of the MSG began to rise at the expense of the TEM. Nowadays the industry is evenly split between the MSG and the TEM and new equipment makers (NEM), like Samsung. With the TEM and NEM focussing on the development of amplifiers, transceivers and Bragg grating, and the MSG is innovating in new production methods, new types of fibre and connectors.
4.2.3 Results concepts

The first question asked was:

What is the influence of technical discontinuity on new companies entering a technology?

The entry rate for coaxial cable was rather stable and ranged between 31% and 42%. This can again be explained by the maturity of the technology and the related loss of dynamics. The entry rate for optical fibre was much more dynamic with high rates in the 1970s and 1980s and surprisingly low rates in the 1990s. The high rate in the beginning can be explained by the development of the technology and the opening up of new potential attracts more and more companies that start innovating in the specific technological field. The second spike is during the second half of the 1980s as the invention of the erbium-doped fibre amplifier opened new applications for the technology. After this spike the entry rate drops significantly and even drops under the entry rate for coaxial cable.

![ENTRY]

Figure 18: Development of the ENTRY-score for coaxial cable and optical fibre over the years

The technical discontinuity had a positive effect on the entry rate for optical fibre and no effect on the entry rate for coaxial cable. The fact that the knowledge regarding coaxial cable became more or less obsolete had no effect on the entry rate.
The second question was:

What is the influence of technical discontinuity on the stability of a company as a source of innovation?

The stability in the ranking of the coaxial cable technology is further proof for the maturity of the technology. The stability drops in the end of the 1980s and the beginning of the 1990s due to the influx of chemical companies and the subsequent use of new materials (polymers) in coaxial cable connectors. After this the stability rose again.

The stability of the optical fibre rankings was very low in the beginning. As the technology developed the stability rate rose significantly and by the mid 1990s it was at the same level as the stability rate of coaxial cable.

Figure 19: Development of the STABILITY-score for coaxial cable and optical fibre over the years

The technical discontinuity led to low levels of stability for optical fibre. This changed over time. There was no significant effect on the stability of coaxial cable.
The third and last question was:

What is the influence of technical discontinuity in the concentration of innovative behaviour?

The concentration of innovative behaviour (HHI) of both techniques is depicted in the graph below. The concentration level for coaxial cable was already on the low side and this diminished even further over the years. The reason for this is the mature status of the technology. The newer optical fibre technology started with a very concentration, as the technology starts with a few innovators and gradually becomes more and more mainstream as the knowledge spreads.

The remarkable conclusion is that both techniques achieve the same level of concentration after only a short period.

The technical discontinuity had a significant effect on the concentration of innovative behaviour in the optical fibre technology. There was no significant influence on innovative behaviour in coaxial cable technology.
5 Conclusion, discussion and recommendations

This final part will initially give an answer to the main research question and some sub questions. The second part will give a discussion of points of concern regarding the limitations of the methodology, and it will finish with some avenues for future research.

5.1 Conclusion

The goal of this study was to provide an insight into the effect of lowering technical entry barriers on the innovative behaviour of firms in the telecom equipment sector. The accompanying main research question is:

What is the influence of modularization and technological discontinuity on the innovative behaviour of firms?

It can be concluded that the modular design architecture had no effect on the rate of new companies entering the industry. The technology without the modular design architecture, PBX, even had a higher entry rate than the technology with modular design architecture and that the entry rate plummeted even further after the official announcement of the modular design by ITU in 1993. The influence of modularity on the stability of companies as sources of innovation seems to be positive. When the architecture became official in 1993 the stability of the ranking grew significantly. However, the stability of PBX also grew on the same period. It seems there is no influence of the modular architecture on the concentration of innovative behaviour. Both technologies have approximately the same levels of concentration of innovative activity. After the formalization of the modularization the HHI does not change significantly. In the case of IN and PBX the effect of modularization on the innovative behaviour of firms has been minimal. It appears there is no real difference in the trends both switching technologies follow, albeit there is a difference in the intensity of the behaviour.

