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The evolution of complex industrial systems : the dynamics of major IT sectors

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Summary and Conclusions

This thesis concerns the evolution of complex industrial systems over time, more in particular it focuses on the development of three major information technology sectors: i.e. computers, telecommunications and semiconductors. Whereas traditional theories of organization and economics are often concerned with static, cross-sectional analyses we put forward an integrated evolutionary framework which is inherently dynamic. We argue that the use of such a framework considerably improves our understanding of the evolution of complex industrial systems. Our integrated framework is based on two distinct but related biological inspired schools of thought. For the study of the evolution of market structures and the importance of particular organizational types under different environmental circumstances we make use of ideas derived from organizational ecology theories, whereas for the study of technological change we build on the elaborated framework developed by evolutionary economists. Although ecological and evolutionary approaches form the core of our framework we combine biology-inspired concepts with ideas from strategic management, organization theory, industrial economics, new institutionalism and international business studies.

Following evolutionary theorists we argue that technological change is gradual and that superior firms and technologies are rewarded by the 'selection' environment. In the initial phase of the industry life cycle technological change is expected to be radical and uncertainty is high. During time a product or technology is likely to arise which stands out above all other products or technologies. These so-called 'basic designs' serve as a sort of 'technological guideposts' for further developments in the technology. Once a basic design is established technological progress tends to follow consistent paths or trajectories. The cumulative character of technological progress facilitates a rapid expansion of the boundaries of the technology until the natural limits of the technology are approached and technological progress slows down. At that time decreasing returns from investment in research and development induce firms to redirect their focus towards other technological paths.

Supply side developments in the industry are described on the basis of five different organizational types. In the early stages of a high technology industry when both market and technological uncertainty are high, first mover firms are said to have a considerable advantage in the preemption of new market opportunities. These so-called r-type firms are generally characterized by small and fast to build organizational structures which enable them to move quickly into new resource spaces. After some time, the establishment of a technological regime initiates a period of more stable technological development. Efficiency then replaces innovativeness as the most important element in a firm's competitive strategy. At that time so-called K-generalist enter the market. K-generalists rely on efficient rigid organizational structures and tend to emphasize efficiency and accountability. When the natural limits of the current paradigm are approached and a stabilization of the industry takes place, another type of firms, so-called K-specialists start to outcompete their generalist rivals. Ultimately the market growth starts to decline and new opportunities in other technological directions are likely to emerge. At that time a new life cycle might be initiated and r-type firms are once again expected to be the first to invade the new market.

On the basis of this pattern of market and technological evolution we came up with 7 basic hypotheses. These hypotheses are empirically evaluated under three completely different industry settings. First we studied one of the most dynamic industry sectors of all times, namely the international computer industry. We examined the history of the computer industry ever since its creation up to recent developments in the market. The computer industry has always been characterized by intense international competition and rapid technological progress. Then we proceeded with a market that in contrast to the computer industry for a long time has been characterized by the absense of competition in its market, namely the telecommunications industry. The telecommunications industry has always been characterize by domestic internally directed markets in which one main supplier occupied a monopolistic position. At first this monopolistic market structure was due to the dominance of a single patent, later regulatory forces reinforced the monopoly position of the dominant firm. Only recently liberalisation and deregulatory actions have paved the way for more (international) competition in the market. After we evaluated our framework under such diverse industry conditions we focused on the semiconductor industry. We choose to study this industry because it is characterized by strong forces of creative destruction that take place after the establishment of a new technological regime. Therefore, market structures have changed substantially over time. In the most recent period a battle for market dominance takes place between Japanese firms that dominate the memory market and US companies that occupy superior positions in the important micro-processor market. Given the large differences among the various sectors it is very interesting to compare the effectiveness of our integrated framework under such diverse conditions. Table 36 shows the findings of our evaluation of the seven basic hypotheses as put forward in the second chapter.

