Mergers & Acquisitions and Innovation Performance in the Telecommunications Equipment Industry*

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ABSTRACT

The telecommunications equipment industry witnessed an enormous worldwide round of Mergers & Acquisitions (M&A). This paper examines the innovation determinants of M&A activity and the consequences of M&A on the technological potential and the innovation performance. We extend the resource-based theory in elucidating external technology sourcing and provide empirical evidence on the keen reliance of the equipment firms on M&A as a technology sourcing strategy for the period 1988-2004. Employing the matching propensity score approach, this study provides evidence that mergers realize a significant growth in the innovation performance of firms. The post-merger innovation performance is, in turn, driven by both the prior success in in-house R&D commitment and the deterioration of internal technological capabilities at acquiring firms.

Keywords: Mergers & Acquisitions, Innovation Performance, Telecommunications Equipment Industry

JEL Classifications: O30, G34, L63

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1. Introduction

It is striking that most Mergers and Acquisitions (M&A) are associated with technological and/or regulatory shocks. This pattern supports the large sample results of Mitchell and Mulherin (1996) that merger activity is related to industry shocks. Schoenberg and Reeves (1999) argue that deregulation is the single most important factor determining acquisition activity at the industry level. Another study by Andrade *et al*. (2001) shows that deregulation becomes a dominant factor in M&A activity after the late 1980s and accounts for nearly half of the merger activity since then. Le Blanc (2002) points out the distinction of exogenous shocks to the industry structure, both technological (innovation) and institutional (deregulation), and the strategic nature of mergers to alter the industry structure, improve their competitive position, and increase their market power. At the same time, a complementary explanation of merger waves involves endogenous effects, where an initial merger in an industry triggers a chain of successive mergers.

The simultaneous impact of both effects is particularly relevant for the telecommunications industry, where a radical change in the environment, e.g. the 1996 Telecom Act in the US and the 1998 deadline for telecom markets liberalization in Europe, pushed some pioneer firms to decide and quickly embark on a technological merger strategy, triggering similar moves in the whole industry through some kind of subsequent race for assets and target firms (Figure 1). During this period, R&D and innovation increasingly shifted toward the producers of telecommunications equipment. As the trade and regulatory liberalization primarily has globalized the demand for telecommunications equipment, technological change in the industry has had upstream effects on R&D (Figure 2). Moreover, the growth in patenting has been tremendous - from 1988 to 1998 the number of communication equipment patents applied by the UPSTO increased by more than four times (Figure 3).

As the telecommunications equipment industry was opened to entry, some firms chose to be niche manufactures such as AVM[1] or Pandatel[2], offering a narrow range of equipment products, whereas big players such as Alcatel-Lucent, Nokia-Siemens, Motorola, Ericsson adopted a strategy to expand beyond their former boundaries. In between there are numerous firms operating in a specific equipment sub-sector with a partly regional or global focus. Through international strategies, firms were not only able to enter foreign markets, but also able to seek foreign assets (both of a tangible and an intangible nature) and to build R&D, and supply and production facilities abroad. External strategic options such as M&A provide an established market position, access to existing networks and infrastructure, to a range of capabilities that they need in order to further develop both core activities and complementary activities.

While the regulatory liberalization foremost has globalized the demand for telecommunications equipment, technological developments have also created new opportunities and

[1] AVM operates in the area of PC connection through digital communication technologies such as ISDN, GSM, and xDSL technology.
[2] Pandatel is a leading manufacturer of optoelectronic components and wavelength division multiplexers.

threats for the equipment producers. The emergence of the New Economy and the introduction of new technologies such as mobile phones and broadband have forced the equipment producers to reconsider their strategy, their technological base, and their product portfolio. The technological process which is progressively blurring the boundaries between information and communications technologies has required technological diversification amongst the incumbents and opened up multiple entry options also for new players (Di Minin and Palmberg, 2006). Building on the future changes in the scope of different product markets, the convergence of various technology subfields piles up arguments of scope economies, possible market share leveraging, and network effects to motivate M&A.

In that context, the equipment producers had to make adequate adaptations to the technological changes and quickly respond to the essential technological development – often through technological acquisitions. In order to enhance or to sustain their competitive advantage M&A have, thus, aimed at providing a unique geographical coverage or a unique range of various products within and between the segments such as communication devices, public and enterprise network equipment, and system and network management that can be bundled in a single proposal.

The literature on M&A in the telecommunications industry is extensive and mostly focuses on the telecom service providers (e.g., Jamison, 1998; Kim, 2005; Le Blanc, 2002; Rosenberg, 1998; Warf, 2003). While the importance of technological innovation is widely acknowledged within this literature, it is surprising how little attention it has received in justifying M&A. At the same time, while the intense M&A activity within the telecom service providers passed its ripple effects on to the telecom equipment producers, we are not aware of any study which investigates the linkage between recent rises *both* in M&A and innovation activity in the telecommunications equipment industry.

This paper attempts to make contribution on two fronts. On the theoretical front, this paper incorporates the nature and type of innovation in which firms engage in explaining technology mergers[3] and extends the resource-based approach in elucidating external technology sourcing. On the empirical front, this paper reveals the keen reliance of the telecommunications equipment firms on mergers as a technology sourcing strategy. It further addresses important exploratory issues: first, does the innovation activity of firms depict a significant predictor of entering the merger activity? Second, how do firms that choose mergers and firms that stay outside of the merger activity differ with respect to their innovation performance? Third, the follow up question is then what are the effects of mergers on the innovative performance of firms if we control for the differences in innovation performance prior to M&A activities?

The remainder of the paper is organized as follows: Section 2 outlines the innovation rationale for merging in the telecommunications equipment industry and gives an overview of the corresponding merger cases. Section 3 develops a theoretical framework to our research questions. The empirical methodology is presented in Section 4. Section 5 provides a description of the data. In

[3] In the following sections, we use the terms mergers and acquisitions interchangeably by referring to the combined unit.

Section 6, we present and discuss empirical results and their robustness. Section 6 concludes with a summary of our findings and some implications for further research.

2. Innovation Rationale for Merging in the Telecommunications Equipment Industry

Telecommunications equipment firms seek to expand their array of activity, both in types of products offered and within geographical areas offered.[4] The combination of two sets of resources and capabilities allows firms to implement *expansion* strategies quickly and efficiently. If the merging firms are complementary, the acquiring firm is able to enter new, lucrative, fast-growing markets, coordinate its product portfolio or gain new distribution channels. For instance, the acquisition of the public telecom equipment business from Robert Bosch Telekom provided Marconi's communication division with an excellent opportunity to enter the German market.[5] Moreover, Bosch's Public Network's broadband wireless access products complemented Marconi's own range of access products. Another example of the transnational transactions was the acquisition of Phillips by AT&T.[6] Through this acquisition AT&T attained an international premier position in transmission networks, microwave transmission access, and mobile infrastructure system solutions and provided strong strategic fit with existing equipment vendors in Europe. As part of its strategic move into next generation IP carrier networking, Ericsson acquired TouchWave, Inc., a Silicon Valley based provider of enterprise IP-telephony solutions. The acquisition gave Ericsson fully featured Internet Protocol (IP) PBX systems that support with voice over IP and wireless LAN terminals, enhanced its presence in the US and targeted new distribution channels.

One of the significant trends in the industry is the separation of component suppliers that design and manufacture the specialized components from systems provider that manufacture entire pieces of equipment and equipment systems.[7] The component firms play a crucial role in supporting the communications equipment supply chain. It is at the component level that many technological breakthroughs have been achieved and enables the technologies for the system providers. Although a division of labor between systems and components manufacturing is becoming evident, component manufacturers are providing more *integrated modules* to their systems customers rather than just raw components. By incorporating the key technologies into their product portfolios, systems providers can offer the technical capabilities within their equipment which is demanded by their service provider customers. The impact of greater reliance by systems providers on their suppliers is that the latter

[4] The merger cases we describe in this section are restricted to the time period 1988-2004 which corresponds with the time frame of our empirical analysis.

[5] In its transaction in 2000, Marconi paid USD153 million, whereas most of the assets to be transferred to Marconi are located in Germany. *Case COMP/M.1800 (European Commission)*

[6] The acquisition took place in the framework of the process of restructuring of AT&T which led to the separation of the telecommunications equipment business from other groups one year later in 1997. *Case IV/M.651(European Commission)*

[7] This trend is particularly evident in the optical communications equipment sector (Merrill Lynch, 2000).

have to provide broader product lines in order to offer a greater integration role, or are impelled to provide *platform technologies*[8] that can be used to integrate discrete devices. In the optical components subfield, the most innovation driven sector, a wave of consolidation occurred led by JDS Uniphase, a manufacturer of fiber optic products and a leader in the integration of discrete components into multi-functional components and high-performance modules. Within a year, JDS Uniphase had acquired 11 optical component providers.[9] These acquisitions accelerated JDS Uniphase's ability to integrate significant technologies and associated intellectual properties into its high-value optical modules.

Given that key breakthroughs in the technology occur at the component level, systems providers seem to have adopted an integration strategy, which is to leverage the work of component suppliers and then to add value – and product differentiation – mostly through system level architecture and software. Moreover, the characteristics of the network industry also give the equipment providers an attractiveness of the merging. The firm's competitive advantage in the network industry comes from the capacity of its products to network with each other in order to form systems which are adapted to the specialized needs of individual customers.[10] *Network effects*, in context of equipment manufacturing, occur when the service provider's customers' value of equipment increases with the number of the customers using that same equipment or complementary equipment. The rise in the number of service provider customers using the equipment increases the number of complements for that equipment which in turn increases the value of the equipment. The complexity of the devices leads to two common costs in running multivendor networks: costs of learning new devices and costs of ensuring compatibility and interoperability between multiple devices (Forman and Chen, 2003). Network externalities in the router equipment sector, for example, primarily arise due to the incompleteness of compatibility of routers and switches (Tanaka and Murakami, 2003). Although all routers and switches, which fall within broad range of vendors classified as networking equipment providers[11], adopt the same interface based on the. TCP/IP protocol, the implementation of the interface depends on the vendor. Thus, compatibility within routers and switchers is not perfect among vendors. Hence, the mergers in the network industry often produce significant cost savings due to its network specifics. In some instances with significant economies of scale or when the costs of designing components to work with different systems, i.e. interoperability, are high, a merger can actually be efficient for the market – at least for the service provider customers.[12]

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[8] Platform technologies are technologies that can be used to facilitate a broad range of applications based activities. Access to appropriate platform technologies can reduce costs and avoid unnecessary duplication of facilities, increase international R&D competitiveness, and provide an environment of effective networking and collaboration.