So, does the modularization affect the market structure and its innovative behaviour? No, there is no evidence to support this hypothesis in the case study that was conducted. To the contrary, it seems that the modularization had a negative effect on the openness and innovativeness of the technology in question, i.e. Intelligent Network. Is there any evidence that it's the other way around; that the structure of the market and its innovative behaviour influence the architecture of the products? In the period after 1984 (start of the liberalization in the US) the patenting intensity increased in both technologies and not only for IN. The reason for developing a modular architecture for IN was directly related to the liberalization of the telecommunications market, however the PBX did not develop a modular architecture as a result of this liberalization. Nevertheless, the empirical part focused mainly on the possibility of modularity increasing the innovative behaviour and therefore influencing the market structure.
The technical discontinuity did have an effect on the innovative behaviour in the transmission industry. The occurrence of a technical discontinuity affected the entry rates, with very high entry rates in the beginning of the 1970s for optical fibre; this was clearly an industry in an open and fluid stage. Nonetheless after the 1980s it lost a lot of its dynamics. The entry rate for coaxial cable remained stable during the entire period, even after large scale introduction of fibre. This can be explained by the fact that coaxial cable did not lose its entire relevance as it is still used in many applications. The optical fibre industry started very unstable. As the new industry developed, the stability of the ranking rose accordingly. The stability of coaxial cable dropped in the 1980s but it cannot be said with certainty if there is a relation between this and the introduction of optical fibre. There was a change of the importance of chemical companies as sources of innovation around that period. Nevertheless from the 1980s onwards the stability levels from both technologies run parallel. The concentration levels in the new optical fibre technology were significantly higher then in the coaxial cable industry. This difference changed however rapidly as the technology developed further. The introduction of optical fibre did not have any influence on the concentration levels in coaxial cable. Hypotheses predicted that some companies could make the transition to the new technology and some couldn't, leaving them stranded in the coaxial cable technology, and thus the coaxial cable industry would have a higher concentration level. But because coaxial cable technology remained a significant technology, all the major players in the industry remained and the concentration level remained stable. However it was true that some of the companies became also active in the new industry while other companies remained only active in the coaxial cable industry.

The technical discontinuity in transmission technology that was caused by the transition from coaxial cable to optical fibre resulted in new companies entering the market. The lowering of the technical entry barriers changed the entire structure of the industry. However, as the new technology progressed, the barriers rose again and optical fibre became just as open (or closed) as coaxial cable. This happened even before the technology was completely developed and the focus changed from product innovations to mainly process innovations. It is however clear that a technical discontinuity can change an industry significantly, although the effect on the old technology was limited.

Modularization did not affect the innovative behaviour of the firms and it therefore did not change the structure of the market. Technological discontinuity did have an effect on the innovative behaviour, although not to the extent that it could be used as a justification for the events described in the introduction. The conclusion that can be drawn from this thesis is that modularity and technical discontinuity do not have to lead to a significant lowering of the technical entry barriers.
5.1.1 Consequences for strategy

How can modularization and technical discontinuity affect the strategy of firms or regulators?

For regulators the only process that they could influence would be modularization, as technical discontinuity is caused by breakthroughs in R&D and these are fortunately outside the control of most regulators. In an attempt to make a certain industry more competitive regulators could, if necessary, persuaded certain industries to adopt a modular architecture. In the past they persuaded certain industries to adopt a modular structure to their services. This is a very common concept in the telecommunications services industry, but not in the telecommunications equipment industry.

In the case researched in this study the effectiveness of such a tool was very limited. The IN had even a slowdown of innovative behaviour and new entrants after the publication of the modular architecture (Q.1200). There are many possible reasons for this slowdown. The first reason can be the technology itself and its position in the entire field of network opportunities. The relevancy of IN diminished as new technologies emerged and therefore there where less new entrants, etc. The second and most likely reason is the problems and sub-optimal outcomes that are linked with standard setting by a large group or body, i.e. ITU. The process of establishing the standard interfaces and other related issues is often made suboptimal because of the compromises that are made to come to a single standard. This leads to an outcome that is acceptable to all, but not the technological optimal standard.