TABLE 36 *Confirmation or rejection of the seven basic hypotheses for three different industry settings.*

	Hypotheses						
Industry	1	2	3	4	5	6	7
Computers	√	√	√	√	√	√	*
Telecom	-	√	√	√	√	√	√
Semiconductors	-	-	√	√	√	√	√

√ *hypothesis confirmed*
- *hypothesis not confirmed*
* *hypothesis not evaluated*

Our first hypothesis was based on the assumption that new markets are created by radical technological innovations. At the time of founding, a new market is often characterized by substantial uncertainty about the technological feasibility of the innovation and its potential market size. Therefore commercial firms and potential investors are often very sceptic about entering the newly born market. Because of the absence of a commercial market and because technological developments are often dependent on the underlying scientific knowledge base we hypothesize that universities and government institutions are the main incubators of radically new technologies. Our analyses show that this hypothesis can only be confirmed in the computer industry. In the United States universities carried out large government sponsored projects whereas in Germany and Britain a large number of government institutions were trying to develop computers for wartime applications. In the telecommunications industry government institutions and universities played a more modest role. Especially Schumpeterian entrepreneurs such as Cooke and Wheatherstone and Samual Morse in the telegraph market and Graham Bell and Elisha Gray in the telephone market played a much more important role. The importance of these entrepreneurs in the first stage of the telecommunications industry was possible because their early devices were relatively simple and easy to build. Neither sophisticated materials, expensive equipment nor thorough scientific knowledge was needed to build the early telecommunication devices. In the semiconductor industry government purchasement and support played a vital role in the establishment of the early market but universities and government institutions played only a minor role. The great majority of developments in the early semiconductor market came from the efforts of a single firm: American Telephone and Telegraph (AT&T). AT&T was extremely interested in the development of semiconductor devices for use in its switching and transmission equipment. Our analysis therefore indicates that the role of incubators can be played by a variety of organizations depending on the complexity of the early devices, the role of scientific knowledge and the potential value of a new device for commercial organizations.

Our second hypothesis argues that a newly emerging high technology market is likely to be explored by r-specialist organizations that pursue offensive innovation strategies. This hypothesis is among others based on the classic argument given by Arrow (1962a) that a new entrant benefits more from a new innovation than incumbent organizations because for incumbent organizations innovations may cannibalize profits from other products. Therefore, the impetus to move into a new market is correspondingly higher for new organizations. Because innovative features are often more important than price during this stage of development, firms are expected to focus on technological leadership in the market. Our second hypothesis was confirmed in all sectors but the semiconductor industry, where it could only be confirmed for the US market and not for Europe and Japan. In the computer industry the major university institutes spun-off a large number of new enterprises that used offensive innovative strategies in order to satisfice military demand for highly innovative products. In the telecommunications industry early customers primarily consisted of stock brokers, newspaper agencies, railroad owners and the state. This group of customers was well prepared to pay premium prices for increased quality of the services and for a larger distance that could be achieved by the telecommunication services. In the early telecommunications industry new organizations did not spin-off from the major universities but were created by the same entrepreneurs that invented the first telecommunication devices. The importance of innovative new companies was also found in the early US semiconductor industry where small new organizations managed to drive all the major vacuum tube producing companies out of the market. A somewhat different pattern was found in the case of Europe and Japan where the low mobility of engineers and the lack of sufficient venture capital inhibited the entrance of small organizations into the market. Therefore hypothesis two could only partly be confirmed in the semiconductor industry.

Our third hypothesis was concerned with the cumulative nature of technological developments after the establishment of a technological regime. It is argued that the market and technological uncertainty that characterizes newly born markets gradually decreases. Through selection processes it becomes clear which technology stands out above all other technologies. A product or technology which is able to accumulate a critical mass of consensus may then be able to become a 'basic design' on which future research will be based. The search for radical new technological changes is then substituted by cumulative improvements along a specific path or trajectory (hypothesis three). This hypothesis is confirmed in all sectors under study. Basic designs such as the von Neumann architecture (computer industry), Morse's telegraph device, Bell's telephone (telecommunications industry) and Texas Instrument's silicon transistor have all served as a 'technological guidepost' for many decades.

The standardized character of technological change induces firms to redirect their focus away from technological performance and design towards price. Under circumstances of fierce competition large efficient organizations are often much better placed to serve the, now price-sensitive, market than their smaller competitors. Their advantages in terms of static economies of scope and scale enable these firms to set prices well below those of their smaller competitors. We therefore expect that after the establishment of a new technological regime, K-generalists and polymorphists start to outcompete r-specialists (Hypothesis four). This hypothesis is confirmed in all three industries under study. In the computer industry this so-called r- to K transition was started by a wave of acquisitions in which major r-type organizations were taken over by larger k-type organizations. In the telecommunications industry the r- to K transition started by the gradual transformation of the two most important r-type organizations (American Bell and Western Union) into large K-type organizations. By taking advantage of their patents and rights of way American Bell and Western Union were able to complete their transformation into large well established companies. Only a few years after the establishment of every new technological regime in the semiconductor industry large organizations proved to be more successful in commercializing the newly established products than smaller organizations. It must however be stressed that, in addition to static economies of scale and scope, dynamic economies of scale such as learning curve advantages also played a very important role in this industry. Therefore large organizations need to combine their efficient production structures with a high-tech orientation. Our evaluation of the evolution of the three distinct industrial systems therefore confirms that after the establishment of a new technological regime, K-generalist tend to outcompete r-specialists.

