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Twinning Networks: Co-evolution and competition of system component technologies in the local area network industry

Roberto Fontana

Science Policy Research Unit
Mantell Building
University of Sussex
Falmer, Brighton
BN1 9RF, UK

Tel: +44 (0) 1273 686758
Fax: +44 (0) 1273 685865
Email:
M.E.Winder@sussex.ac.uk
http://www.sussex.ac.uk/spru/

TWINNING NETWORKS: CO-EVOLUTION AND COMPETITION OF SYSTEM COMPONENT TECHNOLOGIES IN THE LOCAL AREA NETWORK INDUSTRY

Roberto Fontana

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ABSTRACT

This work analyses the evolution of the Local Area Network industry in terms of the interaction of technological and economic dimensions over time. It focuses in particular on two suppliers of LAN systems: the access technology industry and the internetworking industry. Two elements driving the evolution are identified, 1) cross-substitution among the components when costs are reduced or performance improved,and 2) the need to preserve the compatibility with existing components or technologies. The effects of these mechanisms on the dynamics of entry and exit of firms in both industries are analysed by using the Organisational Ecology approach. We find that the effects on the dynamic are different depending on the presence or absence of innovation. These mechanisms may ensure a matching between the two industries and a virtuous cycle of growth in absence of innovation. Nevertheless, when an innovation occurs in one of the two industries and the carrying capacity of the system is altered, the 'match' is disrupted and it may be difficult to re-establish a matching position, thus the virtuous cycle may turn into a 'vicious one'. An interpretation of the reasons for this mismatching is given by using the concept of 'lineage process' to describe the application of a technology in new domains and by stressing the role that elements different from adaptation and availability of resource may play in delaying the process.

Note to the reader: the legibility of the dissertation is greatly enhanced by keeping the tables within the text. For this reason we did not create a separate appendix at the end of the dissertation, even if keeping the tables within the text exceeds the word limit.

ACKNOWLEDGEMENTS

Writing a dissertation is like embarking on a long voyage. At the start you are eager to leave the harbour. When you are surrounded only by water it is difficult to keep yourself on the right track and you would like to find a route back. When you start to see the land again you find new strength and forget how bad it was to scan the horizon without finding any sign of life.

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Time present and time past
Are both perhaps present in time future,
And time future contained in time past.
(...)What might have been is an abstraction
Remaining a perpetual possibility
Only in a world of speculation.
What might have been and what has been
Point to one end, which is always present.
T.S. Eliot

This work is dedicated to the memory of my father

Table of Contents

INTRODUCTION

The main concern of this work is to provide an account and interpretation of the evolution of the Local Area Network (LAN) industry. Since the function of a LAN is to provide data communication among different terminal equipment by linking them through switching points over areas of different size, the service provided by LAN is a combination of inputs from both the information and communication technology industries. The technological evolution of the respective components and dynamics of the industries shape the evolution and diffusion of LANs over time. We concentrate on the evolution of two of these industries, the industry of access technology and that of internetworking. Their interaction is hypothesised to be crucial to determine the paths along which the diffusion of the LANs has occurred. We will stress mainly the 'systemic effect' as a determinant of the diffusion of LANs but we are not so much interested in the technological aspects of this effect as in its economic assumptions and consequences. In particular, we will try to identify the economic mechanisms which, in a systemic context, interact with the technological dimensions and contributes to shape the evolution of the industry over time.

Starting from these assumptions, the work tries to answer to the following questions. What are the economic mechanisms which shape the technological evolution in a LAN? How do these mechanisms influence the dynamic of the industries supplying the components to the system? How is the dynamic of the system affected by the evolution of the single industries?

We will try to answer these question by using what J.A. Schumpeter defined as the *"three techniques* (which) *distinguish the 'scientific' economist from all other people who think, talk, and write about economic topics"*[1]*:* history, statistics and 'theory'. Any understanding of economic phenomena is impossible without a reconstruction of historical, institutional facts which might have influenced the economic outcome. Moreover, we need to present these facts in such a way to produce meaning and provide statistics that represent the necessary condition to obtain this goal. Nevertheless, mere statistical and historical accounts do not provide an adequate explanation without the support of economic theory. We need a theory both to provide explanatory hypothesis of the observations made and to suggest additional new

[1] J.A. Schumpeter (1954), p.12;

hypothesis to investigate in the future in order to establish new results.[2] The structure of the present work reflects these purposes.

Chapter one provides a historical account of the evolution of the LAN industry in terms of technology and economics. The technological viewpoint highlights how the evolution of LANs results from the interaction of the technical change among the components (computers, access technology, connecting devices). We distinguish two phases according to which components seem to guide the process. During the first phase (1985-1989), it is mainly performance improvements in terminal equipment and developments in the access technology field that spur the diffusion of local networks. During the second phase (1990-1997) major changes in the connecting devices industry together with a stalemate in the access technology industry's evolution shift the locus of rapid growth toward internetworking products. For each phase, both the major technological constraints and the focusing devices are identified. The economic viewpoint focuses on how the technical changes open up new economic opportunities for firms in the market and on how firms profit from these opportunities. By analysing the evolution of the market structure of two segments in the internetworking market (routers and switches) and by investigating the proliferation of alternative standards in the access technology field, we identify economic mechanisms including cross-substitution effects, network externalities and compatibility issues that are influencing industrial developments.

In chapter two both perspective and method change. The focus is on the dynamic of the LAN industry as the result of the evolution of the interactions between the access tecnology industry and the internetworking industry. The main goal is to analyse how the overall dynamic changes as a consequence of technical change affecting each industry. The approach we choose for this investigation is that of 'Organisational Ecology' (OE). This choice follows from both 'practical' and analytical considerations. From the practical viewpoint, the data we have on firms' presence in both industries fit in the 'demographic style' typical of the OE approach. From the analytical viewpoint, OE uses concepts (legitimacy and competition) which help to connect the demographic trends with the economic mechanisms identified in the first chapter. The analysis

[2] "(...)hypotheses of these kind are also *suggested* by facts (...) but in strict logic they are arbitrary creations of the analyst. (...) they do not *embody* final results of of research that are supposed to be interesting for their own sake, but are mere instruments or tools framed for the purpose of *establishing* interesting results".
J.A. Schumpeter (1954), p. 15, emphasis in the original;

indicates that different dynamics of the industries should prevail depending upon the absence or presence of innovations. When rapid innovation is present, the findings do not seem to fit with the theory. A possible explanation of changes in the growth dynamics in terms of the interactions between the two industries is suggested at the end of the chapter.

In chapter three we gather all the threads and try to interpretate the findings in the light of the existing literature. We stress three points. Minor incremental changes in the technology and major radical impacts in the market combine in the LAN-Internetworking industry. This pattern of innovation resembles a ‘process of lineage’ that occurs when an existing technology branches into new domains of applications. However we argue that the usual mechanisms behind the lineage process do not completely capture the dynamic of the process in this case. The separation between adoption and the availability of resources, which parallels the distinction between legitimacy and competition as determinants of the industry evolution, blurs in presence of network externalities and issues of compatibility. Demand and supply become so intertwined that the evolution of the entire industry depends on their correct matching over time. If they do not match, the presence of the economic mechanisms highlighted in the first chapter may delay the application of the technology to another domain.

CHAPTER 1

THE DIFFUSION OF THE LOCAL AREA NETWORKS

The simplest way to define a Local Area Network (LAN) is as a family of conduits linking different communication devices. The conduits may consist either of ordinary telephone wires or more sophisticated cabling and LANs may have different topologies. LANs differ from the earliest computer networks (60's and 70's). These early networks were highly heterogeneous and 'proprietary', developed mainly for intra-company use (DEC and IBM), and were based on the multi-user System principle. They provided stable and simple connections between a mainframe computer and 'dumb' terminals, but they did not imply any direct user to user communication.[3] The development of LANs is a direct consequence of the advent of PCs. PCs and distributed computing provided isolated single-user environments, but the extension of applications services (mainly printing) to single users proved to be very expensive (in the first half of the 80's for instance, adding a printer to PCs could double their price). Tying users together was perceived as a way to reduce the costs while extending the access to new information technology. That is why LANs initially emerged to allow departments to share printers and data and that is why they were mainly based on existing intra-company networks. Local networks existed before the introduction and the diffusion in use of microcomputers. As soon as microcomputers were introduced in the firms' environment, sharing data and interacting with other users became a major priority. The perceived ability of LANs to achieve these objectives and to reduce the total price of equipment for a group of users was a reason behind the early diffusion of LANs.

1.1 The first phase (1985-1989)

Together with the diffusion of microcomputers, the endorsement of Ethernet as a standard access technology for LAN communication in 1985 gave a decisive push to the market. Ethernet as access technology for data communication had been developed during the 70's by the Xerox laboratories at Menlo Park. It had been first introduced in the market in 1979 by the 'Dix consortium' (DEC, Intel, Xerox) and, following the specifications of the consortium, in February 1980 it had started to be considered for standard definition. In a context of 'open standards' the first official document came out

[3] Any user to user communication was mediated by the central computer.

in the December 1982 when the IEEE working group ratified the adoption of Carrier Sense Multiple Access with Collision Detection (CSMA/CD) as access method for Ethernet. Three years later, after the 'Dix consortium' had accepted the new specifications, the official publication of Ethernet as a standard was made worldwide.[4]

Meanwhile, an alternative technology was rising to prominence in the LAN environment that aimed to compete with Ethernet. IBM had been experimenting with the Token Ring technology over its computer system for a decade while new producers joined the group of sponsors at the beginning of the 80's.[5] Since most of its characteristics were already well known, when the Token Ring alternative was introduced in the market by IBM in 1985, several producers (Proteon, Ungermann-Bass, 3Com) were ready to compete with IBM in the Token Ring environment.[6]

Up to the end of the 80's the Ethernet segment seemed to attract more producers than Token Ring. As we can see in Table 1 (below) the number of incumbents in the Ethernet segment was always higher than in the Token Ring segment. Moreover the presence of many competitors did not prevent new firms from entering the segment as is shown by the increasing number of new entrants in the Ethernet segment and by their increasing share of the total new entry. A mixture of technological characteristics and a 'temporal advantage', since it had been the first access technology to be standardised in the market, might have given 'momentum' to Ethernet irrespective of some disadvantages which might have prevented some users from adopting it.