[9] Between June 1999 and July 2000 JDS Uniphase had acquired 11 firms at a cost of US$ 60.6 billion.

[10] For more on network effects, see Katz and Shapiro (1994).

[11] i.e., data-communications equipment providers.

[12] On the other hand, the mergers in network industries can also increase the monopoly power of the dominant firm by creating significant barriers to entry as customers can be *locked-in* or tied to a particular product by significant investments into that product.

Cisco Systems – the dominant supplier in the market for networking equipments – has been attempting to create an end-to-end service network architecture by pursuing a vision "of being all things to all users." Cisco's frequent acquisitions were among others in the area of router technology, some of which specifically related to either software or ASIC[13] development which represents the two key technologies of router systems producers (Merrill Lynch, 2000). These ASICs are highly proprietary and a substantial proportion of a vendor's intellectual property is contained within them.

Such acquisitions where the merger strategy adheres to the *technology value* and the associated knowledge base are extremely important for the established equipment vendors, allowing them to adapt rapidly to the dynamic market environment. Almost all equipment sub-sectors have been prolific acquirer of technology. Examples exhibiting Cisco's[14] remarkable number of *technology acquisitions* include Granite Systems, purchased for its Gigabit Ethernet technology; Radiata, Inc., which provided Cisco with leading semiconductor technology for developing next generation wireless networks; Komodo Technology, Inc. with its technology on a smooth transition path from traditional circuit-switched networks to new packet-based networks.

Even firms that are not large-scaled but are known for their home-grown products have used external technology sources as a mean of value added innovation. Through its acquisitions of four firms within a year, ADVA Optical Networking, a German-based leading global provider of end-to-end optical networking solutions, attained access to diverse knowledge bases such as software developing in integrated access devices, a designing and manufacturing of carrier class fiber access equipment, and intelligent storage area networking gateways as well as R&D skills and expertise.[15] Each of these transactions was done purposely to gain in-depth knowledge of each technology and to strengthen the position as a provider of optical network solutions.

Acquisition of *valuable patents* in order to reassert patent portfolio has been a crucial means of technological acquisition. Acquiring Chipcom increased 3Com's granted and pending U.S. patents from 97 to 122.[16] The patents enhanced the company's innovation in diverse technology areas such as increasing network throughput, simplifying internetworking connectivity, enabling multimedia over existing Ethernet lines, and improving LAN security. Furthermore, in mobile infrastructure equipment, Qualcomm, the world leader of CDMA digital wireless technology, acquired SnapTrack Inc., a leader in wireless position location technology. Through this acquisition, Qualcomm obtained SnapTrack's

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[13] Advances in Application-Specific Integrated Circuits (ASIC) technology undertaken by router manufactures have been responsible for important improvements in router performance.

[14] With its relatively diversified product range, Cisco is unbeatable in its record of acquisitions – for instance, between 1993 and 2000 a total of 71 acquisitions took place across the equipment sub-sectors.

[15] For around a total of USD195 million, ADVA acquired Cellware Broadband (Germany), First Fibre (UK), Storage Area Network (UK) and R&D team from Siemens in Norway in 2000.

[16] With the combined innovation of the Chipcom and 3Com development teams (1995), 3Com achieved a steady stream of new patents in the following years.

patent portfolio of nearly 50 patents, either issued or pending, that are critical to the efficient, cost-effective deployment of Wireless Assisted GPS systems.[17]

Since the telecommunications equipment industry has been shaped by highly knowledge intensity, the rationale of merging activities needs to take into account technological changes which have modified the competitive and productive context of firms during the last two decades. In other words, in order to justify the desideratum of mergers as an external technology source, it is essential to attend to *the nature and type of innovation* in which firms engage and its competitive impact upon an industry.

3. Theoretical Framework

Resource-based theory seeks to bridge the gap between theories of internal organizational capabilities, on the one hand, and external competitive strategy theories, on the other hand (Barney and Clark, 2007).[18] Instead of viewing the firm as an organization to minimize production costs (production based theory), the resource-based view of the firm shifts the focus from cost- to value-consideration and views the firm as a creator of benefits (Hoffman and Schaper-Rinkel, 2001). Resource-based theory defines a firm as a bundle of resources and capabilities and argues that different firms' resources and capabilities can be a major reason for the persistent heterogeneity in a firm's performance. This approach focuses on the characteristics of valuable resources and capabilities that one firm possesses and that competitor firms find difficult to create on their own.

Resource-based theory, however, implicitly assumes that firms have the same capability in appropriating the advantages and benefits generated by a technology, or that a technology's competitive advantage can be reaped by any firm no matter whether or not the firm has the capability to assimilate and exploit it. This assumption has been adjusted by the *absorptive capacity* approach, which suggests that whether or not a firm can identify and assimilate and exploit external technologies varies among firms and even varies in the same firm over time and in different situations (Cohen and Levinthal, 1989, 1990; Lane and Lubatkin, 1998). Moreover, with their theory about the persistence of the large industrial corporation, Nelson and Winter (1982) and Mowery, Oxley, and Silverman (1996) add a cumulative dimension to the theory of the firm by exposing the organizational capabilities which are characterized by tacit knowledge and embeddedness in organizational routines. They emphasize the role of organizational differences in the firm *dynamic capabilities*, especially differences in abilities to generate and gain from innovation and define dynamic capabilities as the firm's ability to integrate, build, and reconfigure internal and external competences to address changing environments.

Following Joseph Schumpeter (1942), the literature characterizes different sets of industry conditions which affect the competitive impact of technological innovations. New-Schumpeterian

[17] In 2000, Qualcomm paid USD 1 billion in stock for the acquisition which should accelerate the introduction of powerful location-enabled mobile devices.

[18] Barney and Clark (2007) provide an in-depth survey on the resource-based theory.

authors (Utterback and Abernathy, 1975, 1978; Tushman and Anderson, 1986) have proposed a punctuated equilibrium model for analyzing the technological change process. According to this model, the evolution of technology-based organizations and industries is characterized by long periods of stability and marked by abrupt changes associated with the emergence of new technologies. Initially, the lack of a dominant design facilitates the market entry of firms and the competition among technological alternatives, usually product innovations. During the consolidation of a dominant design, the industrial structure undergoes several changes due to the firms' strategies towards standardization. After the emergence of a dominant technology, the innovative efforts of the firms in the market are, in general, process innovations, and the industrial structure enters a phase of maturity and stable equilibrium.

However, the punctuated equilibrium model does not apply to industrial settings that have been characterized as continuously chaotic, uncertain, and as "high-velocity" (Eisenhardt and Bourgeois, 1988). Instead, a punctuated disequilibrium model (Page, Wiersama, and Perry, 1989) may be more appropriate. This model assumes that in many industries, discontinuity and change is the norm; that innovation is technologically driven, and that there are no long periods of stable design convergence. Under such conditions, firms seeking technological know-how will be more likely to pursue *architectural innovation* which is triggered by a change in the linkages between core components in an established product while the core design concept behind each component remains the same (Henderson and Clark, 1990). Although there are several other dimensions on which it may be useful to define the different types of technological change, the use of the term architectural innovation enables us to identify innovations that have a more significant impact on the relationships between components than on the core technologies of the components themselves.

The telecommunications equipment industry has experienced a great amount of technological innovation as a consequence of the convergence process between information and communication technologies. The initial radical innovation was the application of integrate circuit technology to allow digital switching of telephone calls which changed the core design concepts of telephone systems. After the introduction of this radical innovation, the telecommunications equipment industry has settled on building architectural knowledge that represents learning a little about many different possible designs in contrast to learning a great deal about the dominant design (Henderson and Clark, 1990). The firms actively developed both knowledge about alternative components and knowledge of how these components can be integrated. Much of this innovation could be characterized as architectural since it has led to the reconfiguration of components and changes in the way equipment addresses a variety of user needs.

With respect to the architectural innovation prevalent in the telecommunications equipment industry, established firms often face difficulties in adapting to architectural technological change. These difficulties accrue at *identification* and *development* of architectural knowledge as well as at *application* of new architectural innovation (Henderson and Clark, 1990). In the following, we analytically examine the merger rationale according to these stages of technological evolution. Certainly, the rationales behind mergers ascribed to these stages are not mutually exclusive. It is feasible to assume that they are at least to some degree intertwined between the innovation stages.

A. Mergers for Identification of Architectural Innovation

Under conditions of uncertainty, firms face the identification problem: Firms require significant time and resources to identify a particular knowledge as architectural, since architectural innovation can often initially be accommodated within old frameworks. Since core design concept remains untouched by architectural innovation, the organization may misunderstand the nature of the threat. This is distinctive to established firms in the market or market leaders, mostly large firms by which an appropriate innovation may be screened out by the information filters and communication channels that embody old architectural knowledge. Moreover, economic models suggest that established firms have an incentive to invest in incremental innovations that add to their established knowledge base and protect or enhance their existing rent stream (Dosi, 1988; Teece, 1996). Thus, they seek to maximize the returns from known technology rather than devote resources for architectural innovations with an uncertain payoff. In contrast to incremental innovations, architectural innovations place a premium on exploration in design and the assimilation of new knowledge. Hereby, the firm's knowledge base, defined as a set of knowledge and competencies, remains a preliminary condition in the assimilation of spillovers from R&D efforts of the environment. Cohen & Levinthal (1989) and Rosenberg (1990) insist on potential synergies between the firm's own knowledge base and external flows of scientific and technical knowledge. Internal R&D activity does not only stimulate innovation, but it also enhances the firm's ability to recognize and assimilate outside knowledge. By contributing R&D to the firms' *absorptive capacity*, however, it should be noted that technological performance does not necessarily depend on past or referential performance, but rather on absorptive capacity generated in the past. In other words, firms with high absorptive capacity will exploit new ideas regardless of their past performance. For Rothaermel (2001), organizational learning motivates exploration alliances in order to build new competencies through the exploration of new technological knowledge. With the aim of discovering a new technology, *exploration mergers* may allow the acquisition of new capabilities by sharing tacit knowledge such as basic R&D related to emerging technologies.