Although the pattern of r- to K transition at first may take place very slowly the rate of r- to K transition increases enormously when competitive pressures intensify (hypothesis five). This hypothesis is based on the assumption that the degree of selection is positively related to the degree of competition in the market. From an organizational ecology point of view, the degree of competition is above all dependent on the carrying capacity of a specific organizational field. As the carrying capacity is approached and competitive forces intensify, r-type organizations will be increasingly replaced by their K-type competitors, at least under conditions of price-based competition. In all three studies we were able to confirm this hypothesis. Increased competition in the computer industry enabled the leading K-type organizations to reinforce their dominant position in the market. In the telecommunications industry increased competition that was due to the deregulation of the telecommunications markets has led to oligopolistic rivalry among a small number of very large K-type organizations. In the semiconductor industry the early dominance of r-type organizations was soon replaced by a concentrated market structure that was dominated by only five large organizations.

Our sixth hypothesis is based on the concept of 'niche-elaboration' (Pianka, 1979) which argues that the sophistication of users and the preoccupation of large firms with serving the overall market opens up a number of niches in which specialized firms can gain high rewards by focusing on the specific needs of a sophisticated customer group. We argue that whereas initially the market was not large enough to support multiple niches, the emergence of a mass-market makes a strategy of segmentation viable (Popper and Buskirk, 1992). Once again this hypothesis was confirmed in all sectors. In the computer industry IBM's power to dominate the market, high entry barriers and the emphasis on price-competition gave smaller firms not a single opportunities to compete effectively in the mainframe market. Therefore, small specialist firms started to focus on specific market niches. Small specialist organizations were responsible for opening up three very important market niches. DEC opened up the mini-computer market, whereas Amdahl and Apple opened up the markets for supercomputers and micro-computers respectively. In the telecommunications industry the efforts of small specialist firms were at first not very successful. Strong government regulation prohibited other organizations to enter AT&Ts markets. The persistent actions of small organizations would however eventually open up markets for Customer Premises Equipment (CPE) and the microwave services market for new competition. Although new firms were not able to attack AT&T's dominant position in its core markets (transmission and switching) swarms of new organizations have successfully entered specific market niches. In the semiconductor industry specialist organizations opened up market niches for application-specific memory devices, custom chips and RISC microprocessors.

In analogy with the 'success breeds failure syndrome' that was described by Starbuck, Greve and Hedberg (1978) we argue that large K-type organizations would have severe difficulties in dealing with a paradigmatic technology shift (hypothesis seven). The elaborated structure of K-strategists and their capital intensive production system enables them to withstand competition for a long time, but also prevents them from moving swiftly into new resource spaces. Therefore, if new technological opportunities arise and the opportunities in the 'old' paradigm decrease, r-strategists will be able to take advantage of the new opportunities much more quickly than their established competitors. This so-called K- to r transition was found in all markets except for the computer market where a paradigmatic technology shift has not (yet) occurred. A typical example of a K- to r transition took place in the telecommuni-cations industry where Bell managed to establish a dominant position in the telephone market because its much large K-type competitor (Western Union) failed to recognize the opportunities in this market. In the semiconductor industry a paradigmatic shift in the early 1970s deteriorated the positions of large well established K-type organizations in favour of small new innovative companies. From the established companies only Motorola managed to gain a dominant position in the new paradigm.

To summarize, our integrated framework as presented in the second chapter was able to predict fairly accurately the technological and market developments in all industries that were studied. Despite the important differences in industrial conditions that characterize the three markets there is a remarkable resemblance in their evolution over time. This gives strong support for a further development of an integrated evolutionary framework[121]. All aspects considered we might conclude that both biological inspired theories, although in their infancy, seem to be very promising in handling dynamic phenomena. However, much effort is needed for the construction of a mature framework. According to Kuhn (1970) ".... the success of a paradigm (......) is at the start largely a promise of success discoverable in selected and still incomplete examples. Normal science consists in the actualization of that promise, an actualization achieved by extending the knowledge of those facts that the paradigm displays as particularly revealing, by increasing the extent of the match between those facts and the paradigm's

[121] Given the observed importance of the policy framework in, in particular, the telecommunications sector an extension of the framework to treat the policy environment might be needed to grasp the full dynamics of these sectors.