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[4] Ethernet is based upon a bus topology and uses coaxial cables as wiring system. A bus topology is rather inexpensive. Since each device is an independent unit in the network, its failure does not affect the performance of the other devices. Nevertheless, on a bus topology the signal usually weakens as it is transferred through many devices. For this reason, on a bus topology the scope of the network is limited or the introduction of repeaters is required to re-generate the signal and avoid a decrease in performance.
See Hegering H.G., Laepple A. (1993), pp.20-25;

[5] In the 70's the ring topology was used to link controllers to looped workstations in the IBM 3600 on-line computer system mainly adopted by banks. In 1981 Proteon shipped a 10 Mb/s Token Ring to be used by Universities and Research Institutes. See Abrahams J.R. (1991), p.2;

[6] In a Token Ring topology each node acts as a repeater of the signal so there are no limits of speed or distance as in the bus topology. The costs of the network are proportional to the number of nodes and the use of shielded twisted pair as wiring system makes them a cheap alternative to Ethernet. Nevertheless, because of the topology, a failed node can break the ring and prevent the other stations from using the network. To avoid this one terminal is designed as control station. This improves the reliability compared to Ethernet but increases also the complexity of the network and the operating costs.

Tab.1:US LAN Market: Total Incumbents and Total New Entry according to Access Technology;

		Incumbents			New Entrants	
Year	**Total**	**Ethernet (% of Tot.)**	**Token Ring (% of Tot.)**	**Total**	**Ethernet (% of Tot.)**	**Token Ring (% of Tot.)**
1985	47	34(72%)	5(11%)	47	43(72%)	1(2%)
1986	72	62(86%)	13(18%)	43	34(79%)	5(12%)
1987	121	99(82%)	29(24%)	74	56(76%)	7(9%)
1988	151	127(84%)	45(30%)	75	65(87%)	15(20%)
1989	152	131(86%)	46(30%)	75	66(88%)	16(21%)
Average	108.6	90.6(83%)	27.6	63	51(81%)	8.8(14%)

Source: Author's elaboration based on The Data Communications LAN Firms Directory (several issues);

Notes: we do not report the data for the Token Bus segment. That is why the single segments do not sum up to the total; The shares do not sum up to 100% because many firms are present in both segments at the same time;

Three points were crucial when deciding the adoption of the access technology. First the kind of media supported. Ethernet supported the expensive coaxial cable instead of the cheap Shielded Twisted Pair (STP) chosen by Token Ring. Second the extension of the configuration. The bus topology chosen by Ethernet usually required a higher (and more expensive) total length of cabling than the ring topology. Third the kind of terminal equipment attached.[7] The combination of a more expensive wiring system and a wider area to connect, in most cases represented a disadvantage on the demand side for Ethernet compared to Token Ring. Regardless these cost considerations, the demand for Ethernet LANs was also influenced by the presence of higher product quality competition than in the Token Ring market and by user interest in features and capabilities. The result was a relatively inelastic demand with respect to price.[8] Moreover the use of an expensive medium over a larger area, which increased the costs of wiring the network, might have forced adopters not to reverse their decisions until they had recouped their investments.

[7] A Data Communication Users' survey reveals that in 1989, 90.4% of Ethernet users employed coaxial cables for their networks. 63.5% of them used the network to connect multiple buildings. Minicomputers were the most common kind of device attached (90.4%). See Data Communications (June 1989);

[8] A survey by Data Communication in June 1987-88 found out that for most of the firms (51%) the most important factor behind their LAN purchase decision was the availability of features and the functionality. Price was decisive only for 6% of the firms. Data Communications (1987-88), June issue;

The presence of sunk costs on the demand side stemming from Ethernet's deeper than Token Rings' penetration in the installed base, because of the temporal advantage it enjoyed as well as user preferences reflected in price inelasticity, enabled Ethernet to attract more producers than Token Ring and this spurred even more its acceptance.

The standardisation of Ethernet boosted the diffusion of LANs but also, represented a turning point in the diffusion of LANs. LAN diffusion progressively de-coupled from the demand of computers. Ifwe look at the demand trends, both micro-minicomputers shipments and LANs connections increase and seem to be correlated until 1986 (see Tab.2).

The difference in the rates of growth in 1985 (+102% for LANs against +6% and +18% for micro and mini respectively) reflects partly the 'bad' year for computer producers and the existence of a latent demand from previous microcomputer diffusion for LANs to satisfy. From 1987 the rates of growth for LANs started to move independently both of mini and (from 1988) of micro shipments. This reflected a change in priority for firms, from the need to connect standalone computers and share applications to the need to connect existing LANs and it also meant the opening of a new phase in the LAN industry's growth.

Tab.2: Computers (and LANs) shipments (and connections) and revenues (1984-1988);

ITEM	UNIT	1984	1985	1986	1987	1988
Mainframes (units shipped)	1,000	3.5	3.4	3.4	3.7	3.9
			(-3%)	(-)	(9%)	(5%)
Revenues	Bil Dol	12.8	12.6	12.8	13.9	14.4
Super minicomputers (units shipped)	1,000	6.2	7.3	7.9	7.6	10.4
			(18%)	(8%)	(-4%)	(37%)
Revenues	Bil Dol	3.6	3.9	4.4	4.4	5.2
Microcomputers (units shipped)	1,000	198.4	211.2	215.5	238.7	244.6
			(6%)	(2%)	(11%)	(2%)
Revenues	Bil Dol	3.7	3.9	4.1	4.2	4.2
LANs (tot connections)	1,000	340.0	690.0	1,100	1,802	3,700
			(102%)	(59%)	(64%)	(105%)
Revenues	Bil Dol	326.0	593.0	913.0	1,535	2,820

Source: Dataquest, Consolidated Data Base (April 1989);

Note: The percentages in brackets show the year to year rates of growth;

1.2 The second phase (1990-1997)

Three events contributed to the opening of a new phase for the LAN industry: the diffusion of Ethernet over Twisted-Pair (TP), the increased performances at a lower price offered by new computers, the booming of the internetworking market. The first two operated as 'inducement mechanisms' and the third represented the solution to the new constraints posed to the system by those mechanisms.

In 1991, the IEEE working group endorsed Ethernet on Twisted Pair as a standard (100BaseT standard) received a joint proposal from Hewlett Packard, Synoptics Communication and Wang Technologies. From a technological viewpoint, the use of twisted-pair presented drawbacks compared with the performance of coaxial cable, which was the standard cable system, but twisted-pair had the crucial economic advantage of being already implemented in the buildings in the form of telephone cables and the other advantage of having already been adopted by Token Ring as standard wiring. The use of twisted-pair meant a decrease in the initial costs of installation[9] of the network, less space required for cabling and cross-connection panels and the use of one standard type of wiring for all electronic communications. The opportunity of changing the electronics without changing the wiring increased the incentive to replace existing computers with new ones. New computers were not simple substitutes of existing ones but they could provide higher performance at a lower price.

Besides, by the end of the 80's the relative advantage of tying computers and sharing applications on a high performance(and expensive) 'central' computer, which had been the main force driving the industry in the early years, had already started to decline. As the price of microcomputers and peripherals fell, as a consequence of increasing competition in the computer market, the cost savings from adding one more unit to the system dropped as well. Firms became more concerned with connecting LANs than with connecting standalone computers to shared applications. To connect different LANs new devices called bridges were introduced. Bridges connected different networks by performing a 'store and forward function'. They received the data from different networks and subsequently transmitted them to all of the addresses on all of

[9] The cost of material and installation for the cabling, including cross-connect subsystems and outlets, may amount to as much as 40% of the overall costs of a network and it is frequently estimated at 20% of the total expenditures of the system.

the connected LANs. Due to their low processing capabilities they could not differentiate between addresses and they could not support more than one path to each destination. The consequence of a growing number of hosts and the increasing number of addresses to which data might be sent, was that in presence of 'mesh topologies' they became incapable of handling increases in traffic.

Thus, as networks were linked together additional costs emerged due to the increasing complexity of the network. These problems were accompanied by reliability considerations. Since the fallibility of a system is equal to the combined (stochastically determined) failure rates of all its components, the more the components the higher the overall failure rate, the higher the costs of support and maintenance for the network. When LANs are linked together, additional layers are added on, but the greater the number of layers (and of units), the greater the complexity of the network. From an economic viewpoint the price of connecting simple networks into complex networks is not generally a linear function of the number of simple networks since it is affected by the topology, traffic saturation at the level of backbone and also by the compatibility among the network protocols. To add each network is not always the same since as the complex network grows larger the price of connecting and providing the service to individual simple networks tends to rise. Additional costs arise when the LANs to be connected have been grown up separately, as was the case of many intra-firms networks, according to different strategies, supported by different access technologies and supporting different protocols. [10]

Bridges were becoming increasingly incapable to cope with those problems of complexity because of their specific technological characteristics. In a increasingly complex network environment, bridges were very liable to faults and they lacked an organisation which might help to manage the network and control the flow of the data. Reducing the complexity of the network and increasing reliability and its ability to be managed so as to avoid additional costs became the priority for customers.

[10] The price of complex networks to simple networks is expressed by the general formula: $p = (Np_s)(1 + CF)$ where p_S is the price of the simple network, CF is a complexity factor expressed as a percentage of the total simple network cost, N is the number of nodes (networks) connected. When the complexity increases further, the formula becomes: $p = (Np_s)(1 + CF)^{(1+SCF)}$ where SCF represent the additional burden imposed by the growing complexity.
Brandon Walker R. (1988): 'Into the woods: a LAN manager's field guide', Data Communications, Nov. 15 1988, pp.23-41;

Moreover, both the increased performance of computers connected in a the network and the diffusion of twisted-pair pointed to the lack of speed in data transmission as the main constraint which, in a given LAN environment, might restrain the system from further expansion. The increased performance of computers demanded more bandwidth availability to transmit the higher quantity of the data needed to be processed. The adoption of twisted-pair and the subsequent reduction of costs increased the opportunity to further extend the LAN. The combination of the two might end up with worsening the lack of speed problem and reducing the economic benefits of connecting LANs.

New solutions were required both to exploit the technological opportunity represented by the improvement of computers' performances and to cope with the increasing complexity of the network. The quest for these solutions opened up a second phase in the history of the LANs industry where, beside the evolution of the access technology, the technological evolution of the connecting equipment started to play such an important role that a separate industry was created (the internetworking industry). The history of the second phase is a mix of fast growth and increasing competition in the internetworking equipment industry and of uncertainty and proliferation of different standards in the access technology. Each industry deserves a separate analysis and to it we now turn.

1.3 The Internetworking Industry

The rapid establishment and growth of the router market offers evidence about how quickly suppliers coped with the new priorities and users accepted the new solutions. The router segment represents the clearest example of fast and continuous growth in the internetworking market from 1989 up to the present (see Tab.3).

Starting in 1989 the router[11] market has passed through three stages, each opened up by some kind of technological innovation (either radical or incremental). The

[11] A router is a device used to 'segment' the network into a number of regions in which the traffic is distributed between nodes within the region. This reduces the complexity of the system. The main function of the router is to connect different regions and, to perform this task, a router must be capable of interpreting the different network protocols to detect both the sender and receiver addresses with streams of data in order to forward the data. The hardware architecture of a generic router is made up of network interfaces plugged into a backplane. The system constructed upon several boards and includes a CPU which handles the coordination of the router's functions, such as setting up signal reception and transmission and actual packet

introduction of the 'multiprotocol function' was the innovation that opened up the market and engaged router producers in a close and direct competition with bridges makers.