B. Mergers for Development of Architectural Innovation

Since success in the telecommunications equipment industry turns on the synthesis of component technologies in creative new designs, firms' *innovation competence* relies on the active development of both knowledge about alternative components and knowledge of how these components can be integrated. Thereby, an ongoing internal *R&D commitment* allows the firms to not only scan the environment for component and architectural knowledge better, but it also enables the firms to evaluate complementary technology better (Veugelers, 1997). When a firm decides to acquire a technology, its own R&D operations allow it to integrate the technology better because external knowledge sources do not automatically find their way into the firm's innovation process (Cassiman and Veugelers, 2002).

Once a firm has recognized the nature of an architectural innovation, it encounters the next constraints to switch to a new mode of learning and then invest time and resources in learning about the new architecture (Henderson and Clark, 1990). Firm routines and organizational approaches that are successful in one technology paradigm do not necessarily translate into success in subsequent and other paradigms. *Organizational inertia* constraints the abilities of established firms because the structures and systems facilitate survival in stable and predictable environments become liabilities in environments undergoing rapid change (Hannan and Freeman, 1984). Since established firms focus on nurturing organizationally embedded knowledge, their emphasis on continuous improvement in such knowledge can inhibit learning new architectural knowledge, thus becoming subject to inertial forces. Such *knowledge inertia* enters into force when a firm is particularly blocked from adjusting to the market environment by their prior success in developing innovation competencies and by the fact that it must build new architectural knowledge in a context in which some of its old architectural knowledge may be relevant (Shu-hsien Liao, 2001).

In order to transfer the broad, but shallow knowledge that is particularly important for architectural innovation and, in turn, leverage existing competencies, firms may engage in *exploitation mergers* that allow them to benefit directly from the technological expertise of emergent firms which are characterized by the absence of internal forces of inertia and long-standing commitments to established value networks (Hagedoorn and Schakenraad, 1994; Rothaermel, 2001).

At the same time, the exploitation mergers enable firms to build new *upstream value chain* activities. Richman and Macher's (2004) findings from their case study analysis contribute to the framework that the successful development of new technological paradigms often requires *new and different routines* (Nelson and Winter, 1982). If a firm is unable to execute a technology strategy to accommodate to an emerging architectural innovation on its own, it may elect to acquire firms that have already begun to develop or commercialize products under a new technological paradigm. Hence, the focal firm gains access to both new technologies and the underlying routines and resources that support those technologies.

In turn, the creation and the implementation of new routines to develop and adjust to new technologies require the development of mechanisms that allow firms to constantly and consistently adapt to frequent architectural innovations. Firm's *organizational slack* resources can encourage transfer of technology (e.g., Nohria & Gulati, 1996) and provide the resources for discretionary investments such as R&D (e.g., Bourgeois, 1981). With an increasing organizational slack and through its impact on absorptive capacity, managers accept more risk and choose mergers that provide a higher degree of interaction between the involved firms and exposure to the tacit knowledge in the involved parties and great potential for knowledge transfer compared to other external R&D sources like licensing and joint venture (Steensma and Corley, 2001).

In industries like telecommunications equipment manufacturing, the responsiveness of organizational slack to exploit external knowledge flows faces considerable time constraints due to highly competitive conditions caused by short cycles of architectural innovation and to the fact that, in new product development, the strategies of telecommunications equipment firms are not always market driven - for the pursuit of innovation often involves technologies with applications that meet the future rather than present customers' demand. Given the rapid pace of innovation, firms may not have the time to develop innovations on their own if they seek to remain competitive andmay need to acquire such innovations to keep up.

C. Mergers for Application of Architectural Innovation

Once any dominant design is established, the initial set of components is refined and elaborated, and the progress takes the shape of improvements in the components within the framework of a stable architecture. The corresponding *gestation period* of technological innovation can be, however, affected by government regulations and industry standards. Long gestation periods strain capital resources of new entrants before they have successfully marketed new products. The liquidity constraints of new entrants might enhance a bargaining power of established firms, better enabling them to gain access to technological innovations of new entrants through mergers on favorable terms.

Moreover, although a technology can be architectural in the sense that it relies upon a new knowledge base and on a new production processes, it does not alter the way the new products are commercialized. Thus, if the *downstream value chain* activities of established firms retain their value, established firms may then be in a position to benefit from the new technology by undertaking mergers with emergent firms (Rothaermel, 2001; Teece, 1992). At the same time, due to a lack of strong enterprise channels, the emergent firms are less likely to have the resources to bring an invention to the marketplace. This lack of manufacturing and distributing activity can be filled by large firms which possess a greater ability to finance a large amount of R&D as well.

4. Empirical Methodology

4.1 Assessing the Merger Propensity

In the first stage of the analysis, we explore the attractiveness of telecommunications equipment firms as merger candidates by investigating the determinants of mergers. Employing a random utility model, we consider firm i's decision of whether to acquire, to be acquired, to have involvement in a pooling merger or to stay outside the merger market. The utilities associated with each of these choices k are modeled as a function of the firm's characteristics X_i which affect the utilities differently:

$$U_{ik} = X_i \beta_k + e_{ik} \quad (1)$$

While the level of utility is not observable, we can, however, infer from the firms' choices how they rank each of these alternatives. If we assume that the e_{ij} are distributed Weibull, the differences in the disturbances are distributed logistic and a multinomial logit can be used to estimate the differences in the β_k parameters.

The propensity of engaging in a merger is based on a panel that consists of innovation-related and financial variables on both merged and non-merged firms for which data were available during the 1988 to 2004 period. The probability that firm i chooses alternative k is specified as:

$$Pr(i \text{ chooses } k) = \frac{exp\left(\beta_k' X_i\right)}{\sum_l^m exp\left(\beta_l' X_i\right)} = \frac{1}{\sum_l^m exp\left[\left(\beta_l - \beta_k\right)' X_i\right]} \quad (2)$$

where $\beta_1,...,\beta_m$ are m vectors of unknown regression parameters.

An important property of the multinomial logit model is that relative probabilities are independent from each other, which is the so-called independence of irrelevant alternatives (IIA) property. In order to obtain robust standard errors of estimated coefficients, appropriate tests were conducted, which are discussed in the section 6.1.

In the following, we explain the innovation determinants of mergers captured by the empirical analysis and assess the plausibility of the merger choice. As noted before, the main prescription of the resource-based approach asserts that only resources that are valuable, rare, inimitable, and non-substitutable can be sources of competitive advantage. Due to the fact that such resources are described as intangible, rather than tangible, the research stream tends to be idiosyncratic in that previous studies focus on a very limited set of resource variables or a single firm. While such studies are beneficial, they are limited in their generalizability. By quantitatively studying resource effects across a large sample of multiple firms, the results provide generalizable findings for the resource-based approach. According to Michalisin *et al*. (1997) and Levitas and Chi (2002), this is an important need because it adds broader, more robust tests of the theory.

In this paper, we employ both tangible and intangible resources, which are quantitatively measurable, as the determinants of mergers. The innovation performance of a firm is examined with respect to the resources for its R&D commitment, R&D competence, absorptive capacity, and knowledge inertia.

R&D commitment of the firm is an important resource in driving the firm's technological development. High R&D commitment means that the firms have sufficient capabilities to mount an effective market challenge to high technology from external sourcing. To capture R&D's role in promoting technological innovation, we take the R&D intensity as a share of R&D expenditure in total assets.

The measure of *innovation competence* is in line with those of Henderson and Cockburn's (1994), who provide the concept of core competence and divide it into two critical elements of competence to be measured. While "component competence" is the locally embedded knowledge and skills, "architectural competence" is the ability to integrate the component competencies in a new and flexible way and to develop fresh component competencies as they are required. Due to the difficulty of gaining access to the intra-organizational resource-level information, we restrict the measure by the *component competence*. Since proprietary knowledge becomes a strategically important capability in high-tech firms, we use the citation-based patent intensity as a measure of component competence.

In order to account not only for the quantity but also the quality of the patented inventions, we measure the patent-based characteristics of a firm using the number of forward citations of patents. The number of citations received by any given patent is truncated in time because we only know about the citations received thus far. In other words, the number of forward citations a patent received depends on the year of the application. We, therefore, normalize the citation counts by their average value calculated over all patents belonging to the same technological sub-class whose application was filed in the same year.[19] We then weight each patent of a firm by the number of normalized citations that it subsequently received (Trajtenberg, 1990).

Knowledge inertia stemming from the use of routine problem solving procedures, stagnant knowledge sources, and an overemphasis on refining and improving existing knowledge, preventing the firm from exploring alternative knowledge sources (Shu-hsien Liao, 2001), is measured by its outcome, namely by R&D productivity. R&D productivity accounts for the extent to which R&D brings forth new knowledge and is defined as a ratio of citation-weighted patent to R&D expenditure.