For firms the introduction of modularity can have a positive effect on innovation, like in the case of the IBM 360, or a negative effect, like in the case of IN. It is therefore difficult for firms to predict the outcome of a modularisation process, unless they use it only internally, but in that case there is no effect on technical entry barriers. It is therefore difficult to indicate a strategy.

How can technical discontinuity affect the strategy of firms?

The biggest technical discontinuity in the telecommunications equipment industry is happening at the moment; the shift from circuit switched networks to packet switched networks. This change could, unfortunately, not be researched as it is still ongoing and the scope of the patent dataset available was until 2002. This shift will change the face of the industry, to what extend is depended on a number of factors. The factor that was most important in the case researched in this study was the remaining relevance of the old technology. If it remains relevant, companies do not have to be able to switch from the old technology to the new technology. If there is a technology that lost its relevance, it is imperative that companies make the jump from the old to the new technology and thus have innovative behaviour that enables that jump. So, firms have to make the assessment if a new technology is possibly a technical discontinuity and what this will mean for their technology base. If they determine a new technology is a technical discontinuity they have to apply an innovation strategy geared towards jumping from one technology towards another.
5.2 Discussion

The two case studies only cover four technologies. There are, however, far more technologies than those four and it is therefore difficult to generalise the results of these cases. What they do say is that modularization and technical discontinuity does not have to lead to a completely new market structure.

The case on modularity maybe further hampered by the nature of the innovations, the new service blocks that can be developed within the Q.1200 context are software innovations. These kinds of innovations are only limitedly protected by patents and therefore only have a limited effect on the results of the patent analysis.

This comes on top of the fact that there can be serious limitations to the use of patent data, the most glaring being that not all innovations are patented. First, not all inventions meet the patentability criteria set by the USPTO: the invention has to be novel, to be nontrivial, and to have commercial application. Second, the inventor has to make the strategic decision to patent, as opposed to secrecy or other means of appropriability. Unfortunately it is not clear to which extend patents are representative of the wider universe of inventions, since there is no systematic data about inventions that are not patented (Jaffe, 2002).

5.3 Recommendations for further research

In the theory section regarding modularity, several theories regarding the relation between industry structure and architecture were discussed. One of those theories argued that the industry structure affects the architecture and not the other way around as is the main reasoning in this thesis. It claimed that an industry with many sources of innovation led automatically to a modular architecture. The break up of the integration between service providers and equipment makers as seen in the end of the 1990s led to an increase in sources of innovation. It would be interesting to research the influence of these actions on the prevailing types of architecture in telecommunications.

Another avenue, regarding modularity that could be researched is the role of the architect. The form of modularity that was researched in this thesis was set by a public standard setting body, i.e. ITU. It would be interesting to research if there is a significant different effect of modularity on innovative behaviour if the standards are set by another type of body. Regarding technical discontinuity it is interesting do research into the factors that determine the intensity of technical discontinuity. In this research relevance was identified as a contributing factor, but what are other factors?

Finally, it would be interesting to repeat this research in ten or fifteen year's time, because a patent analysis becomes more definitive over time, due to truncation effects. This research used a database with patents from 1972 and 2002, with the majority of patents from the 1980s and early 1990s. However, a majority of technological developments that influence the entry barriers are ongoing and the changes within the structure of the telecommunications industry only came in to real effect around the year 2000. The real extent of these events was therefore not completely clear in this research and a follow up study in a decade or so could be interesting. This research also identified the types of firms active in the technologies during certain periods. Some of these types of companies involved in certain periods contradicted the literature by for instance Fransman (2002). Further research could reveal why these findings contradict Fransman.


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Appendix A

The queries used to construct the dataset from the homepage of the USPTO (http://patft.uspto.gov/netahtml/PTO/search-adv.htm) are stated below.

**Intelligent Network**

The queries for the Intelligent network were split up according to the four planes (as described in the IN conceptual model). The results of every plane were augmented with the patents that cited those patents, enlarging the dataset even further.