Tab.3:US Internetworking Market: Total Revenues ($ millions) and Rates of Growth (%) per market segment (1989-1996);

Year	Bridges	Routers	Switches
1989	202	85	-
1990	254(25%)	170(100%)	-
1991	274(8%)	275(62%)	-
1992	388(42%)	623(126%)	-
1993	438(13%)	1108(78%)	-
1994	263(-40%)	1356(22%)	232
1995	-	1953(44%)	710(206%)
1996	-	2763(41%)	2461(246%)

Source: Data Communications Market Forecast (several issues);

At the end of this period the segment entered a 'diversification stage' (1992-1994) in which new and old producers started to offer 'scaled down' versions of previous products following mainly two different innovative strategies software-only routing or hardware-based routing. With the diffusion of the switch technology in 1994, the router technology entered another phase, marked initially by intense competition, and then by progressive convergence with switches. Since this pattern represent the main feature of the second phase, we now turn to an analysis of its technological and economic implications.

1.3.1 The router segment

From an economic viewpoint, the feature of the router segment common to all these stages was the combination of an increasing competition with a relatively stable market environment. High rates of entry and exit for firms and decreasing prices combined with relatively stable market shares and the proliferation of new segments over time as the process went on. Tab.4 shows how the initial stock of incumbents increased almost of

forwarding, of non volatile RAM for storage and configuration of the information and of a 'watchdog timer' to restart in case of system failure. See Boulè R., Moy J. (1989), 'Inside Routers: a Technology Guide for Network Builders', Data Communications, Sept 21, pp.53-66.

50% over five years as a net result of a steady increase of new entrants and a decrease in the number of firms leaving the segment.

Tab.4: US Internetworking Market: Router Segment: total incumbents, entry, exit (1993-1997);

YEAR	TOT. INC. (ROG)	TOT. NE. (AS A % OF INC.)	ROG FOR NE	TOT. EXITS (AS A %OF INC.)	ROG FOR EXITS
1993	66	66	-	-	-
1994	58(-12%)	20(30%)	-70%	28(42%)	-
1995	66(14%)	32(55%)	60%	24(41%)	-14%
1996	95(44%)	44(66%)	38%	15(23%)	-38%
1997	98(3%)	28(29%)	-36%	25(26%)	66%
AV.	77(12%)	38	-2%	23	5%

Source: Author's calculations based on The Data Communications Intenetworking Firms' Directory (several issues);

Note: TOT INC stands for Total Incumbents, ROG stands for Rate of Growth, NE for New Entry, AV for Average

As a result of this dynamic, competition seems to have increased and driven the prices down, even if this did not seem to have given the market a more competitive structure. A comparison of market shares between 1990 and 1996 (in Tab. 5) shows an increase in the CR_4 going toward more concentration even if the players are the same and they have just reshuffled their positions.

Tab.5: Worldwide Router Market: Revenues' Market Shares (1990-1997)

Firms	1990	1997
Cisco Sys.	35.2%	63%
DEC	20.3%	2%
3Com	13.2%	6%
Wellfleet/ Bay Networks*	8.7%	15%
Proteon	7.8%	2%
ACC	7.0%	-
Others	7.8%	10%
CR_4	**77.4%**	**86%**

Source:IDC(1990)andDataquest(1997) taken from Data Communications

**Note: Bay Networks was created in July 1994 from a merger between Wellfleet Communication and Synoptics Communications;*

A closer look at the data can help to shed some light on this apparent paradox. Our data about entry and exit cover the entire period of diversification which, as we saw above, was characterised by the absence of major innovations, and the early years of the ‘convergence stage’ with the opening up of the switches segment. During this period, total revenues in the router segment continued to grow and averages prices to fall, but at different rates according to the different subsegments. Table 6 reports the average prices for the two main subsegments in the router market together with the total entries into them. As we can see, in the first two years, prices decreased more in the multiprotocol subsegment than in the access router subsegment. From 1995 onward the pattern is the opposite with the prices continuing to fall but at a higher rate for the access router subsegment than for the multiprotocol one. Parallel to this, new entries continue to increase in the access router segment but to decrease in the multiprotocol segment.

Tab. 6: US Routers Market: Average uncorrected prices (in US dollars) and tot NEs per product subsegment;

			Access Routers		Multiprotocol Routers	
Year	**Tot NEs in the segment but NOT in the industry**	**Total NEs both in the segment AND in the industry**	**Av prices**	**tot NEs**	**Av prices**	**tot NEs**
1993	-	-	5,008	30	9,739	48
1994	9	11	4,945	23	8,771	21
1995	10	22	3,779	24	8,410	8
1996	10	34	2,944	33	9,325	3
1997	2	26	3,250	19	-	-

Source: Author’s calculations based on Data Communications Internetworking Firms’ Directory (several issues);

Competition did seem to affect the multiprotocol more than the access router sub-segment at the beginning because more firms coming from both other sub-segments within the router market, entered this subsegment immediately. In the access router segment, prices started to fall moere quickly than in the multiprotocol segment only in 1995 partly because the switches segment took off and partly because the number of NEs increased. In the former case, competition increased because a possible product substitute opened up a new segment at the industry level. In the latter case competition came from within the router segment mainly from firms which had previously entered the multiprotocol sub-segment. It seems that increased competition from a product substitute exerted a higher effect on routers' prices than increased competition within the product segment.

Increased competition within the router segment is less effective because of higher barriers to entry represented by the high capabilities required to provide the software responsible for the multiprotocol routing function. Most of the new firms which entered the sub-segment during the diversification stage could not provide the routing function in their products which had to be handled by the PCs, while established firms responded to the challenge of new entrants with new products that contained proprietary software and hardware. So if we look at the Concentration Ratios of the single market sub-segments within the router market (Tab.7) we realise that the multiprotocol sub-segment is more concentrated than the remote access sub-segment. Competition in multiprotocol sub-segment may have increased as the result of new firms entering the segment, but it is more unlikely that new entrants will affect the market shares of the market leaders.

Tab. 7: US Router Market: Subsegments' Revenues Market Shares

Multiprotocol segment			Remote Access Segment		
Firms	**1997**	**1996**	**Firms**	**1997**	**1996**
Cisco Sys	64%	58%	3Com	34%	6.2%
Bay Networks	10%	12.7%	Ascend	27%	22.7%
3Com	4%	4.6%	Cisco Sys	18%	11.4%
IBM	2%	2%	Shiva	5%	8.2%
Motorola	2%	5.5%	Us Robotics	-	26.1%
Others	18%	17.2%	Others	16%	25.4%
CR_4	**80%**	**80.8%**	**CR_4**	**84%***	**68.4%**

Source: Author's elaboration based on Dell'Oro Group Reports (Nov. 1997);

**Note: The increase in the CI_4 is due to the acquisition of US Robotics by 3Com in 1997;*

Increased competition from outside the market is more effective in disrupting technological barriers than increased competition within existing segments, even if it exerts its effects more slowly on those sub-segments where the barriers to entry are higher. Thus within sector entry appears to have had less impact on market outcomes, includin relative growth, than inter-segment competition.

1.3.2 The switches segment

In 1994, the opening of the switches market exerted a deep impact on the sales of the other segments in the internetworking industry. Routers sales slowed down and the bridges segment experienced a negative growth in sales for the first time in its history. The introduction of switches was a definite hit on the bridges market which had already been seriously injured after the competition against routers at the end of 80’s, but at the same time switched networking also represented a window of opportunity for firms to undermine, for the first time since its foundation, the growth of the router segment and to lay foundations for future changes in the entire industry.

The first switch was introduced in 1990 by a US based company, Kalpana, as an attempt to satisfy the constantly increasing demand for bandwidth coming from the new high performance PCs and applications which were more and more linked over Ethernet LANs. Due to the high uncertainty on the access technology side, where the proliferation of many alternative high speed technologies had not yet led to the endorsement of any one of them as the alternative standard to Ethernet, innovating at the level of the internetworking component was almost ‘compulsory’ for producers to overcome this performance deadlock. The idea behind the switches is to bring into networking a principle employed by telephone technology where, when the stations are connected to a switch, the switches ensure the exclusive availability of the entire bandwidth of a communication channel (10 Mbit/s in the Ethernet case).

The early switches introduced in the market could be considered from a technological point of view a logical development of bridges. Like bridges, early switches operated at layer two of the OSI protocol scheme and like bridges there were incapable of distinguish among all the different addresses where the data packets could be forwarded to. These limits were mainly due to the configurations of the CPUs’ architectures which did not allow the devices to set up and maintain the address tables, the forwarding and the management processes. These first generation switches had all the shortcomings which had led to the levelling off of the expansion of bridges and to their partial substitution by routers after the late 80’s intense competition: few ports supported, relatively simple address tables to avoid delays in the storing and forward process, no capabilities to segment the network, exposure to broadcast storms. They were faster than bridges, but they supported only situations in which the traffic was mainly local, and LANs architectures were flat. For these reasons, when they early appeared in the market they were closer substitutes for bridges, and they engaged a direct competition with them rather than with routers, which gave the bridges market a death blow.

Second generation switches incorporated a high speed search mechanism which allowed them to search the address tables very quickly and minimise the delay between receiving and forwarding a data packet. This enabled them to support more ports, to be used in relatively complex LANs environments and also to perform some functions at higher functional levels,[12] challenging what until then had represented the exclusive technological domain of routers. This domain of application distinguished them from all the other internetworking products and supported very high growth rates in their market.

This entry into router's technological field was the consequence of technological improvements which affected the forward capabilities of the CPU both at the software and at the hardware level.[13] At the software level, the ever more widespread adoption of RISC processors (in particular the Intel i960) induced producers to focus on the quality of software code (e.g. its overall operating speed) or on a specific technological feature of code (e.g. real time processing of addresses), enhancing the performance of the switches and make it relatively easy to upgrade the switches via available software downloading. This flexibility was obtained at the expense of performance since the intrinsic limits of the architecture may prevent switches from supporting the data processing as the number of ports increases. High performance and flexibility of upgrading, seemed be enjoyable only by limiting the number of ports on the switches.