In their review of the *absorptive capacity* approach, Zahra and George (2002) argue that there exist substantial differences among the dimensions of absorptive capacity – the ability to "identify, assimilate and exploit knowledge from the environment" (Cohen and Levinthal, 1989), which allow them to coexist and be measured and validated independently. According to Zahra and George (2002), the "potential absorptive capacity" enables the firms to be receptive to identification and assimilation external knowledge, while "realized absorptive capacity" reflects the firm's exploitation capability to leverage the knowledge that has been absorbed. We employ the stock of accumulated patents in order to capture the path-dependent and cumulative nature of absorptive capacity.[20] Thereby, we are able to capture the first two components of absorptive capacity directly, namely the ability *to identify* and *to assimilate* the new knowledge from mergers. The stock of accumulated knowledge of a firm is measured using citation-based patents and calculated by applying the perpetual inventory method by assuming a depreciation rate of 15 percent per annum (Hall, 1990). Hence, the individual patents in the

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[19] This is the *fixed-effects* approach proposed in Hall *et al*. (2001)

[20] Many studied used R&D intensity as a measurement of absorptive capacity. However, recent studies provide evidence that the "two faces of R&D" (Cohen and Levinthal, 1989) dominate each other in the short-run, i.e. R&D expenditures are predominantly a means of developing new knowledge and innovation rather than a means of building absorptive capacity (Schmidt, 2005).

firm's knowledge base provide the basis for comparing the firm's own knowledge base with that of other firms.

In order to control for the significant role of technology development as a rationale for engaging in mergers, we include dummy variables which indicate zero (or very low) R&D intensity and zero (citation-weighted) patent intensity.[21]

Our measure of organizational slack focuses on a firm's available and potential slack resources, which represent resources available and not yet committed for particular allocations and the future ability to generate resources, respectively. Geiger & Cashen (2002) highlight the role of organizational slack as an important condition that facilitates innovation adoption and, thus, contributes to a firm's innovativeness.[22] In keeping with previous studies (e.g., Singh, 1986; Bromiley, 1991), we rely on accounting data and measure the available slack using the ratio of cash flow to total assets and the potential slack using Tobin's *q*. In financial terms, the cash flow ratio represents the financial capabilities of firms and amounts for funds available to a firm for operations, investments, and acquisitions. We approximate Tobin's *q* by calculating the ratio of the market value to the book value of a firm's assets, where the former is the sum of the book value of long-term debt and the market value of common equity. Being a forward looking indicator, a high value of *q* suggests favorable growth opportunities (e.g., Gugler *et al*., 2004).

Besides the large firms, the relatively small firms in the telecommunications equipment industry have often become public entity.[23] Given the evidence that firms that innovate receive a market premium over similar firms that do not innovate (e.g., Chaney, Devinney, and Winer, 1991), firms with growing market value may appear to be likely acquisition targets or merger partners for mature firms looking to absorb growth opportunities. Firm size and firm growth are measured by the book value of total assets and the annual growth rate of the market value, respectively. All monetary values are deflated by a price index for communications equipment manufacturing based on the 1999 price.[24]

4.2 Assessing the Merger Impact

In the second stage of the analysis, we investigate the effect of mergers on the innovation performance of the firms. Given the high degree of architectural innovation affecting the telecommunications

[21] For the firms with missing R&D intensity over time, we set the R&D intensity equal to zero. Indeed, the manual inspection of the observations with missing values indicates that the missing R&D values belong entirely to that part of the relative small firms that provide low or no R&D activity.

[22] Geiger & Cashen (2002) investigate the different dimensions of slack and find available slack to have an inverted U-shaped relationship with innovation adoption, while potential slack has a linear positive relationship to innovation adoption.

[23] This trend is reasoned by the fact that becoming an independent public entity provides smaller firms with stock options which are essential for retaining high labor skills and that market valuations for independent component firms are much higher than for those that closely depend on the parent firms (Merrill Lynch, 2000).

[24] Moreover, all covariates in the regressions have been lagged by one year in order to avoid potential endogeneity problems as well as possible biases arising from different merger accounting methods and financial statement consolidation.

equipment industry, we expect that successful equipment firms take advantage of technological mergers to enhance their innovation position and performance. Mergers may extend the technological base of firms involved, allowing them to achieve greater economies of scale and scope in R&D through more efficient deployment of knowledge resources. That is, mergers may enlarge the overall R&D budget of firms engaged, which then enables them to tackle larger R&D projects and, thereby, this spreads the risk of innovation. Furthermore, since in fast moving markets with abbreviated product life cycles, the uncertainty and the risk of investing in unproven technologies are often shouldered by outside investors, the merger insiders may involve greater incentives to invest in R&D after the acquiring of an auspicious technology.

Greater R&D commitment, however, does not guarantee per se that the firms will have higher levels of innovation competence with respect to patent intensity, especially if mergers undertaken have low knowledge and technology complementarity with the firms involved. Therefore, the integration of complementary knowledge and technology may increase innovation output through mergers leading to more advanced technologies being developed (e.g., Gerpott, 1995).

If technology is playing an important role in the external knowledge acquisition strategy, then firms undertaking mergers, while at the same time acquiring patents, will renew and enhance their path-dependent absorptive capacity in terms of accumulated patent portfolio.

Given the difficulties faced by the development of architectural innovation, we expect that technological mergers are used to overcome the knowledge inertia and the lack of competitive innovation competence as well. At the same time, however, the organizational obstacles faced in mergers with regard to the larger R&D departments as well as the miscarried and inappropriate integration of the technology-based firms (Duysters and Hagedoorn, 2000) may diminish the marginal returns from R&D investment in their extent and speed.

In addition, the overall performance of the merged firms will be analyzed by means of firm size, market value, cash-flow ratio, and Tobin's *q*. Being the measures of growth opportunities and financial capability of a firm, Tobin's *q* and cash flow give an indication to the financing type of a merger. The first stage estimates may enable us to indicate whether a merger is financed by stock and/or debt or internally generated resources like cash flow. In particular, if firms with higher Tobin's *q* are more likely to engage in mergers, then we predict that an average merger is financed through stock instead of cash, which may lead to a decreasing post-merger Tobin's *q*. The findings from studies on the firms' post-merger performance show that, in the long-run, stock acquirers perform poorly compared to cash acquirers and matching firms that do not merge (e.g., Loughran and Vijh, 1997)[25].

Most studies investigate the impact of a merger on the market value of a firm by limiting the scope of a study to the around days of the merger announcement and, thus, ignoring the contemporaneous impact of innovation as well. Given the evidence that a continued emphasis on R&D

[25] Loughran and Vijh (1997) analyze the excess return for the five-year period after the acquisition.

and an introduction of new products (positively) affect the market value of firms in the technologically based industries (e.g., Pakes, 1985; Chaney, Devinney, and Winer, 1991) and in order to capture both coexisting effects of technological mergers and their innovation value on the firm's market value, we consider the long-run effect similar to the other performance determinants as described in Section 6.2.

Our analysis of the effects of mergers controls for endogeneity and ex-ante observable firm characteristics using a propensity score method (Dehejia and Wahba, 2002). Controlling for the differences in the merged and non-merged firms' performances prior to the merger, we estimate the firms' post-merger innovation performance compared to what they would have in the absence of the merger.

For each firm i in the sample, let M_i be a merger indicator that equals one when the firm engages in a merger and zero otherwise. We denote Y_{i1} as the innovation performance of merging and Y_{i0} as the innovation performance of non-merging firms and observe M_i and, hence, $Y_i = M_i \cdot Y_{i1} + (1 - M_i) \cdot Y_{i0}$. Accordingly, let $E\left[Y_{i1} \middle| M_i = 1\right]$ and $E\left[Y_{i0} \middle| M_i = 0\right]$ denote average outcomes of the technological performances of merged and non-merged firms, respectively. The effect we are interested in is that of the merger on the technological performance of the merged firms, or the difference between the expected innovative performances of the merged firms and the firms that would have experienced if they did not merge:

$$\tau\Big|_{M_i=1} = E\left[Y_{i1} \middle| M_i = 1\right] - E\left[Y_{i0} \middle| M_i = 1\right] \tag{3}$$

This denotes the expected treatment effect on the treated. Since we do not have the counterfactual evidence of what would have happened if a firm had not engaged in a merger, $E\left[Y_{i0} \middle| M_i = 1\right]$ is unobservable. However, it can be estimated by $E\left[Y_{i0} \middle| M_i = 0\right]$ and the effect can be then given by the difference in the average outcome between the merged and non-merged innovative performances:

$$\tau^e = E\left[Y_{i1} \middle| M_i = 1\right] - E\left[Y_{i0} \middle| M_i = 0\right] \tag{4}$$

In fact, we have observations of the firms that did not engage in a merger, but if the merged and the non-merged firms systematically differ in their firm characteristics, (4) will be a biased estimator of (3) (Hirano *et al*., 2002).

Rubin (1997) and Rosenbaum and Rubin (1983, 1984) showed that a propensity score analysis of observational data can be used to create groups of treated and control units that have similar characteristics, whereby comparisons can be made within these matched groups. In these groups, there are firms that have been merged and firms that have not been merged; hence, the allocation of the merger can be considered to be random inside the groups of firms.

The merger propensity score is defined as the conditional probability of engaging in a merger given a set of observed covariates X_i:

$$p\left(M_i\right) = \Pr\left(M_i = 1 \middle| X_i\right) = E\left[M_i \middle| X_i\right] \quad (5)$$

The treatment effect of a merger is then estimated as the expectation of the conditional effects over the distribution of the propensity score in the merged sample:

$$\tau\Big|_{M_i=1} = E_{p(M_i)}\left\{E\left[Y_{i1}\middle| p\left(M_i\right), M_i = 1\right] - E\left[Y_{i0}\middle| p\left(M_i\right), M_i = 0\right] \middle| M_i = 1\right\} \quad (6)$$

The propensity score matching relies on two key assumptions (Rosenbaum and Rubin, 1983, 1984). The first, conditional independence assumption (CIA) requires that conditional on the propensity score potential outcomes are independent of treatment assignment. The CIA assumes that selection into treatment occurs only on observable characteristics. Hence, unbiased treatment effect estimates are obtained when we have controlled for all relevant covariates. The second assumption is the common support or overlap condition, meaning that firms must have a positive probability of being either merger or non-merger rather than just having same covariate values. In sum, the propensity score matching relies on the "strong ignorability" assumption, which implies that for common values of covariates, the choice of treatment is not based on the benefits of alternative treatments.