predictions, and by further articulation of the paradigm itself" (Kuhn, 1970: 23-24). Thus, if 'normal science' is able to enhance the ecological and evolutionary paradigm sufficiently, it may eventually replace the prevailing economic paradigms. Cross fertilization between the evolutionary and ecological theories seems to be an extremely important tool in achieving matureness of both the ecological and evolutionary economic theories (see also Andersen, 1994). Opportunities for cross fertilization are however not restricted to biological inspired theories. In the literature the integration of biological inspired theories with theories of industrial organization (Boone and van Witteloostuijn, 1995), new institutionalism (Tucker et al., 1990) and even with strategic management theories (Carroll, 1990) have been proposed. Therefore we will argue that 'local search' on a specific scientific trajectory should be replaced by broader search patterns into new trajectories and scientific paradigms. This might eventually lead to the convergence of previously distinct scientific paradigms.

The second part of this thesis concerns an in-depth empirical analysis of three major forces that have jointly determined a considerable part of the development of the IT sector during the past decade: technological convergence, strategic technology partnering and globalization tendencies. Table 37 shows the findings of our evaluation of 10 hypotheses as put forward in the second part of our thesis.

TABLE 37 *Confirmation or rejection of the ten hypotheses in the second part of this thesis.*

hypotheses	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*
	√	-	√	√	√	√	-	-	-	-

√ *hypothesis confirmed*
\- *hypothesis not confirmed*

Chapter six was primarily concerned with an empirical analysis of the technological convergence process. Technological convergence can be described as the growing similarity among the technological foundations of the different IT segments. The pervasive effect of semiconductors and software has blurred the traditional boundaries between the various IT markets. An empirical analysis is used to examine whether the convergence of information technologies has led to a growing similarity of companies that are active in different IT markets. More in particular we tried to find out whether ongoing patterns of technological and product market convergence have affected the technological cores of leading companies in the computer, telecommunications and semiconductor industry. Following evolutionary and ecological theorists we argue that a firm's reliance on basic routines severely reduces its speed of adaptation. In spite of the technological convergence that is found in technologies and products we therefore expected to find companies that are still basically focused on their traditional core technologies. The second major research issue that is addressed in chapter six is concerned with the use of strategic alliances as a means to monitor several technological developments. We therefore argued that firms would tend to converge through means of strategic technology alliances. Our empirical analysis was based on two types of data: patent data and data on strategic technology alliances. A simple linear regression is used to measure the relationship between time and the relative importance of patents and alliances in a particular industry sector. The results of the regression analysis showed a confirmation of hypothesis eight which asserted that firms are still doing more of the same instead of being involved in a process of redefining their 'core' business. Hypothesis nine which argued that firms converge through means of strategic alliances could however not be confirmed by our empirical analysis. In spite of an overall growth in the number of strategic technology alliances over time, cooperative agreements have not been used extensively to deal with the forces of technological convergence. A possible explanation for this finding is that the use of cooperative agreements for technology acquisition is only effective if those agreements are combined with a comparable degree of internal development. Overall our findings indicate that in spite of the observed growth in technological convergence the technological structures of firms have not been significantly affected, at least not in terms of their patents and strategic technology alliancing behaviour.