At the hardware level, the picture is different. Here the main improvements stemmed from the re-configuration of the switches' hardware by using ASICs (Application Specific Integrated Circuits). In the specific case of switches, the advantages of ASICs in carry out specific tasks, were exploited to process the data packets at the maximum speed of the transmission medium. Thanks to their high level of component integration, ASICs

[12] There are two types of layer three switches according to the method of forwarding they employ: packet-by-packet (PPL3) and cut-through (CTL3). PPL3 switches examine all packets and forward them to their destination by using the same routing protocols used by router (Open shortest path first), the same routing tables and understanding the network topology. They are identical to routers since they operate completely at layer three and they are faster than routers.
CTL3 switches operate at the layer three just to detect the destination of the data packet by opening only a small portion of it and then they switch the rest of the packet at layer two benefiting from the low delays and the high throughput provided by the switches.

[13] This section draws heavily on Hein M.-Grifiths D. (1997);

can produce in one chip the processing power of five to ten RISC chips but the relevant codes are implemented directly in the hardware which is very difficult to modify. Any time the switch needs to be upgraded, a new ASIC chip must be produced. ASICs are relatively cheap to manufacture especially in great quantities and this translates into greater cost-effectiveness (and lower prices) for the ASIC-based switches compared with software-based ones, but the process of development of a new chip always takes a long time and is very risky. To diminish risk manufacturers usually develop their ASICs in two stages. First they integrate their codes into components called Field Programmable Gate Array (FPGA) which are cheaper to produce than ASICs. Then they modify the code and replace the FPGA with pure ASICs.

FPGA usually process the code slower than ASICs but, since upgrading the code is quicker than developing a new code, producers can offset the costs of a lower initial performance with the benefits coming from a reduction in the total development time. Once the new code is developed and implemented on new ASICs, economies of scale enable low costs.[14] We have summed up the trade-offs between software based and hardware based switches in Tab. 8.

From an economic viewpoint, the innovation represented by the switched architecture exerted a great impact on the internetworking industry. A sign that the new product had fulfilled a latent demand for more bandwidth in the market, was an immediate increase in sales aided by falling prices. As a result, in 1997 an Ethernet or Fast Ethernet switch was priced (on average) only 35% more than an access router. The price premium was even smaller as switches had higher performances.

[14] How many ASICs to implement in a switch is a choice of producers. Two strategies are usually followed. They can either use a single central ASIC for the switch or implement a separate ASIC for each port. In the first case the switch will be less expensive but, with a lower port density, more keen to be used in smaller networks. In the second case the switch will be more expensive but also more scalable.

Tab. 8: Comparison between ASIC and processor based switches;

Function	**ASIC switch**	**Processor switch**
Processor	ASIC	Standard processor
Design	Design specially tailored to requirement	Chipset developed for general requirement
Instruction sets	All IS implemented in the hardware	Additional software required
Processing speed	High	Low
Modifications	Difficult to implement	Can be implemented by changing the code
Scalability	High	Low scalability
Risk	Very high	Low
Cost	High	Low

Source: Hein M.-Griffiths D. (1997), p.142;

Tab.9: US Internetworking Market: Switches Segment: Revenues' market shares (1994-1997);

Firms	**1994**	**Firms**	**1997**
Kalpana**	34.7%	**Cisco****	23%
3Com	10.1%	**3Com**	16.4%
Cisco**	8.7%	**BayNetworks***	15.4%
UB Networks	6.5%	**Cabletron**	12%
Artel	5.9%	**FORE**	2.9%
Net. Peripherals	5.8%	**IBM**	2.6%
Alantec	4.1%	**Digital**	2.2%
Lannet	2.9%	**Xylan**	2.2%
Plaintree	1.0%	**HP**	2.2%
Xnet	1.0%	**Madge**	1.8%
Synoptics*	0.1%	**Intel**	0.8%
Others	19.3%	**Others**	21.1%
CR_4	**60%**	**CR_4**	**66.8%**

Source: Author's elaboration based on Dataquest Inc.(1994) and Dell'Oro Group Report (1997);

*Note: *Synoptics merged with Wellfleet in July 1994 to create Bay Networks;*

***Cisco acquired Kalpana in 1995;*

The commitment of suppliers to address demand came together with a change in the structure of the segment, although this change was different from the one experienced in the router segment.
A comparison between the market shares in 1994, just after the boom of the sales, and at the end of 1997 (see Tab.9 above), shows a movement toward consolidation in the industry ending with an increase in CR_4.

Contrary to what had happened in the router segment where the increase in the CR did not bring about major changes in firms' ranking, here the segment experienced a marked shuffle as the result both of a change in the relative position of incumbents and of the entry of new firms. Unfortunately we are not able to fully reconstruct the pattern of entry and exit over the period 1994-1997 which would be helpful in understanding the dynamic behind this process. two of the important changes can, however, be identified. First, among the incumbents which strengthened their position, two of them did it through acquisitions. Cisco acquired Kalpana, the market leader and the pioneer in the switches segment, in 1995, Synoptics merged with Wellfleet to create Bay Networks in 1994. As in the routers' market, mergers and acquisitions seemed to have increased the overall level of concentration. Second, among the leaders in 1997 only Cabletron was not in the market three years before and its fast rise seems to be more a reflection of its capacity to master products across different access technologies than a consequence of a deep commitment to develop and market the switched architecture.[15] Beside these firms, all the other incumbents at the end of 1997 had not been in the industry in 1994. This reinforces the 'shuffle hypothesis' and suggests that new entrants might have been mainly responsible for it.

The 'switch revolution' is very much related to the evolution of the access technology field. When it occurred in 1990, a swarm of alternative access technologies was both competing in the market to become 'de-facto' standards and being backed within official standard committees to be ratified as 'de-jure' standards. Once they became established, it became clear that switches represented not only another solution to boost bandwidth, but also an alternative which decoupled, from the first time since their births, the evolution of the internetworking industry from the evolution of the access technology. The option to increase bandwidth and to handle different access

[15] At the end of 1997 Cabletron was the only firm, in the switches market, delivering products in each of the access technology sub-segments. Cabletron had acquired this capacity to master several access technologies from its leading position in the hub segment.

technologies at the same time without recabling changed the priorities for firms. It became essential to integrate the new switched architecture on the large installed Ethernet base rather than to find a substitute to Ethernet. This induced firms to supply Ethernet based product in their product lines and also ended up with revitalising the oldest LANs' segment. This can be quickly and quickly grasped by looking both at the relationships between switch revenues and the access technologies and at the pattern of new entries in the switches segment for a specific year 1997 (See Tab. 10). The Ethernet and Fast Ethernet segments take the highest share of the total revenues among the alternatives. Ethernet's switches are not only the cheapest, thanks mainly to the highest total number of incumbents in the segment, but are the segment is also the segment which still attracts the highest proportion of NEs. This clearly supports our claim about changing priorities.[16]

Tab. 10: US switches market: 1997 average uncorrected prices, market shares and NEs per access technology;

Technology	Av Price (in US dollar)	Revenue shares	Tot. NEs per sub-segment (1997)	Tot Inc per sub-segment (1997)	NEs/ Tot Inc per sub-segment
ATM	9,953	7%	7	26	22.5%
Giga-bit Ethernet	36,499	NA.	8	14	25.8%
Ethernet and Fast Ethernet	4,841	80%	17	74	54.8%
Token Ring	8,397	7%	1	8	3.2%
FDDI	15,872	6%	0	3	0%

Source: Author's elaboration based on Data Communications LAN Firms Directory (several issues);

The Ethernet and Fast Ethernet segments take the highest share of the total revenues among the alternatives. Ethernet's switches are not only the cheapest, thanks mainly to the highest total number of incumbents in the segment, but are the segment is also the segment which still attracts the highest proportion of NEs. This clearly supports our claim about changing priorities.[17] The same argument about the 'compatibility driven

[16] Since our data on firms' mobility do not distinguish between Ethernet and Fast Ethernet, maybe most of the new firms in this segment provides fast Ethernet switches. Anyway this do not seem to undermine our claim that NEs are mainly driven by compatibility considerations.

[17] Since our data on firms' mobility do not distinguish between Ethernet and Fast Ethernet, maybe most of the new firms in this segment provides fast Ethernet switches. Anyway this do not seem to undermine our claim that NEs are mainly driven by compatibility considerations.

process of entry' is reinforced by the fact that more firms enter the Gigabit Ethernet switches segment than the Token Ring one even if, given the higher relative price for G-bit Ethernet, new entrants may be more motivated by a lure for high profits than by a large installed base to sell their products to. It is important to stress how, among the new alternative technologies segments, ATM has the same share of revenue of Token Ring with more incumbents in the market and attracts a higher number of new firms. In this case the compatibility issue does not make the difference but, given the high expectations on ATM both on the performance (integration of audio, video with data transmission) and on the bandwidth it can provide, firms may be attempted to enter the segment to gain a first mover's advantage over the competitors.

These data can also be used to partially address the relevant question of the economic effects of the technological substitutability between switches and routers. As we saw above, especially after the introduction of the second generation of products, layer three switches' suppliers really challenged their router's competitors by providing cheaper products displaying the same functions with higher performances. Competition from the switches segment seemed to hit the router market more intensively than increased competition within the segment had done in the past. Routers seemed bound to experience the same pattern of decline that bridges had already experienced. Actually this did not happen nor has it yet occurred. Revenues for switches continue to soar, but revenues for routers keep steady and this seems to contrast with the substitutability argument and with what happened in the past.

This apparent contradiction. The first explanation stresses only the role of the technology in shaping the outcome as the relevant point to consider. According to this explanation, the technological fields which both routers and switches belong to are too similar to prevent them from converging on just one product. The fact that it has not happened yet is mainly a consequence of a lack of 'stimuli' from within the technological system for that kind of integration to occur. Were that sort of pressure to appear or to turn into effective competition, maybe as a consequence of further 'push' coming from technological improvements in the terminal equipment connected to the network, the convergence would accelerate and the technologies would converge or the one performing better would prevail.

This explanation indicates an important point when dealing with technological innovations in a system since it hints at the relationships among the components of the technical systems as having a major responsibility for market evolution over time. Data on firm mobility suggest that in 1997 25% of incumbents in the switches segment were active also in the router segment and that the share (over the total new entrants) of new entrants in both segments is higher than the share of NEs only in one of the two segments, supporting the argument about the common technological base.

Nevertheless this argument misses one point. Technological pressures might be present, but if there is not an economic incentive to innovate, extending the field of application of an existing technology 'per se' will not be economically successful. In the specific case of the substitutability between switches and routers the economic benefits from the convergence in terms of transfer of a common knowledge base among different products, reflected in the diffusion of common design practises and manufacturing methods, must be valued against the losses firms may incur once they have to phase out already existing product lines to avoid expensive overlaps. To embrace the new switched architecture might not be profitable for router producers, even if meaningful from the technological viewpoint, if they have to scrap their installed base. A better solution would be for them to have the two markets coexist and this seems to be a better explanation for what is happening now.[18]

1.4 The evolution of the access technology

The development and diffusion of the switch were also a consequence of the stalemate which occurred in the access technology field at the beginning of the '90s when new solutions were required to overcome the bandwidth shortage problem. The main reason why Ethernet started to represent a bottleneck for further development of LANs was the so called 'total and node throughput issue'. The total throughput is the total amount of traffic that can be carried overall. For a given amount of bandwidth, as more users started to be added to the network each one received a smaller share of the total bandwidth available. The node throughput is the amount of traffic that one device (either server or workstation) can transfer or receive from the network. The potential gain in performance obtainable from fast servers decreased if they had to let other users share the network.