5 Data

In order to examine the interaction between merger and innovation activity, a new firm-level data set is constructed which covers the overwhelming majority of firms in the telecommunications equipment industry that operated in any year over the 18-yearperiod, 1987 to 2004 (including lagged periods). This data set is created by a complex matching process of information from initially four separate databases.

We define the telecommunications equipment firms as those which have primary activity in the communications equipment Standard International Codes (SIC) 3661, 3663, or 3669. The population of firms and their financial information including R&D expenditures were drawn from Compustat and Global Vantage databases. After eliminating firms with missing financial information, we can identify a sample of 638 telecommunications equipment firms for those data on R&D expenditures, total assets, market value, cash flow, and long-term debt.

The patent statistics for the telecommunications equipment industry are based on the database which is compiled by the National Bureau of Economic Research (NBER, Hall *et al.*, 2001). This database comprises detailed information on all US patents granted between 1963 and 2002 and all patent citations made between 1975 and 2002. The patent and citations data were procured originally from the US Patent Office and from Derwent Information Services, respectively. Although this US data could imply a bias in favor of US firms and against non-US firms, the group of non-US firms in this sample represents a group of innovative and rather large firms that are known to patent worldwide. Our data set includes information on the patent number, the application and grant dates, the detailed technology field(s) of the innovation, the name(s) of the inventors, the city and state from which the patent was filed, and citations of prior patents on which the current work builds. We include the patents for which firms applied in twelve main classes of the International Patent Classification (IPC) 178, 333, 340, 342, 343, 358, 367, 370, 375, 379, 385, or 455 - in the category communication equipment. As the distribution of the value of patented innovations is extremely skewed, we also consider the number of forward citations as an indicator of the importance or the value of innovations for each patent, thereby overcoming the limitations of simple counts (Brouwer and Kleinknecht, 1999; Griliches, 1990; Hall, 2001). During the observed period, 251 firms from our sample applied for a total of 11,226 patents in communication equipment (including multiple applications by the same firm in the same year and for the whole period); this produces a total of 86,442 citations.[26]

M&A transaction data were obtained from the Thomson One Banker-Deals database. Updated daily, this database offers detailed information on merger transactions including target and acquirer profiles, deal terms, financial and legal advisor assignments, deal value and deal status. This database includes alliances with a deal value of more than 1 million USD, thus ensuring that the overwhelming majority of mergers are covered. Our initial sample on merger transactions contains information on 364 completed deals (including multiple deals by the same firm in the same year and during the observed period) carried out by 178 firms and announced during the period from 1987 to 2004. Using information from the data source, we distinguished between the role that a firm played in a M&A transaction and classified the firms in our sample in general as an acquirer, a target, or a partner in a pooling merger. While 84.8 per cent of the merger firms took part up to three times in a merger, we can observe that the merger activity of the telecommunications equipment industry is characterized by the transactions of certain firms.[27] For our econometric analysis, we restrict the multiple transactions carried out by one firm in the same year to the largest transaction only.[28] Finally, the estimation sample consists of total 302 M&A transactions, which involve 186 acquirer, 22 targets[29], and 94 partners in pooling mergers.

[26] The data set is truncated which might cause a downward bias in the citation counts of recent patents.

[27] For instance, the large-scale firms such as Ericsson, Siemens, Cisco, Motorola, and Alcatel carried out 17.86 percent of the total merger transactions.

[28] The frequency of merger transactions carried out by one firm in the same year is as follows: 294 firms with one deal, 44 firms with two deals, six firms with three deals, and three firms with four deals in a given year during the sample period.

[29] We lack accounting data on the target firms for transactions that involve the acquisitions mostly of privately held and/or relatively small firms that are not operated in the US and not listed in Global Vantage.

The databases were matched through the matching algorithm on the basis of firm names, CUSIP numbers[30], and address information provided by each database. The firms that are lacking information or have inadequate data on the matching procedure were cross-checked and completed with information reported in the Dun & Bradstreet's "Who owns whom" annual issues.

6 Empirical Results and Discussion

6.1 Pre-Merger Innovation Performance

In this section, we examine the merger decision of the telecommunications equipment firms in a multivariate analysis. Summary statistics of the variables and their correlations are shown in Table 1.

INSERT TABLE 1 ABOUT HERE

Given that both merging and non-merging firms are included in the sample, we can distinguish between the characteristics of merging firms in transaction events and the firms outside of the merger market. Table 2 presents the t-statistics on the differences in means of the firms' characteristics separately for merged and non-merged firms. Merged and non-merged firms in the sample suggest significant differences in the observed characteristics. Firms that actually merged are characterized by a greater knowledge stock expressed in accumulated intellectual property rights than firms that did not merge. In terms of total assets, there is a significant size difference between merged and non-merged firms, thus showing that larger firms are more likely to acquire. The merged firms had, on average, a larger Tobin's *q* and cash-flow ratio, and they were less likely to have missing R&D values and zero (citation-weighted) patent intensity. The firms in our sample do not differ significantly in their R&D and (citation-weighted) patent intensity as well as research productivity prior to a merger.

INSERT TABLE 2 ABOUT HERE

Equation (2) is estimated using a multinomial logit model with four outcomes: to be an acquirer, to be acquired, to be a pooling merger, or to be not involved in a merger. There are substantial drawbacks associated with the use of the multinomial logit estimation because it assumes that the disturbances are independent across alternatives. This assumption suggests that if a firm was choosing between the four alternatives, then there is no relationship between a firm's disturbances for being an acquirer, a target, a partner in a pooling merger, or no involvement in a merger. In the context of this analysis, it is likely that merger behavior will not fulfill this requirement. The test of the

[30] CUSIP stands for Committee on Uniform Securities Identification Procedures.

maintained assumption of independence of irrelevant alternatives (IIA) will indicate whether the ratio of probabilities of any two alternatives is entirely unaffected by the systematic utilities of any other alternatives. In order to examine how the estimation results are affected by this property, four Hausman's specification tests (Hausman, 1978) were conducted. The results from multinomial logit are compared with those from binomial logits between the non-merged firms sample and each of the samples of acquiring, acquired, and pooling merged firms as well as between acquirer and pooling merger samples. The *p*-values associated with the resulting test statistics were .88, .93, .76, and .67, respectively. Therefore, the null hypotheses are not rejected each which implies that the IIA assumption is not violated. Furthermore, the results of the binomial logit regressions were almost identical to those of multinomial logit model which is comforting as it substantiates that the independence assumption is not a concern in our analysis and that we obtain robust estimates of the variance of coefficients.

Table 3 presents the marginal effects for the multinomial logit regression. The statistics for the joint hypothesis and likelihood ratio tests are also reported. All estimated models are highly significant as indicated by the likelihood ratio tests of the null hypothesis that the slope coefficients are jointly zero, which are rejected at the 1 percent level using the chi-square test statistic. However, the results of the target probability regression show a lack of preciseness due to the variation among the small sample of target firms. While the coefficient estimates of the target probability model, which are not reported here, provide significance on some few independent variables, the marginal effects do not provide any significant results on the target probability. In order to account for the significant coefficient estimates of the target probability, the marginal effects of the target probability model are reported in Table 3 in line with the marginal effects of other probability estimations.31

INSERT TABLE 3 ABOUT HERE

The results indicate that merging firms as a whole seem to have, on average, a significantly different innovation profile compared to that of non-merging firms. Firms with greater R&D intensity have a significantly greater propensity to undertake acquisitions. A one standard deviation increase in a firm's R&D intensity is associated with a .75 percentage point increase in the likelihood of acquiring another firm, which corresponds to a 10.73 percent propensity increase.[32] We also obtain a significantly negative coefficient of the determinant for zero (or very low) R&D intensity. Therefore, the acquirers are more likely to have non zero R&D commitment in the year before the merger. At the same time, the non-merging firms tend to have more frequent zero R&D intensity than merging firms. A nearly 20 percent increase in the absence of R&D commitment (which corresponds to a one standard deviation) increases the propensity of *not* being involved in mergers by almost 91 percent.

[31] In Table 3, we denote the corresponding significance in parentheses.

[32] The mean predicted probability to acquire in a particular year is .07 (Table 4).

We find evidence in our data that the most internally R&D-committed firms are most likely to seek technological advancement in the acquisition market.

The estimated marginal effects on innovation competence, which is measured by (citation-based) patent intensity, provide quite significantly different results on being an acquirer and being a partner in a pooling merger. Firms with greater patent intensities are more likely to be an acquirer, whereas firms with smaller patent intensities are more likely to be a partner in a pooling merger. Hence, a decline in innovation competence seems to be the driving force behind the merger activity. The indicator for zero patent intensity has, somewhat surprisingly, an insignificant impact on the propensity of merger activity.

The merging firms are more likely to have a large accumulated citation-based patent stock. This evidence seems to be in accordance with the theoretical argument that a large stock of accumulated knowledge is essential if the acquirer (or one partner in a pooling merger) is to have the necessary absorptive capacity to identify the appropriate target (or another partner in a pooling merger). The fact that firms with a rather low accumulated knowledge stock are less likely to engage in a merger supports this evidence. Moreover, the coefficient estimates of the multinomial logit model, which are not reported here, indicate that the acquisition targets possess a significantly larger accumulated knowledge stock than the non-merged firms. These results mutually support the hypothesis that higher levels of absorptive capacity and the strengthening of its creation on the part of research-focused firms are necessary for those firms to identify and assimilate new knowledge and innovation into their R&D programs effectively. Consequently, by embodying the "potential absorptive capacity," the merging firms provide a crucial fundament for conducting the "realized absorptive capacity," i.e. the ability to exploit the knowledge from external sourcing, which is a primary source of performance improvement analyzed in the next section.