Chapter seven has been concerned with the rapid increase in the number of strategic technology alliances in the IT sector. Traditionally cooperative agreements used to be undertaken between enterprises in order to gain access to foreign markets or to bypass government regulations. Today cooperative agreements are undertaken for a much wider range of strategic reasons. The scope of these alliances is usually global and cooperative companies are often more or less comparable in size. Because firms are now often engaged in multiple alliances with different partners at the same time it has become necessary to abandon the traditional focus on the alliances of one specific organization. Instead a 'network' perspective is proposed. From a network perspective the number of alliances is only one of several important variables. It is argued that the assessment of the power of organizations in a network requires a more extensive analysis of the position of that particular organization in the network, its connection to other players as well as its ability to control flows of information. Our main goal of chapter seven is to evaluate eight basic hypothesis about the use of strategic technology alliances. The first part of chapter seven is concerned with the identification of the basic trends in strategic technology partnering. We expected that the number of alliances has increased considerably over time (hypothesis 10). An empirical analysis of the growth of the number of strategic technology alliances in the field of information technology shows that the number of such alliances has gone up dramatically. Before the 1970s strategic technology alliances were virtually unknown. A steady growth in the number of newly established alliances in the 1970s was replaced by escalating growth during the 1980s. In the early 1990s the growth in the number of newly established strategic technology alliances remains very high but seems to level off. This pattern of growth clearly confirms hypothesis 10. A detailed analysis of sectoral data on the establishment of strategic technology alliances showed that there were major differences in both the number and evolution of newly established alliances among the various industry sectors. We assumed that the rapid increase in the number of alliances over time was for a large part due to the need for more flexibility in the market. The increasing importance of flexibility in today's market was said to drive firms to choose for more flexible forms of organization. Therefore we expected that the equity/non-equity ratio of strategic technology alliances has decreased significantly over time (hypothesis 11). A critical assesment of the number of equity versus non-equity agreements confirmed this hypothesis by showing that this ratio has indeed increased considerably during time. A related analysis was concerned with the evolution of the basic rationales for strategic partnering in information technologies. A critical evaluation of the relative distri-bution of various rationales over time showed that new rationales such as a reduction in lead times and technological complementarity have taken over the role of market access as the predominant reason to establish strategic technology alliances. This confirms hypothesis 12 which argues that traditional (access) reasons have been replaced by other reasons that are related to recent changes in the international environment. After we evaluated the trends in the number of newly established strategic technology alliances we focused on the evolution of cooperative networks. An analysis of the overall network structure of the various sectors showed that sparse networks in the early 1970s have evolved into extremely dense network in the late 1980s and early 1990s. Especially the semiconductor network stands out in this respect, whereas the computer industry shows only a relatively modest rise in network density in the last period under study. This confirms our expectation (hypothesis 13) that the trend in the number of alliances is not only due to the entrance of new firms into the network but also for a considerable part to the increasing number of alliances that are established by individual firms. The same pattern of increased alliance activity was found in the centrality measures that were related to the number of direct links (degree centrality) and in the power to control flows of information between other companies in the network (betweenness centrality). After having focused on the overall network structures we directed our attention to the positions of the individual players in the network. Our main expectation was that there would be a strong relationship between technological and market structural developments and the evolution of networks of strategic technology alliances (hypotheses 14-17). The results of our analysis on the evolution of networks in the various industry sectors however show that although there are a large number of indirect relationships between industry development and networks of strategic alliances there appears to be no linear relationship between them.

Chapter eight addresses one of the most important and critical features of today's economy: internationalization. This process of internationalization has received widespread interest in the literature. Most authors have argued that patterns of internationalization would lead to a single global world market in which companies have no particular relationship to any specific country. In the first part of the chapter we analyze patterns of internationalization of corporate technological activity in the by now familiar three industry sectors: computers, telecommunications and semiconductors. The main question that is addressed in this part is whether companies are gradually becoming more international in terms of their internal and external technology flows and the location of their R&D facilities. Data from the European Patent Office (EPO) enabled us to analyze patterns of international patenting behaviour. The results of the analysis indicate that only a small degree of corporate technological activity takes place abroad. Additional research on strategic alliances shows that in spite of becoming more international in focus alliances have become increasingly concentrated within major economic regions. Therefore our analysis suggests that if internationalization takes place at all it is only found in a number of exceptional cases. After we assessed trends in the degree of internationa-lization of corporate technological activity we focused on the nature of globally operating companies. The question was raised whether large multinational firms are gradually losing their national characteristics and become truly globalized companies. In the literature it is often argued that firms that face the same homogenous environment will take on similar structures and strategies. The results of an empirical analysis on the structures and strategies of companies from various different home countries revealed that despite their international orientation companies in all three sectors can still be recognized in terms of their region of origin. Our results therefore suggest that either internationalization tendencies have not been strong enough to generate clear patterns of isomorphism or that imprintment forces have restricted companies from taking on 'global' strategies and structures. Firms are found to be still basically influenced by the social, cultural, technological and competitive conditions under which they were established. The main conclusion is therefore that internationalization of innovation appears to be still less important than expected both in terms of actual internationalization trends as well as in terms of the globalization of companies themselves.

The empirical analyses in the second part of this thesis seem to confirm our basic assumption that companies seem to be characterized by strong inertia. Whereas firms seem to make increasing use of strategic alliances as a means to deal with changing environmental conditions they do not seem to be able (or willing) to change their 'core' structures according to the demands of the environment. Although pressures for internationalization and convergence seem to be very high, companies seem to have retained their traditional structures and strategies. This gives strong support for the further development of theories that do not assume rapid adaptive change within organizations. Inertia seems to be an essential characteristic of organizations and should therefore be a core concern of every theory of organization.