[18] Moreover, data on sales suggest that the router sub-segment where the growth is actually coming from is the high end of the market, as if routers were losing their status of internetworking products and becoming sorts of WAN interfaces. This envisages a future of coexistence for switches and routers when the former are used in the low-end of the backbone and the latter to connect LANs to the backbone.

Overcome this bottleneck was perceived immediately as the main priority by firms in the industry and several alternatives were quickly introduced in the market. At the end of 1993 there were ten access technologies competing in the market and only one of them (FDDI) has had already been endorsed officially as a standard. Four of them implemented a token passing architecture (FDDI, CDDI (FDDI over copper), FDDI for multimedia, FFOL (FDDI follow-on-LAN the eventual successor of FDDI at 2.4Gbit/s)), three of them were Ethernet-based (Fast Ethernet (CSMA/CD), Fast Ethernet (100Base-VG), Isochronous Ethernet) and two implemented a switched architecture (ATM, Fiber Channel).

This proliferation of alternatives was the consequence of specific strategies of the vendors to seize a share of the market as large as possible in the hope of getting their access technology standardised through either a 'de facto' or 'de jure' standard-setting processes which would officiallly endorse one of the alternatives. According to this logic FDDI the first standard to be officially endorsed and the first technology to have entered the market should have enjoyed a relative advantage over the other alternatives. Actually this did not seem to happen. Table 11(next page) reports the total number of firms and new entry in the hub market according to access technology supported over the period 1993-1996.[19] The share of firms into the FDDI segment over the total has never been higher than 21%, a peak reached after four years after the standardisation. Fast Ethernet (CSMA/CD) reached a higher share (25%) only two years after the standardisation even if it was introduced later than FDDI. Moreover, the average price of both the alternatives have always been lower then FDDI (See Tab.12).

[19] Since we lack data about the number of sponsors of the access technologies over the period we are analysing, we use data about the hub market as a proxy of the diffusion of each technology to investigate the incentive for producers to enter the market into a specific segment. Hubs are networking devices which are mainly used to link existing LANs either together or to the backbone. Since new access technologies performed at higher speeds than Ethernet or Token Ring, which were implemented by most of the existing LANs, they needed hubs to be connected to existing networks. Obviously hubs are sold in a separate market whose price and concentration depends on the capacity of firms to design and manufacture products rather than simply choosing the access technology to support. However with these caveat we think they could provide indirect evidence at least of the trend in the diffusion of the access technology too.

<u>Tab.11: US Hub market: Total Incumbents tot New Entry and new entry as a share of total incumbents(%) per Access Technology (1993-1996);</u>

Year	Tot INC	Tot NEs FDDI	Tot NEs Fast Ethernet	Tot NEs 100VG-Any LAN
1993	71	8	-	-
1994	108	14(13%)	-	-
1995	65	13(20%)	3(5%)	4(6%)
1996	71	15(21%)	18(25%)	5(7%)
Average	78.75	12.5	10.5	4.5

Source: Author's elaboration based on The Data Communications LAN Firms'Directory (several issues);

Note: TOT INC stands for Total Incumbents, NE for New Entry;

<u>Tab.12 : US hub market: Average Uncorrected Prices per access technology;</u>

Year	FDDI	100 VG-Any LAN	Fast Ethernet
1993	11,706	-	-
1994	6,612	-	-
1995	6,667	2,448	2,238
1996	6,470	2,049	2,373

Source: Author's elaboration based on The Data Communications LAN Firms'Directory (several issues);

FDDI had been the first alternative to be standardised. FDDI's high price attracted new sponsors by rewarding them with higher profits than producers of rival technologies. Relatively low barriers to entry the FDDI segment represented a further incentive for new firms to sponsor it. Despite all these advantages the evidence suggests that FDDI did not benefit. On the contrary Fast Ethernet although it was a second comer was immediately recognised as viable and profitable by the producers.

There are two possible explanations of this outcome. One is that compatibility was the main concern behind firms' decisions about which alternative to sponsor. In the case of the access technology, compatibility means both conformity with the already installed access technologies and conformity with the cables already in place. Fast Ethernet used the same topology and the same packet format of the existing 10 Mbs Ethernet and the costs of connection were very low since a hub equipped with a memory buffer could handle the speed difference. Fast Ethernet worked over cheap and already available copper cables, instead of the expensive optic fibers supporting FDDI. FDDI clearly had major drawbacks with both these points when compared to Fast Ethernet.

The second explanation deals with performance. Here FDDI had more advantages than the competing technologies especially because fiber optics solved the problem of electromagnetic interference whose limitation was the main challenge to transmission of data at higher speed over copper. Nevertheless, the performance yardsticks became ATM and Fiber Channel and not the Ethernet upgrades. Being switched architectures, ATM and Fiber Channel allowed for the simultaneous transmission of packets at lower speed instead of the transmission of a single stream of packets at a higher speed as happened with the shared architecture. For this reason they could ensure better performances than FDDI both in interactive connections and in the integration of data, video and voice.

Both FDDI and Fast Ethernet were shared architecture and they were outcompeted along this dimension by the ATM and Fiber Channel alternative. Nevertheless FDDI presented drawbacks also in terms of compatibility while the presence of a wide compatible installed base guaranteed the viability and profitability, via rapid adoption, of Fast Ethernet. Moreover, as we have seen above, the introduction of the switch in the internetworking market, which revitalised the segment of previously adopted access technology such as Ethernet, probably focused the development of innovations in access technology upon alternatives compatible with the existing ones.

This combination of factors stresses the importance of the compatibility over others as the central concerns which drove the decisions of the producers about which alternative access technology to sponsor. The motive of preserving compatibility with existing technologies enhanced the viability of certain technologies, delayed the development of other alternatives some of which were less viable but other which were more viable[20], and thwarted both the strategies of the first movers and the attempts of official committees to establish just one standard.

[20] This is the case of ATM. See below for a discussion of this.

Conclusion

The picture of the evolution of the LAN industry sketched in this chapter has stressed some of the typical features of technical systems. As LANs are made of several different components coming from different markets, the evolution of each market influenced the diffusion of LANs through the effect of technological and economic complementarities.[21] These effects displayed at different points in time and according to different intensities. Very often they amplified each other and the final supply and demand for LANs were shaped by these interactions.

After an early phase in which the diffusion was 'pulled' by the economic benefits of linking computers together, we got through a period where the 'technology push' coming from both the evolution of the access technology (Ethernet over TP) and the improvement of computers' performance introduced new opportunities but also set new technological constraints. The exploitation of this new opportunities and the attempt to overcome the technological constraints set new economic priorities for firms and opened up the second phase of the evolution of the industry with the creation of the internetworking market and with the introduction of new access technologies.

The separate analysis of both has highlighted the importance of several economic factors in shaping their evolution such as direct and cross-substitution among products, the importance of the compatibility and of the depth of installed base. To understand how these factors combine together we now turn to a different kind of analysis.

[21]Technological complementarities are due to features of the computer hardware entering the final service. Economic complementarity is the result of changes in the costs and features of other components affecting the data transmission and reflected by the price of the final service provided. Both effects are mainly due to the systemness according to which changes in each of the components within the system may affect the dimensions responsible both for scale and scope economies.

CHAPTER 2

THE DYNAMIC OF THE SYSTEM

If our goal is to understand the evolution of the LAN industry by investigating the dynamics of its components, the analysis of the previous chapter is partial and biased. It is partial because we have not developed a complete picture of the evolution of the internetworking industry but only of two separate segments. To investigate the interactions *between* different markets during the diffusion of LANs, we should consider how markets have grown up and changed their structures over time as a consequence of the interactions among firms *within* each market. The analysis is biased because, although we may have an idea of the mechanisms behind the adjustment process following the introduction of an innovation, we have not specified the dynamic of the industry before the innovation occurred. Thus, we cannot comment upon the effects of the innovation on the relationships *between* the two markets.

To overcome these problems we should compare the dynamic of both industries before and after the introduction of a significant innovation like that of switches. By doing this we can provide a picture both of the 'intrinsic' dynamic and of the effects of a shock represented by an innovation on each industry separately. Unfortunately, because of the lack of data, we can not fully analyse the pattern of entry and exit of the access technology industry from 1985 to 1989 and of the internetworking industry from 1993 to 1997. Nevertheless we think our analysis offers significant insights. First, between 1985 and 1989 access technology was relatively stable; Major technological innovations did not occur until the beginning of the 90's. We may assume that the industry displayed its 'intrinsic dynamic' in this period. Second, between 1993 and 1997 the internetworking market was hit by the innovation represented by the introduction of the switch and its pattern of entry and exit clearly indicates the changes in the environment following this shock.

We expect to find different dynamics of firm growth and entry in the two industries for these two cases. The question of the source of these dynamics is an important issue. One possibility is that the difference merely reflects the effect of the environmental shock. A second is that change in the relationships between the two markets followed the shock but was not directly related. Once known the pattern of entry and exit of each market and the history of the diffusion of LANs so far, we can make some hypotheses on the evolution of the interaction between the access technology and the internetworking market over time and try to solve this puzzle.

2.1 The dynamic of the access technology industry (1985-1989)

We start with the analysis of the dynamic of the access technology industry between 1985 and 1989. As we have seen this was a period of consolidation for Ethernet, without innovations after the standardisation of the access technology. We want to investigate the evolution of the growth rate of incumbents over time which is defined as the difference between the rate of entry and of exit of the firms from the industry.

The evidence is shown in Tab.13. Over the period both the number of new entries and of the exits increases monotonically and although the new entries are never higher than the number of firms leaving the industry, the number of total incumbents increases monotonically too. If we look at the rates of growth (ROGs) the pattern is still uniform.