Given the R&D and citation-based patent intensities, we find that the likelihood of becoming an acquirer is higher with a lower R&D productivity of firms. Although the acquiring firms experienced higher input and output in R&D, they seem to carry either a low number of patents and/or a relatively low-valued patents yield of R&D dollars before acquisitions. This result suggests that there exists an enhanced desire to acquire new technology and innovation-related assets driven by knowledge inertia from the exploitation of the firms' existing knowledge base. However, the patent intensity of the target firms provides insignificant results on both coefficient estimate and marginal effect of the propensity to be acquired. We will come back to this point as some predications regarding the target firms' pre-merger performance can be derived from the next step of our analysis.

Another interesting result is that firms with a poor absorptive capacity and, at the same time presenting higher innovation competence, tend not to engage in mergers. We ascribe these firms to be relatively young and with significantly new know-how. The negative effect of the firm size on the propensity to stay outside of the merger activity also points toward that direction.

Considering the results for the control variables, larger firms, as measured by the book value of total assets, are more likely to engage in merger activity. This suggests that large firms are more willing to make use of their large and more stable internal funds to sourcing external R&D projects. A 100 percent increase in a firm's total assets yields .026 (.031) percentage point increase (decrease) in the likelihood of acquiring another firm (staying outside the acquisition), which is a 37.14 (.034) percent increase (decrease) in the predicted probability.[33] The estimated coefficient of the target firms' size exerts a significantly negative impact on the propensity to be acquired, suggesting that smaller firms are likely to be acquired. In addition, the annual growth of market valuation in the pre-merger year seems not to be conducive for a merger event, at least for the acquirer firms.

In terms of slack resources, the significantly positive effect of the cash flow ratio on the likelihood to acquire another firm suggests that acquiring firms have considerable cash to run a larger firm and agency controls are imperfect. According to Geiger and Cashen (2002), possessing the ability of the available slack tends to precipitate the technological acquisitions. At the same time, firms with a relatively low cash flow ratio tend not to engage in a merger (although statistically significant only at 10 percent level) due to their financial constraints. Thus, either imperfect agency concerns or availability of financing are significant constraints on acquisitions. Consistent with Wiseman and Bromiley (1996), if firms have little slackness, they tend to be risk averse and will choose external technology sourcing other than the acquisitions, which require less slack resource commitments.

On the one hand, given the claims that the most important currency in making the acquisitions in the telecommunications equipment industry has been the offer of highly-valued stock34 and, on the other hand, given the proposition that the acquisition financing through stock options is presupposed by higher investment opportunities in terms of Tobin's *q*, the insignificant Tobin's *q* in the likelihood to acquire is somewhat surprising. We, thus, find an indication that an average merger is more likely to draw upon the cash financing rather than the stock financing.

The potential slack measured by Tobin's *q* seems not to be a significant determinant for the explaining the technological mergers. Growth opportunities are not likely to be of primary priority for firms engaging and for firms outside the merger activity. Moreover, the significant result on the marginal effect of the control for zero (or very low) R&D intensity confirms further that the mergers in the telecommunications equipment industry are to a greater extent caught up in the technological drive. Thus, by the mergers of the equipment producers, the value of growth opportunities is overweighted by the technological value.

6.2 Post-Merger Innovation Performance

[33] The probabilities to be an acquirer and not to be acquired in a particular year are .07 and .8999, respectively (Table 4).

[34] For instance, Cisco is widely known as a permanent stock-acquirer.

We estimate the average treatment effect on the treated by employing stratification matching. Implementing the matching requires choosing a set of variables that satisfy the plausibility of the CIA. This implies that only variables that simultaneously influence the merger decision and the outcome variable(s) should be included. The firm's innovation performance is defined by the annual growth rates of innovation input and output, knowledge stock, and research productivity. In addition, the determinants of the firm's overall performance included the annual growth rates of firm's size, market value, Tobin's *q,* and cash flow ratio. In order to derive the merger propensity score, we estimate the logit model of equation (2) with the annual changes of the determinants of innovation and overall performances.

In order to check the common support region, we compare the maximum and minimum propensity scores in the merged and non-merged groups. That is, we discard all observations that have a propensity score smaller than the minimum and larger than the maximum in the opposite group. As a consequence, any observations lying outside the region of common support given by [0.0072, 0.6101] are excluded. Almost 42.6 percent of non-merged firms have a propensity score below 0.1, while 7.3 percent of merged firms have the same low propensity scores.[35] Since the number of treated firms lost due to common support requirement amounts up to 3 percent of the treated group and there are still comparable control firms to remaining treated firms[36], there is a good overlap in the estimated propensities scores for merged and non-merged firms in the sample.

The data in the region of propensity score overlap were sub-classified into five blocks defined by the quintiles of the propensity scores for merged firms.[37] To check for the adequacy of the propensity score model, we then used a two-way ANOVA to assess whether the propensity score balances each covariate between the merged and non-merged groups of firms. Each covariate is regressed on the merger and the propensity score stratum indicator and their interaction as factors. The insignificant effects of mergers and insignificant effects of the interaction between propensity score stratum and merger indicators determine that the distributions of the covariates within the sub-classes are the same for merged and non-merged firms.[38] The results of T-tests on the differences in outcome means across both groups after the stratification matching are shown in Table 4. The balance in covariates of merged and non-merged firms assures an unbiased estimate of the effect of a merger on the innovation performance (Dehejia and Wahba, 1990).

INSERT TABLE 4 ABOUT HERE

[35] Rosenbaum (1984) argues that a low propensity score below 0.1 percent is not uncommon in distributions of propensity score estimates even for treatment observations.

[36] While the removed 3 percent of the merged firms involve larger firms, the removed 58 percent of the non-merged firms are rather heterogeneous in their firm size measured in total assets.

[37] Five sub-classes (quintiles) constructed from the propensity scores will often suffice to remove over 90 percent of the selection bias due to each of the covariates (Rosenbaum and Rubin, 1984).

[38] Before sub-classification, we found significant effects of mergers on more covariates using one-way ANOVA.

Since the full impact of mergers on the innovation performance takes time and results may not be evident immediately, we examine the impact of a merger in year *t* on the change in outcomes from *t+1* to *t+2*, *t+2* to *t+3*, and *t+3* to *t+4* in order to capture the long-run post-merger performance.[39]

A number of interesting insights emerge from the review of the estimates on the effects of mergers on innovation performance in Table 5. The impact of mergers appears to be more concentrated in the first year following a merger in *t*, where the annual changes from *t+1* to *t+2* are estimated. Herein, stronger results are obtained for our main variables which more strictly explain the firm's innovation performance.

INSERT TABLE 5 ABOUT HERE

We find that mergers are followed by an improvement in the accumulated citation-based patent stock. In addition to the partners in a pooling merger who possessed a large accumulated knowledge stock prior a merger, the acquisition targets also tend to be firms with highly valued patent stock. This result is in accordance with our prediction that accumulated knowledge stock confers an ability to recognize and to assimilate the new knowledge and technology in an environment and this ability seems to enhance the technological strengths even further. Hence, by embodying the "potential absorptive capacity," the merging firms provide a crucial fundament for the conducting the "realized absorptive capacity" (which we cannot measure in this study), i.e. the ability to exploit the knowledge from external sourcing, which is a primary source of performance improvement.

The annual change in R&D intensity displays a significantly positive sign in all three years following a merger. Hence, according to our previous result from the first stage of the analysis, this indicates that the strong R&D commitment of acquiring firms positively influences the recognition and the assimilation of the external knowledge by supplementing in-house R&D effort. Moreover, it suggests that the mergers increase scale and scope of R&D activity rather than depreciate the investments in R&D on behalf of financing the transaction.

The merged firms experience a significantly positive impact on the citation-based patent intensity compared to those outcomes that these firms would have reached if they did not merge. Due to the fact that the acquiring firms had a higher citation-based patent intensity prior to the acquisitions, this effect suggests that an intensification of high-valued patent creation relative to the firm's assets base prior to an acquisition generates a significantly higher innovation output of the merged entity. Additionally, the pooling partners who faced some absence of innovation competence in terms of the innovation output seem to grow following a merger, potentially because the merger provided access to complementary technological resources which the single firms previously lacked. This result is in

[39] We cannot compare pre- and post-merger performance of merged firms with the matched sample of non-merging firms over the same time period because we lack pre-merger accounting data for one component of the merged entity for a significant fraction of our mergers.

accordance with Cassiman *et al.* (2005)[40] who find from the merger case study that the merging firms with complementary technologies and close market relatedness result in more R&D output.

Furthermore, the insignificant result on the post-merger research productivity suggests that the marginal returns from R&D investments do not change with respect to the innovation output. Thus, greater R&D and patent intensities compared to what the firms would reach in the absence of merger do not result in higher R&D productivity. From this result, we cannot argue that the knowledge inertia faced by the acquiring firms before the merger is still existent since we cannot compare pre- and post-merger performance. However, even the post-merger R&D productivity is higher than prior to the merger; the non-merged firms possess still effective deployment of their R&D resources, so that there is no significant difference between the treated and non-treated groups. Furthermore, one point to note is that the estimation of the R&D productivity goes along with a large variance, which may be the reason for the insignificant result.

The impact on the determinants of the firm's overall performance is generally as expected. There is a firm's size growth with respect to the annual change in total assets as typically expected. According to the indication from the first stage of the estimation that the mergers, on average, are more likely to be financed through cash rather than by stock and/or debt, the cash flow ratio is decreasing after the mergers, yet it is insignificant. At the same time, merged and non-merged firms do not significantly differ in their Tobin's *q*, at least for the observation period.

The significant positive increase in the annual growth of the market value confirms that, in the first full year following a merger, overall returns for shareholders are above those of the non-merged firms with similar characteristics. This result is consistent with the evidence that the cash-financed mergers perform better with regard to the market value than non-merged firms with similar characteristics (e.g., Loughran and Vijh, 1997). Moreover, being the simultaneous impact of merger transaction and innovation, the increase in the merged firms' market value does suggest that the technological mergers occurred in the telecommunications equipment industry resulted in the enhanced innovation performance.