Physical plane:

- \((\text{ABST/"service control point" OR ABST/sep) AND ISD/1972$$->2002$$})\)
- \((\text{ABST/"service switching point" OR ABST/ssp) AND ISD/1972$$->2002$$})\)
- \((\text{ABST/"service data point" OR ABST/sdp) AND ISD/1972$$->2002$$})\)
- \((\text{ABST/"intelligent peripheral") AND ISD/1972$$->2002$$})\)
- \((\text{ABST/"service node") AND ISD/1972$$->2002$$})\)

Distributed functional plane:

- \((\text{ABST/"basic call state model" or spec/"basic call state model") AND ISD/1972$$->2002$$})\)
- \((\text{ABST/"call control agent function" or spec/"call control agent function") AND ISD/1972$$->2002$$})\)
- \((\text{ABST/"call control function" or spec/"call control function") AND ISD/1972$$->2002$$})\)
- \((\text{ABST/"call segment" or spec/"call segment") AND ISD/1972$$->2002$$})\)
- \((\text{ABST/"object-oriented finite state machine" or spec/"object-oriented finite state machine") AND ISD/1972$$->2002$$})\)
- \((\text{ABST/"service control function" or spec/"service control function") AND ISD/1972$$->2002$$})\)
- \((\text{ABST/"service management access function" or spec/"service management access function") AND ISD/1972$$->2002$$})\)
- \((\text{ABST/"service management function" or spec/"service management function") AND ISD/1972$$->2002$$})\)
- \((\text{ABST/"specialised resource function" or spec/"specialised resource function") AND ISD/1972$$->2002$$})\)
Global functional plane:

- \((\text{ABST/"service switching function" or spec/"service switching function"}) \text{ AND ISD/1972$$->2002$$})\)

- \((\text{ABST/"basic call process" or spec/"basic call process"}) \text{ AND ISD/1972$$->2002$$})\)

- \((\text{ABST/"service independent building" or spec/"service independent building"}) \text{ AND ISD/1972$$->2002$$})\)

- \((\text{ABST/"gsl service independent building" or spec/"gsl service independent building"}) \text{ AND ISD/1972$$->2002$$})\)

Service plane:

- \((\text{ABST/"calling line identification presentation" or spec/"calling line identification presentation"}) \text{ AND ISD/1972$$->2002$$})\)

- \((\text{ABST/"calling line identification registration" or spec/"calling line identification registration"}) \text{ AND ISD/1972$$->2002$$})\)

- \((\text{ABST/"intelligent network conceptual model" or spec/"intelligent network conceptual model"}) \text{ AND ISD/1972$$->2002$$})\)

- \((\text{ABST/"service features" or spec/"service features"}) \text{ AND ISD/1972$$->2002$$})\)

**Private Branch Exchange**

The query regarding PBX was a lot simpler, due to the fact that this combination of words can only refer to PBX and it generated enough patents to conduct the WPC.

- \((\text{ABST/"private branch exchange" or spec/"private branch exchange"}) \text{ AND ISD/1972$$->2002$$})\)
Coaxial cable

The term coaxial cable is ubiquitous and can be found in all sorts of patents that are not relevant for transmission, the focus of this case. The query was therefore restricted using international technology classes that were relevant for this specific technique. The relevant international classes were selected using the following site:


This led to the query and the results were augmented with the patents that cited those patents, enlarging the dataset even further:

ISD/1972$->2002$ AND (ABST/"coaxial cable") AND (ICL/H01B013/$ or ICL/H01L041/$ or ICL/H01B011/$ or ICL/H01R009/$ or ICL/H01R017/$ or ICL/H01R013/$ or ICL/H04L012/$ or ICL/H01R004/$)

Optical fibre

The term optical fibre is very ubiquitous, as is the case with coaxial cable. Therefore the same strategy was applied as was used for coaxial cable. To further complicate the query there are two ways to spell fibre in the English language. There is the British version, fibre, and the American version, fiber. Both forms were used in the query.

- ISD/1972$->2002$ AND (ABST/"optical fibre" OR ABST/"optical fiber") and (ICL/G02B006/$ or ICL/C03B037/$ or ICL/G01D005/$ or ICL/H04B010/$ or ICL/H01S003/$ or ICL/G01M011/$ or ICL/C03C025/$ or ICL/H01B012/$ or ICL/C03C013/$)