Tab. 13: US LAN industry: Density, Entry and Exit (1985-1989);

YEAR	TOT. INC. (ROG)	TOT. NE. (AS A % OF INC.)	ROG FOR NE	TOT. EXITS (AS A %OF INC.)	ROG FOR EXITS
1985	47	47	-	-	-
1986	73(55%)	43(91%)	-8%	17(36%)	-
1987	124(70%)	74(101%)	72%	23(31%)	35%
1988	154(24%)	75(60%)	1%	45(36%)	96%
1989	159(32%)	75(48%)	0%	70(45%)	55%
AV.	111(42%)	63	16%	39	62%

Source: Author's elaboration based on The Data Communications LAN Firms' Directory (several issues);

Note: TOT INC stands for Total Incumbents, ROG stands for Rate of Growth, NE for New Entrants, AV for Average

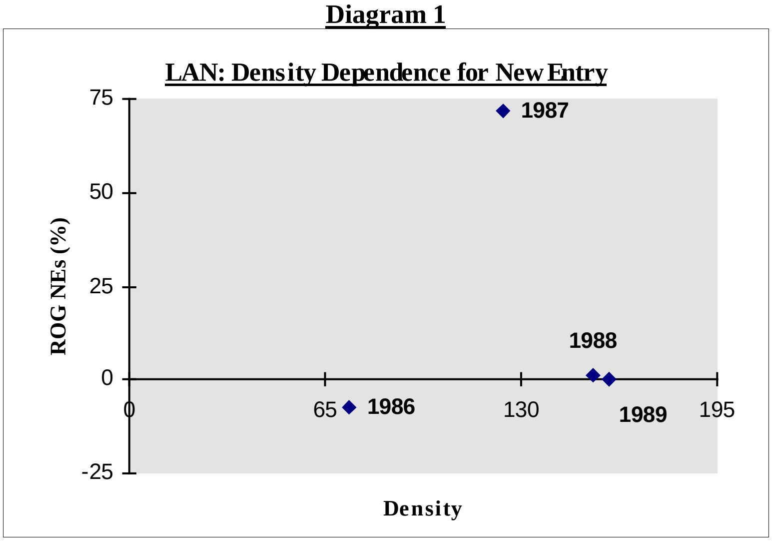
Total incumbents and new entries seems to display a similar decreasing pattern after an increase in the early years. The ROG for total exits increases and then decreases until the end of the period.

Reasons behind entry, exit and persistence in the industry are different since they are three different processes. However, the existence of similar patterns suggests that they can be related.

Both the number of new entries and the number of the total incumbents is small at the beginning but new entry represents a high percentage of the total incumbents. They both increase but when the number of new entrants level off at the end of the period they represent a smaller share of the total incumbents with respect to the beginning of the period. Both the number of exits and their share of the total incumbents are small in the early years. They both increase but, at the end of the period when the number of incumbents in the industry is about three times its initial level, the share of exit to the total number of incumbents is higher than it was at the beginning.

This seems to suggest a positive linear relationship between the density (total incumbents) of the industry and the total number of entry and exit. Nevertheless, if we look at the ROGs the pattern becomes more complicated. Disregarding the monotonic increase in the total incumbents, ROGs both for entry and exits first increase in the early years then decrease at the end of the period. The relationship between density and the ROGs does not seem to be monotonic. It is still positive for low levels of density up to a certain point, but beyond that it becomes negative. For the rate of entry the pattern is the following.

Diagram 1



The evidence suggests that the increase in the number of new entries begins soon after the standardisation of Ethernet and Token ring. Several reasons might have induced firms to enter the industry in this time period.

The endorsement of Ethernet as a standard might have reinforced the advantages it already enjoyed as a consequence of having been the first to be introduced in the market. Before the endorsement, when Ethernet was sponsored only by the Dix consortium and its diffusion still limited, the costs of sponsoring it for a new firm should have been more or less equivalent to the costs of developing an alternative access technology. The expected benefits were higher since, thanks to network externalities, previous adoptions might favour the adoption of the existing technology by new adopters.[22] A strategy of low pricing, which might have enhanced the diffusion of a new alternative technology over the existing one, might have appeared risky and impracticable in a context of already decreasing prices.

The flow of entries was probably reinforced by other factors. An increase in total revenues parallel to the increase in production might have induced some firms to enter attracted by the lure of profits. For this to be effective, the profit margins should not have been eroded by the decline in prices. We do not have evidence to support this claim. However had this effect operated, this alone could not explain the reasons Ethernet kept its advantage over the alternatives[23]. The main point is that the endorsement acted as a source of legitimacy encouraging more firms to enter the market and sponsor *that* existing standard instead of an alternative one.

The positive relationship between density and rate of entry continues until 1987 when it turns into a negative relationship. One possible explanation of this change in the pattern is that by then the number of incumbents in the industry had reached the point where the benefits in terms of legitimacy new firms could get from the addition of other firms to the industry, were offset at the margin by the increase in density brought about by the presence of more firms in the industry.[24] The fact that the peak in the ROG for NEs occurs in 1987 in coincidence with the highest decrease of price over the period seems to confirm this claim. Moreover, in an oligopolistic market, the increase in density

[22] The existence of benefits deriving from the presence of network externalities is confirmed by the fact that Token Ring which was marketed only one year after Ethernet has never reached the popularity of Ethernet even after its endorsement as a standard.

[23] The only evidence we can rely upon, coming from the internetworking industry is that, to implement a device over token ring, the other available technology at that time, has always been more expensive than to do it using Ethernet. Moreover, Token Ring markets have always been more concentrated than others with higher prices and so less competition.

[24] "(...) a form receives legitimation to the extent that its structure and routine follow the dictates of the prevailing istitutional rules (...) an organisational form is istitutionalised or legitimated to the extent that it has a taken for granted character". See Hannan M.T., Carrol G.R. (1992), pp.33-34;

This definition stresses the concept of legitimacy at the level of firms' organisation but it may be refrred also to the technology in the case of the innovating firm. The innovationg firm has major chances to introduce and support the diffusion of an innovation if the innovation conforms to the institutional rules (the case of official standardisation) or if the technological peculiarities of the innovation are well known and easily accepted by the majority of adopters.

multiplies the number of possible interactions among firms and the number of possible results firms have to consider as a consequence of their strategic behaviours. This increases the general level of uncertainty and might prevent more firms from entering the market.

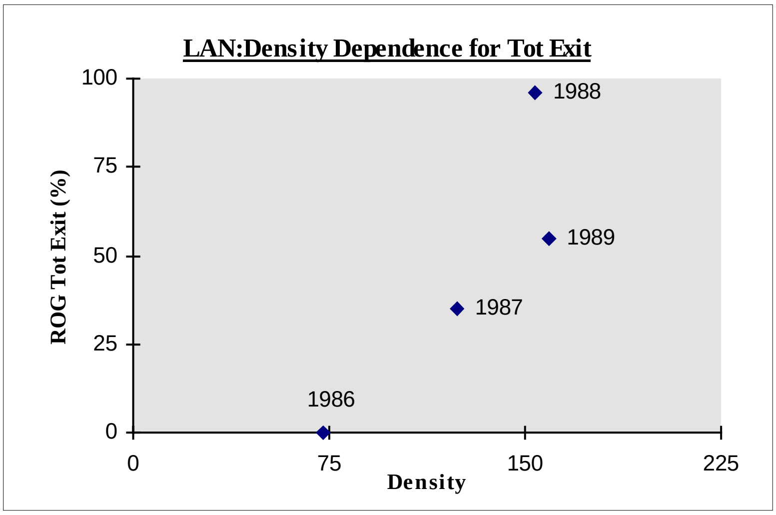
We might think that the same forces underlining the relationship between density and the rate of entry affects the relationship between density and the ROG of exits too. According to the theory, increases in density lower the rate of exit of firms through an increase in legitimacy. This occurs up to a certain point when competition, brought about by further increases in density, overcomes the legitimacy effect and induces an increase in the rate of exit. As density continues to increase, the rate of exit increases as well to a peak when the given resources of the industry have been almost completely exhausted. As a result we should expect to find a U-shaped relationship with high exit rates both at small and high level of density and a decreasing, but from a certain point increasing, pattern in between.[25]

Actually this pattern does not seem to fit our data. The scattergram in Fig.2 (next page) may either fit a linear positive relationship or a non-monotonic relationship (increasing up to 1988 and then decreasing) but it does not seem to conform to the theory.

At low density we have low rates of exit which increase as the density increases. The data seem to capture only the competition effect responsible for the upward sloping part of the U-shaped curve and neglect the legitimacy effect. This pattern is puzzling since, as we have just seen, a legitimacy effect does operate in the case of new entries. The puzzle is partially solved by requiring that legitimacy is supposed to exert at the same time two opposite effects on firms. The legitimacy effect is most effective at a low level of density but it exerts opposite effects on firms entering and leaving the industry. In the case of entries, legitimacy sustains the entry process at low density when the rate of entry is low. In the case of exits the exit rate is high because a small number of incumbents at the beginning prevents the technology from gaining the legitimacy it requires to become established.

Diagram 2

[25] See Hannan M.T., Freeman J. (1989), chap.6;



The point is how the growth rate of incumbents gains momentum as a result of the interaction of these two processes.

If the share of new entries over the total number of incumbents is high as in our case (see Tab 13 third column above), then a high rate of exit *within* new entries (a 'churn' of the new entrants pool) due to low legitimacy may boost the overall rate of exit. The overall rate of exit might be low at a low level of density but this does not necessarily imply that the negative relationship between density and legitimacy is not effective. If a higher number of new firms leaves compared to the total incumbents and if the share of new entry over total incumbents is high, then the rate of exit might be low at the beginning when only firms from the initial stock of incumbents may leave but it increases as new firms enter and immediately leave the industry. The evidence in tables 14 and 15 seem to confirm this hypothesis.

The pattern of exit for incumbents as a share of total exit is decreasing in the early years of incumbency (1986) but then it increases in the following years (Tab.14). The pattern of exit for new firms as a share of total incumbents is decreasing over time for any given year of entry (Tab.15) but as we can see from the average cumulative shares new firms leaving represent always high shares of total incumbents (61% after four years, 42.5% after three years and 37.5% after two years).[26] A smaller number of incumbents seems to leave in the early years than subsequently because total exits are

[26] We got these data from Tab.15 by calculating the simple means of the percentages after two, three and four years of permanence in the industry.

boosted by the increasing number of new firms which enter and leave the industry immediately.