6.3 Sensitivity Analysis

CIA assumes that the effects of casual merger are not influenced by any correlation between unobserved factors and a firm's selection into casual merger. Hence, the treatment effect estimators are not robust against "hidden bias" if unobserved factors like managerial skills and technological shocks that affect the merger are also correlated with the outcomes. After adjusting for selection bias due to non-overlapping support and discrepancies in the distribution between merged and non-merged firms, the purpose of sensitivity analysis is to determine whether or not inference about treatment

[40] By focusing on the role of technological- and market-relatedness, Cassiman *et al.* (2005) analyzed the effect of M&A on the R&D process of 31 merger cases from medium and high-tech industries.

effects may be altered by unobservable variables in order to undermine our conclusions of matching analysis. While it is not possible to estimate the magnitude of selection bias with non-experimental data, the bounding approach proposed by Rosenbaum (2002) does provide a way of judging how strongly an unmeasured confounding variable must affect the selection process.

If we let u_i be an unmeasured covariate that affects the probability p_i of a firm *i* of selecting into the treatment and x_i are the observed covariates that determine treatment and outcome variable, then treatment assignment can be described by log odds as

$$log\left(\frac{p_i}{1-p_i}\right)=k\left(x_i\right)+\gamma u_i \qquad (7)$$

where $0 \le u_i \le 1$.

Rosenbaum (2002) shows that this relationship implies the following bounds on the odds ratio between treated *i* and control *j* units which are matched on the propensity score *P(x)*

$$\frac{1}{\Gamma} \le \frac{p_i\left(1-p_j\right)}{p_j\left(1-p_i\right)} \le \Gamma \qquad (8)$$

where $\Gamma = exp\left(\gamma\left(u_i - u_j\right)\right)$.

Because of the bounds on *u*, a given value of γ measures the degree to which the difference between selection probabilities can be a result of hidden bias. $\gamma = 1$ and, accordingly, $\Gamma = 1$ imply that both matched firms have the same probability of engaging in a merger and, thus, hidden bias does not exist. Increasing values of Γ simulate an increased influence of unobservables on the selection decision. If a large value of Γ does alter inferences about the merger effect, the results are sensitive to potential selection bias.

We adopt Becker and Caliendo’s (2007) procedure for bounding treatment effect estimates for binary outcomes and define new outcome variables which take the binary values according to the annual growth of performance outcomes.[41]

INSERT TABLE 6 ABOUT HERE

Table 6 contains the results of the sensitivity analysis for the significant effects of the mergers on the annual growth of the firms’ innovation input and output and knowledge stock in the first year following a merger. It displays the Mantel and Haenszel (1959) test statistics for the averaged treatment effect on the treated while setting the level of hidden bias to a certain value Γ. The MH test statistics is used to test the null hypothesis of no merger effect and for each assumed Γ, a

[41] Stata procedure *mhbounds* (Becker and Galiendo, 2007) has been applied, which is implemented for the case of binary outcome variables. We define an outcome variable taking the value 1 if a firm had a positive annual growth and 0 otherwise.

hypothetical significance level "p-critical" is calculated, which represents the bound on the significance level of the treatment effect in the case of endogenous self-selection into treatment.

Given the positive estimated treatment effects and, thus, looking at the bounds under the assumption that we have potentially overestimated the true treatment effects, the results indicate that the robustness with respect to hidden bias varies across the outcome variables.[42] Under the assumption of no hidden bias ($e^{\gamma} = 1$), the MH test statistics provide a similar result suggesting significant merger effects. The finding of a positive effect of mergers on the patent intensity is at least robust to the possible presence of selection bias. The critical value of e^{γ} is 1.20, indicating that firms with the same observable characteristics differ in their odds of treatment by 20 percent. Next, the critical value of e^{γ} at which we would have to question our conclusion of a positive effect on the R&D intensity is between 1.40 and 1.60. However, the Rosenbaum bounds are worst-case scenarios. Hence, a critical value of 1.40 does not mean that unobserved heterogeneity exists, and there is no merger effect on the innovation input. This result means that the confidence interval for the R&D intensity effect would include zero if the odds ratio of treatment assignment differs between the merged and non-merged firms by 1.40 due to an unobserved variable. Furthermore, the effect on the knowledge stock remains significantly positive even in the presence of a substantially unobserved bias by a factor of 2. This result implies that if an unobserved variable caused the odds ratio of merging to differ between the merged and non-merged firms by a factor of as much as 2, the 90 percent confidence interval would still exclude zero. Thus, the positive estimated effects on the firm's innovation input and knowledge stock are robust to the unobserved heterogeneity, while the positive effect on the patenting intensity is less so.

7 Conclusions

The emergence of architectural innovations that require new structural relationships create difficulties for firms that have well-established routines based on earlier technological paradigms. Consequently, architectural innovation to develop products in order to meet the specialized needs of customers has been an important underlying factor for the external knowledge acquisition strategies of many telecommunications equipment firms.

This paper delivers insights into the desirability of M&A for the innovation performance of firms by analyzing the mergers that took place in the international telecommunications equipment industry from 1988 until 2004. We find evidence that mergers realize a significant growth in the innovation performance of firms. The post-merger innovation performance is, in turn, driven by both the success of in-house R&D commitment and the weakness of internal technological capabilities at acquiring firms prior to a merger. In particular, we find that the telecommunications equipment firms

[42] The significance levels p^{+} calculated under assumption of overestimation treatment effect are presented.

undertake M&A in order to reassert their R&D commitment and patent program through strengthening scale and scope in R&D, and, thereby, their market position. The equipment manufacturers that experienced low research productivity from ongoing exploitation of R&D efforts in the past are forced to explore potential future innovation trajectories in complementary technologies by acquisitions, whereas those firms with a declining inventive portfolio are involved in pooling mergers to offer comprehensive and integrated equipment solutions. Although mergers allow the equipment firms to revitalize a firm by enhancing and supplementing its knowledge and technology base, they do not foster, on average, a higher level of R&D productivity.

While the time frame this paper analyzes is shaped primarily by technological M&A, the recent market trend in the telecommunications industry is reshaping the equipment M&A. On the one hand, the reduction in the number of service providers through consolidations[43] drives the equipment manufactures to ramp up their size. On the other hand, unlike the past where the telecommunications service providers purchased nearly all new technology in network-based applications from equipment producers, they are increasingly looking towards the emerging Next Generation Network. The service providers' investment is bound to increase in the Internet technology adoption. This investment shift tends to force the equipment producers into survival M&A.[44] At the same time, the increasing converge of enterprise and wide area network markets drives the equipment producers to expand into each traditional market segment through technology M&A. Further research into the linkage between survival and technological M&A as attempts to challenge the emerging Next Generation Network should yield additional important insights.

[43] e.g., acquisition of MCI by Verizon and merger of AT&T/Bell-South/Cingular in 2006
[44] e.g., merger of Alcatel/Lucent in 2006 and Nokia/Siemens in 2007

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Table 1. Descriptive Statistics and Correlation Matrix (n = 9,570 firm-years)

	Variables	Mean	Std. Dev.	1	2	3	4	5	6	7	8
1	R&D Intensity	0.115	0.336	1.000							
2	Patent Intensity	0.019	0.097	0.100	1.000						
3	Patent Stock (Ln)	1.441	1.504	0.106	0.117	1.000					
4	R&D Productivity	0.237	1.194	-0.085	0.667	0.086	1.000				
5	Total Assets (Ln)	4.001	2.120	-0.379	-0.229	0.500	-0.166	1.000			
6	Market Value Growth (Ln)	1.519	3.236	-0.008	0.000	0.011	-0.000	-0.022	1.000		
7	Tobin's *q*	2.091	3.259	0.205	0.103	0.070	0.046	-0.030	0.262	1.000	
8	Cash-Flow Ratio	-0.162	1.460	0.574	-0.062	0.118	0.036	0.278	0.065	-0.023	1.000

Notes: The figures refer to the sample used for the estimation of the multinomial logit model (Table 3). Table cells for variables 1-8 contain the correlations between the variables.

Table 2. Merged versus Non-Merged Firms before Matching

	Mean (Standard Error)		t-statistic for difference in means
	Merged Firms	Non-Merged Firms	
R&D Intensity	0.105	0.115	0.48
	(0.005)	(0.005)	
Patent Intensity	0.014	0.020	
	(0.003)	(0.001)	0.85
Patent Stock (Ln)	2.327	1.378	
	(0.152)	(0.029)	-8.00***
R&D Productivity	0.214	0.238	
	(0.067)	(0.024)	0.27
Total Assets (Ln)	5.344	3.914	
	(0.153)	(0.031)	-10.89***
Market Value Growth (Ln)	1.410	1.611	
	(0.081)	(0.06)	0.52
Tobin's *q*	2.476	2.037	
	(0.158)	(0.057)	-2.01**
Cash-Flow Ratio	0.019	-0.174	
	(0.016)	(0.023)	-2.10**
Indicator for Missing R&D Expenses	0.100	0.175	
	(0.018)	(0.005)	3.20***
Indicator for Zero Patent Intensity	0.455	0.515	
	(0.030)	(0.007)	1.90*

Notes: Standard errors are given in parentheses. ***, **, and * indicate that the difference in sample means is significantly different from zero at the 1%, 5%, and 10% statistical level, respectively.

Table 3. Marginal Effects of the Propensity of Involvement in M&A Activity

	Acquirer	Target	Pooling Merger	No M&A
R&D Intensity	0.034*** (0.011)	-0.62e-04 (0.34e-03)	-0.020 (0.13e-02)	-0.013 (0.017)
Patent Intensity	0.76e-04*** (0.28e-04)	-0.45e-06 (0.17e-05)	-0.39e-04** (0.21e-05)	-0.37e-04 (0.35e-04)
Patent Stock (Ln)	0.34e-04** (0.16e-04)	0.20e-06 $^{(**)}$ (0.72e-06)	0.35e-04*** (0.11e-05)	-0.70e-04*** (0.20e-04)
R&D Productivity	-0.79e-04*** (0.27e-04)	0.67e-06 (0.23e-05)	0.15e-04 (0.19e-05)	0.62e-04* (0.34e-04)
Total Assets (Ln)	0.026*** (0.41e-02)	-0.54e-04 (0.15e-03)	0.48e-02** (0.19e-03)	-0.031*** (0.45e-02)
Market Value Growth (Ln)	-0.78e-05 (0.17e-04)	-0.64e-07 (0.28e-06)	0.88e-05 (0.10e-05)	-0.89e-06 (0.20e-04)
Tobin's *q*	0.36e-04 (0.25e-04)	0.15e-05 (0.58e-05)	0.82e-05 (0.14e-05)	-0.46e-04 (0.30e-04)
Cash-Flow Ratio	0.17e-03*** (0.76e-04)	0.53e-04 (0.14e-03)	0.34e-04 (0.27e-05)	-0.26e-03* (0.16e-03)
Indicator for Missing R&D expenses	-0.044*** (0.017)	0.16e-03 (0.59e-03)	0.37e-02 (0.11e-02)	0.40e-01** (0.21e-01)
Indicator for Zero Patent Intensity	-0.017 (0.014)	-0.10e-03 (0.36e-03)	0.012 (0.84e-03)	0.51e-02 (0.017)
Mean of Dependent Variable (Percentage Points)	7.00	0.01	3.00	89.99
Observations	186	22	94	9,206
Log Likelihood	-1,350.60			
Restricted Log Likelihood	-1,590.54			
Prob > ChiSqd	0.00			

Notes: The marginal effects provide percentage point changes in the probability of an outcome. Marginal effects are computed at means of explanatory variables. Standard errors are given in parentheses. ***, **, and * indicate a significance level of 1%, 5%, and 10%, respectively. The significant estimates which are captured by the coefficient effects, but not by the marginal effects, are reported in parentheses.

Table 4. Merged versus Non-Merged Firms after Matching

Group		Firm-years	R&D Intensity		Patent Intensity		Patent Stock		R&D Productivity	
			mean	t-statistic	mean	t-statistic	mean	t-statistic	mean	t-statistic
1	Merged	64	0.069		0.001		1.280		0.002	
	Non-merged	1622	0.116	0.51	0.012	0.50	0.877	-1.19	0.077	0.67
2	Merged	60	0.0776		0.015		2.293		0.168	
	Non-merged	1339	0.0862	0.15	0.015	-0.02	2.000	-0.78	0.161	-0.03
3	Merged	48	0.108		0.002		1.355		0.001	
	Non-merged	1109	0.142	0.62	0.010	0.71	0.921	-1.24	0.162	0.59
4	Merged	59	0.12		0.006		1.560		0.010	
	Non-merged	765	0.13	0.23	0.013	1.37	1.045	-1.40	0.170	1.26
5	Merged	60	0.135		0.032		3.528		0.384	
	Non-merged	514	0.114	-1.38	0.014	1.45	2.446	*-5.12*	0.222	1.16

Notes: The number of the observations is smaller than those in the Tables 1 and 2 due to the region of common support requirement.

Table 5. Effects of M&A (Average Treatment Effects on the Treated)

Annual Growth	*First year* *(t+1 to t+2)*	*Second year* *(t+2 to t+3)*	*Third year* *(t+3 to t+4)*
R&D Intensity	0.139***	0.193***	0.228***
	(0.045)	(0.052)	(0.039)
Patent Intensity	0.083***	-0.113	-0.051
	(0.004)	(0.152)	(0.436)
Patent Stock (Ln)	0.046***	0.004	0.018
	(0.017)	(0.024)	(0.025)
R&D Productivity	0.816	-0.006	0.238
	(0.626)	(0.589)	(0.315)
Total Assets (Ln)	0.052**	0.041	0.040
	(0.026)	(0.026)	(0.028)
Market Value (Ln)	0.338***	-0.027	0.124
	(0.103)	(0.197)	(0.146)
Tobin's *q*	2.500	2.076	1.694
	(2.920)	(2.053)	(1.642)
Cash-Flow Ratio	-0.031	1.002	-1.052
	(0.874)	(3.016)	(2.096)

Notes: Reported are means. Standard errors are given in parentheses. ***, **, and * indicate a significance level of 1%, 5%, and 10%, respectively.

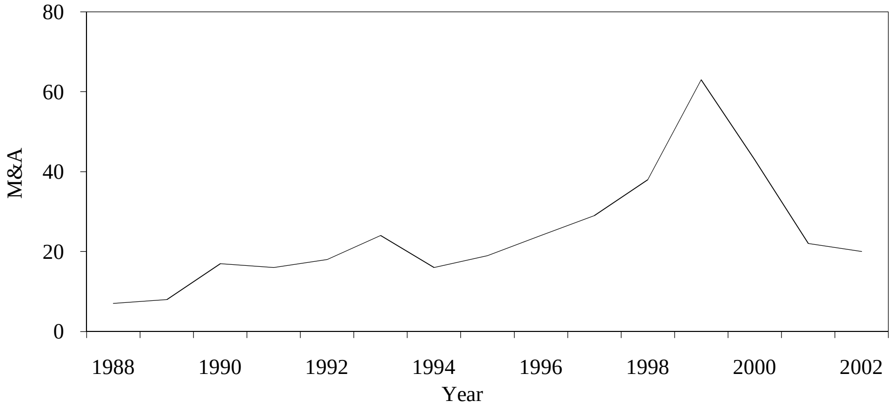
Table 6. Rosenbaum Bounds for Effects of M&A

Gamma	R&D intensity		Patent Intensity		Patent Stock	
	[Q^+-MH; Q^--MH]	p-critical	[Q^+-MH; Q^--MH]	p-critical	[Q^+-MH; Q^--MH]	p-critical
1.00	[1.9775; 1.9775]	0.0002	[1.6774; 1.6774]	0.0334	[1.1254; 1.1254]	0.0000
1.20	[1.7896; 2.5660]	0.0113	[1.4226; 2.2627]	0.0843	[1.0452; 1.8044]	0.0003
1.40	[1.5221; 2.9142]	0.0401	[1.2476; 2.5704]	0.2910	[1.5905; 2.0123]	0.0051
1.60	[1.3764; 3.2422]	0.1211	[1.1898; 2.8621]	0.3200	[0.0864; 2.3213]	0.0124
1.80	[1.1644; 3.5521]	0.2523	[1.1342; 3.1394]	0.5171	[0.0657; 2.7868]	0.0594
2.00	[1.0897; 3.8461]	0.2973	[1.0698; 3.4764]	0.5940	[0.0266; 2.9612]	0.0821

Notes: Q^+-MH and Q^--MH are Mantel-Haenszel test statistics under assumptions of overestimated and underestimated treatment effects. Significance levels are under assumption of overestimation of treatment effects.

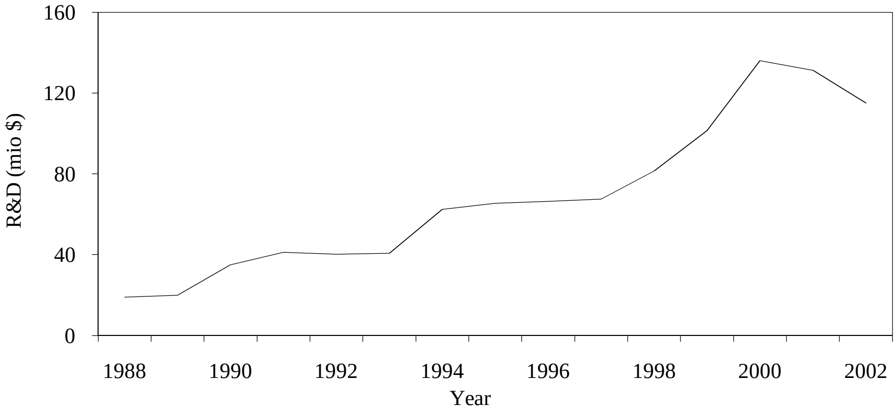
Annex

Figure 1. M&A in the Telecommunications Equipment Industry, 1988-2002



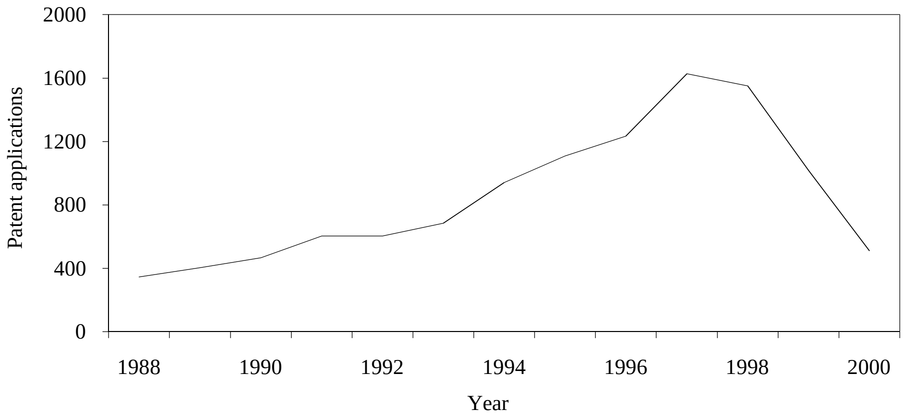
Source: Authors' calculations from Thomson One Banker-Deals

Figure 2. Average R&D Expenditures in the Telecommunications Equipment Industry, 1988-2002



Source: Authors' calculations from Compustat and Global Vantage databases

Figure 3. Patenting in the Telecommunications Equipment Industry, 1988-2000



Source: Authors' calculations from NBER Patent Database

Notes: The abrupt fall in the patent applications after 1998 in figure 3 is primarily caused by the truncation of the patent data sample. We have patents which were granted until 2002. Thus, we end our analysis on patents in 2000 because, in the subsequent years, a truncation due to the grant lag becomes clearly visible.