Tab. 14:US LAN Industry: Pattern of Exit for Incumbents as a % of INC in the year of presence (1985-1989);

YEAR OF EXIT/PRESENCE	1985	1986 (CUM)	1987 (CUM)	1988 (CUM)	1989 (CUM)
1985	NA	-	-	-	-
1986	NA	36%(36%)	-	-	-
1987	NA	25%(61%)	31%(31%)	-	-
1988	NA	13%(74%)	18%(49%)	36%(36%)	-
1989	NA	13%(87%)	23%(72%)	30%(66%)	45%
TOTAL	NA	87%	72%	66%	45%

Source: Author's elaboration based on The Data Communication LAN Firms' Directory (several issues);
Note: CUM stands for cumulative;

Tab. 15:US LAN Industry: Pattern of Exit for New Entry as a % of INC in the year of exit (1985-1989);

YEAR OF ENTRY/EXIT	1985	1986 (CUM)	1987 (CUM)	1988 (CUM)	1989 (CUM)
1985	-	36%(36%)	16%(52%)	5%(57%)	4%(61%)
1986	-	-	18%(18%)	5%(23%)	5%(28%)
1987	-	-	-	27%(27%)	14%(41%)
1988	-	-	-	-	22%
1989	-	-	-	-	-

Source: Author's elaboration based on The Data Communication LAN Firms' Directory (several issues);

Note: CUM stands for Cumulative

What emerges is that the density dependence for ROG of exit may depend on the 'competition effect' but actually this competition is only *within* new entrants and the different dynamics of new entrants and incumbents do not cancel the legitimacy effect. Instead they might be a consequence of the it. Soon after the standardisation of Ethernet which 'legitimised' the technology and set the pace for the early entries, incumbents enjoyed the benefits deriving from low competition and network externalities on the demand side. At this stage, because of the relative small installed base, we may assume that both incumbents and new firms enjoyed quite similar benefits and had quite similar low rates of exit. When the potential demand for linking computers became effective in 1987, incumbents further strengthened their position and the incentive for new firms to enter increased. As a result new entries peaked but the widening of the installed base for early incumbents might have created an entry barrier *within* the industry between them and new firms[27]. As a consequence new firms continued to enter, at a decreasing rate, but since they were incapable of competing effectively against early incumbents they mainly left soon after their entries. The peak in the 1988 rate of exit appears mainly due to the high number of new firms leaving the industry and that when the rate of exit fell after the peak it was mainly because the entry rate was nearly approaching zero.

Since at the end of the period both the rate of exit and the rate of entry conforms to the theory, our pattern seems also to be consistent with the explanation according to which at high level of density the resource constrain seems to affect the overall pattern more than at the beginning. We will deal extensively with this point when talking about the relationships between the two industries at the end of the chapter.

2.2 The dynamic of the internetworking industry (1993-1997)

The dynamic of the internetworking industry looks very different from the one just analysed. Recall that between 1993 and 1997 the industry has been struck by the introduction of the switch which opened up a new market. The patterns for incumbents, total entry and total exit (Tab. 16) is not monotonic but fuzzy.

Tab. 16: US Internetworking Industry: density, entry, exit (1993-1997);

YEAR	TOT. INC. (ROG)	TOT. NE. (AS A % OF INC.)	ROG FOR NE	TOT. EXITS (AS A %OF INC.)	ROG FOR EXITS
1993	103	103	-	-	-
1994	98(-5%)	33(32%)	-68%	38(37%)	-
1995	161(64%)	108(110%)	227%	45(46%)	18%
1996	139(-14%)	53(33%)	-51%	75(46%)	66%
1997	105(-24%)	32(23%)	-40%	66(47%)	-12%
AV.	121(5%)	66	-39%	56	24%

Source: Author's elaboration based on The Data Communication Internetworking Firms'Directory (several issues);

Note: TOT INC stands for Total Incumbents, ROGstands for Rate of Growth, NE for New Entrants,AV for Average;

Their number increases at the beginning of the period and it decreases after a peak. The trends of ROGs reflect this pattern. In particular the ROG of entry is always

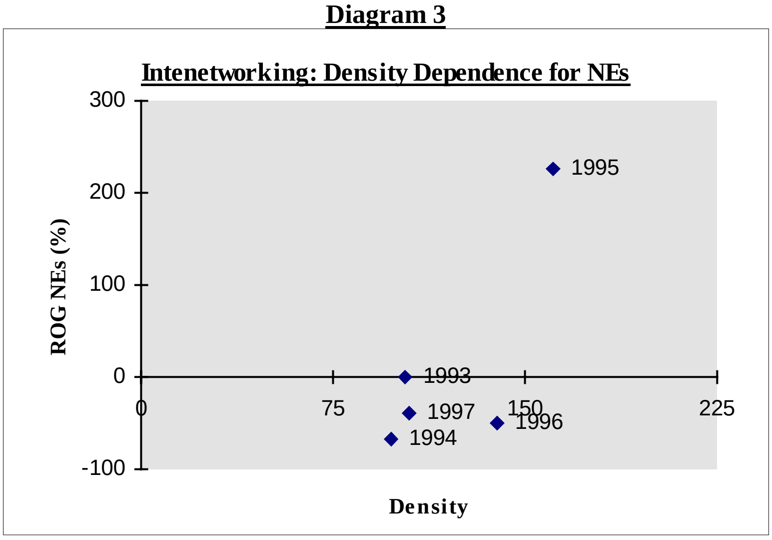
[27] Market shares are not available so we cannot comment upon the consequence on the concentration index.

negative except for the sharp increase (+227%) it experiences in 1995. This peak in the entries is the main feature of the pattern and, since it occurs one year after the boom in the sales of the switches, it is likely a consequence of their introduction. It corresponds also to the peak of the density for the period and this hints that there is some kind of relationship between them.

In the case of the access technology the pattern clearly displayed a non-monotonic relationship between density and the rate of entry. This appears to be the result of the change over time in the effects that increasing density exerted on legitimacy and competition. At low level, the density had a positive influence on the rate of entry because it increased legitimacy. At high level the density had a negative influence because of the high competition which prevented new firms from entering.

In this case the above pattern does not seem to fit our data on density and rate of entry. The scattergram below (see Diag.3) highlights a positive but linear relationship between density and rate of entry as if it captures only the ‘legitimacy effect’.

Diagram 3



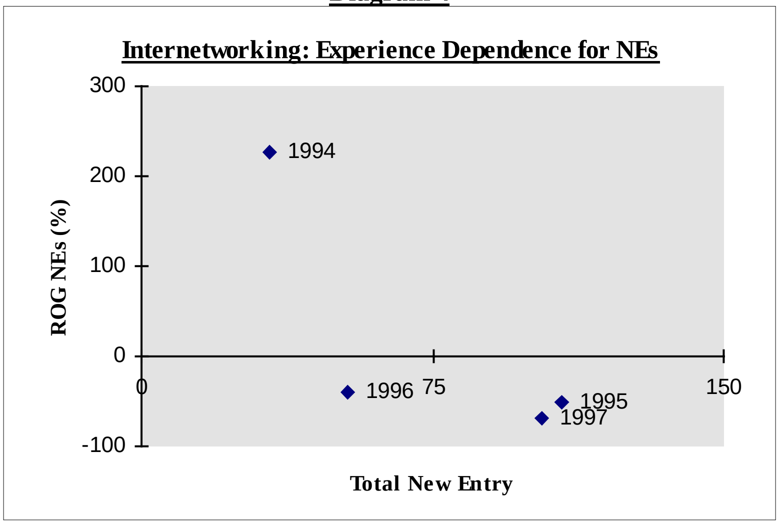
We need to understand what was the source of legitimacy in this case. The increase in the rate of entry between 1994 and 1995 was so sharp that it could not simply reflect a steady process of legitimacy like the one we have analysed in the Ethernet case. Moreover, no official endorsement of the product as a standard had occurred to justify such a rush.

Actually, when the switch market boomed the product had already achieved legitimacy. Two events had contributed to that. Switches were not a complete novelty for the market since they had been introduced four years before as substitutes for bridges. This helped to reduce the technological uncertainty and improve their acceptance once their enhancement had made them potential technological substitutes for routers. Moreover, their prices had already dropped so quickly as to make them also an economic alternative to routers. The perspective of facing such a high demand attracted many producers in the market regardless of the prospect that the low price might have prevented them from making high profits. This,more than the 'legitimacy effect' alone, explains why the peak of entry coincided with the peak in density.

But there is another point to stress about legitimacy. Data shows a decreasing relationship between the rate of growth of new entry and the previous number of new entrants. Had the density exerted a positive effect on the rate of growth of entry only by increasing the legitimacy we should observe a positive relationship between the rate of new entry and the total number of new entrants since it is assumed that an increasing number of new entrants, and not only a high number of incumbents, functions as a positive signal for other new firms, encouraging their entry.[28]

This does not seem to fit with our data (see Diag.4 below). Instead there does seem to be a negative relationship between total new entry and the ROG of new entry. The wave of entry in 1994 attracted new firms immediately but their entry did not seem to trigger any signalling effect to further entries.

Diagram 4



The weakness of the signalling effect in the context of internetworking industry is confirmed also for the rate of exit. Diag.5 (next page) plots the total number of exits

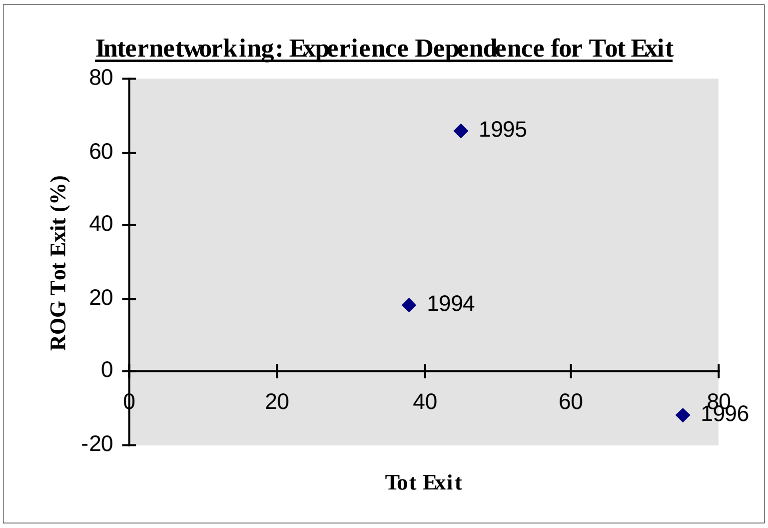
[28] See Hannan M.T., Freeman J. (1989), p.205;

against the rate of exit. The data are very poor and trying to fit any kind of relationship from just three observations is not possible. However some qualitative comments can be made starting from the theory. Usually the theory predicts a positive relationship between the number of recent exits and the actual rate of exits. This assumption reflects the conviction that firms leaving the industry are a symptom of the approaching exhaustion of the carrying capacities signalling to other firms that they had better leave too.[29]

The carrying capacity summarises the dependence of the rate of growth of populations upon different dimensions of the social and economic environment. Among the others, the carrying capacity is affected by changes in the level of resources which can be mobilised, by changes in the institutional and selection processes and by the degree to which the resources are fixed to other organisations. The introduction of the switches clearly altered all these dimensions. By pushing forward the technological frontier the innovation allowed firms in the industry to obtain scale economies in the production of switches and relaxed some of the constraints which had previously prevented routers producers from achieving those economies. By incorporating new functions it changed the relevant parameters affecting consumers' choice and this change in the pattern of demand had repercussions on the selection process. By spurring competition within the industry it reshaped the boundaries among the segments. Since the innovation changed the carrying capacities, recent exits could not represent any 'relevant signal' of resources constraint to other firms and the rate of exit decreased.

Diagram 5

[29] See Hannan M.T., Freeman J. (1989), p. 272;



In our case a negative relationship, which contrasts with the theory, seems to fit better than a positive one. The reason is that the mechanism just described above cannot work in this context.

How can we reconcile the positive relationship between density and the rate of entry with the weakness of the signalling function given the additional presence of a weak legitimacy effect?

A possible explanation is to hypothesise that after the big swarm of new entry, signals of legitimacy came mostly from incumbents entering the switch segment who had previously been in the router segment. Being a transfer within the internetworking industry, this 'entry' does not affect the total number of entrants (which decreases) but it sustains the overall level of density and it represents a signal which continues to influence positively the rate of entry. The evidence provided in the previous chapter about the 'convergence' between the two technologies seems to support this claim.[30]

Another explanation is that some firms left the industry and then entered again. Since the rate of exit is positive, we cannot reduce the dynamic of exit to a simple shuffle within the segment which did not affect at all the overall level of density, or its effect on legitimacy. However if some firms which had left the industry re-entered it soon after, then the overall effect on the level of density might be negligible, but it might represent

[30] See chapter 1;

an incentive for other firms to enter.[31] That some firms entered again the market after leaving is indicated by the non monotonic pattern in Table 17 reporting the pattern of permanence for new firms as a share of the total number of incumbents for any given year of entry. If we look at the average shares for a given time interval we realise that after one year new entries still in the market are 29% of incumbents, 22% after two years and 26% after three years. The increase in the third year is clearly a consequence of the re-entry of firms which had left previously.[32]

Tab.17: US Intenetwoking Industry: Pattern of Permanence for New Entrants as a % of Incumbents in the year of entry (1993-1997);

YEAR OF ENTRY/PRESENCE	1993	1994	1995	1996	1997
1993	100%	62%	47%	44%	35%
1994	-	34%	8%	9%	7%
1995	-	-	67%	26%	9%
1996	-	-	-	38%	19%
1997	-	-	-	-	30%

Source: Author's elaboration based on The Data Communication Internetworking Firms' Directory (several issues);

The above evidence seems to confirm at the industry level the pattern we had already commented upon in the previous chapter. It is the economic substitution effect that drives the dynamic. The economic benefits of the adoption of the switches seemed to have been clear right from the start to suppliers. Nevertheless, the early cross-substitution effect between switches and bridges delayed the impact of switches on the router market, contributed to dilute the legitimacy effect overtime but at the same time influenced the density of the internetworking industry. As a consequence the positive relationship between density and the rate of entry still held but new entries concentrated in one specific year as the result of a rush-in more than of the steady process of 'legitimacy acquisition' which seems to be quite weak. This weakness is reinforced by the absence of any signalling effect as it is confirmed by the negative relationship between recent entries and exit and the rate of entry/exit. After the 'big rush' new entries did not seem to trigger further entries but density continued to affect the rate of entry through the inter-segment entry and exit processes as a result of the technological convergence between routers and switches.

[31] This seems to grasp what occurred between 1996 and 1997 when, despite a fall in the total number of incumbents and in the total number of entries, the rate of entry increased.
[32] See note 4 about these averages;

After the analysis of both the industries we can sum up and comment upon the findings. The two industries differ in their dynamics, in the mechanisms underlying and explaining the dynamics and in the relevance of the approach we applied to study those dynamics. The evidence from the access technology industry confirms the theory. The density of the incumbents would seem to be the relevant dimension to study to grasp the dynamic. The density-dependent concepts of legitimacy and competition would seem to synthesise well the role of network externalities, standardisation and first-mover advantage in explaining the dynamic.

On the contrary the evidence from the internetworking industry does not seem to fit the theory. Density seems to be still relevant but legitimacy and competition alone do not predict the cross-substitution effect, the alternative between standardisation and specialisation, the relevance of sunk costs which as we have seen have influenced the decision of the firms and shaped the evolution of the technology and of the industry. We are now going to use these results to answer the question we introduced at the beginning of the chapter.

2.3 The dynamic of the system

The approach we have chosen to undertake the investigation of the industries' dynamic suits as well for analysing the interactions between the two industries. Once we have an idea of what lies behind the intrinsic rates of growth of the industries in the absence of any resource or competitive constrain (mainly network externalities in the access technology case) and behind the 'environmental shocks' affecting their carrying capacities (mainly the cross-substitution effect in the internetworking case), the last step is to understand how these effects influenced the relationships between the two industries over time.

According to the organisational ecology approach two different populations (markets) compete if each population lowers the carrying capacity for the other through a linear effect on the density of the competitor. Competition can be summarised a coefficient telling the probability of inter-population interaction in resource acquisition relative to intra-population acquisition.

Eventually the coexistence between two populations requires that the effect of density on exit rates *within* a population must be stronger than the competitive effects *between* populations. Similar populations can coexist only under a precise ratio of their carrying capacities. Any shock to the system altering existing carrying capacities is likely to drive the system away from the special condition supporting coexistence. The new equilibrium is unstable and the system will not tend to restore itself to the condition of coexistence.[33]

From the economic viewpoint, access technologies and internetworking products represent different markets whose evolution are not disitnct. During the evolution, new potentialities of the system (in terms of better performance, new functions) became effective in two ways.

In the case of the access technology,network externalities induced the density-legitimacy process through which the endorsement of an access technology as a standard impacted the market. The improved technology allowed LANs to perform better the same functions performed by existing networks, to perform them at a lower cost, and to perform new functions as well. Prices decreased and what happened at this first stage was a movement downward the overall demand curve. This demand was partly met by an installed base of previously existing devices, and partly by a new supply coming from new producers (either of computers or of internetworking devices) which enter the market. This reinforced the previous decrease in the prices by lowering further the cost of LANs. As a consequence, the supply curve of the system shifted downward leading to an equilibrium position at a lower price than the initial one.

The switching innovation ended this ‘virtuous cycle’. From the start switches were priced at half the access technology (FDDI) with which they were competing as a solution to the problem of ‘bandwidth shortage’. Demand for switches increased while demand for FDDI remained stagnant and this prevented competitors from entering the FDDI market.[34] On the supply side many high speed access technologies were proliferating at the same time as alternatives to upgrade Ethernet. High uncertainty about which one would prevail in the end as a standard restrained the suppliers either from entering the market or from endorsing one of them. The absence of competition within the market weakened any incentive to innovate and cut prices of the access technology. Instead in the internetworking market switches’ price continued to decrease as they became widely adopted and suppliers flocked to the market.

[33] See Hannan M.T.,Freeman J. (1989), chapter 6;
[34] See chapter 1;

The overall result was that innovation in the internetworking inhibited innovation in the access technology industry and ended up by reinforcing the diffusion of previously adopted technologies (Ethernet) or by focusing innovation toward new access technologies compatible with the existing ones (Fast Ethernet). The absence of the ‘reinforcing systemic effect’ prevented the system from reaching an equilibrium or from converging to an universal standard. In this second case, demand increased as the price of equipment decreased but the supply curve did not shift downward since costs for suppliers of access technology remained the same or increased.

2.4 Conclusion

The main purpose of this chapter has been to investigate the effects on the industries’ dynamic of the technological evolution which we highlighted at the end of the previous chapter. We needed a theory which could link the effect of network externalities and cross-substitution among products to the rate of entry and exit in both industries, which could account for the effect of environmental changes on the rates, which could give some hints about the interaction between the industries to provide a picture of the evolution of the system. The ‘organisational ecology’ approach has revealed suitable for the purpose.

By decomposing the growth of an industry into three effects (an intrinsic growth rate, resource availability, interaction with another industry) and by stressing the importance of industry density as the mechanism driving the growth of the industry through its effect on legitimacy and competition, we grasped both the cross-sectional heterogeneity of the industries, which have their own dynamics, and the temporal heterogeneity due to the change over time in environmental conditions.

For a given carrying capacity, legitimacy and competition have proved to be effective in explaining the industry dynamic. In this context the coexistence of the two industries turned into a ‘virtuous cycle’ which supported the evolution of the system. When change occurred in the carrying capacity as the consequence of an innovation, legitimacy weakened the ‘virtuous cycle’ and turned it into a vicious one where a new equilibrium at the system level seemed hard to achieve again.

Two different mechanisms seemed to operate differently according to the environmental conditions. Network externalities seemed to be a more effective in a relative static context. Cross-substitution effects seemed to be stronger when a shock hit the system. This raises new questions whose meanings and theoretical implications we will address in the next chapter.

CHAPTER 3

THE ECONOMICS OF INTERNETWORKING

As we have seen so far, the evolution of the LANs has configured them as complex systems resulting from the match of many components coming both from the electronic and the communication technology field. Both the 'systemic' and the 'complex' feature should be considered when trying to assess technically and economically LANs' performance. The 'systemic' nature pointed to the kind of relationships among the different components and the different companies and sectors producing these components. Contrary to what happens in telecommunications systems, on a single LAN each component is an equal partner in the network space. This absence of any kind of 'hierarchy' among components seemed to increase the complexity of the system as the network continued to grow. The 'complex' nature of LANs implied that, like in any electronic system, their fallibility is proportional to the number of their components.

3.1 The technology

The technical trade-offs between those two dimensions have been shaping the evolution of the technological trajectories and have also affected the economic performances of the firms and the dynamic both of the internetworking and of the access technology industry.

Due to the interaction between all the components the effects of technological innovations have configured two trajectories over time. At the level of components, one trajectory of technological innovation in the internetworking industry, common to several products, resulted in an increase in the number of functions available on a single unit of equipment after a new generation of products had been introduced in the market. This occurred both when bridges substituted routers at the end of the 80's and when switches became potential substitutes for routers starting in mid 90's. At the systemic level, the increasing integration of more and more functions at the level of a single component due to technological innovations resulted in a decrease of the complexity via a decrease of the total number of components in the system.[35]

[35] The costs of an electronic system are closely related to the number of components both because of manufacturing costs and system failure rates.

As a consequence of this pattern of evolution two regularities have emerged. First the technological shift associated with newly introduced innovations, has never implied a great leap forward in terms both of the kind and of the quantity of knowledge to be mastered by firms. In spite of this, and this is the second point, the commercial impact of the innovations has always been dramatic.

From the technological viewpoint, innovations rarely involved technological breakthrough and they were most commonly changes at the system level. Switches for instance simply introduced in the data communication field a technology used in telephony communication. For this reason at the beginning they were not significant innovations but only substitutes for bridges. Only with the incremental improvement in the store-and-forward system due to the application either of RISC architecture or the use of ASICs gave them the opportunity to substitute for routers in high speed applications. Moreover the diffusion of switches was triggered by the adoption of more powerful computers within the network and it benefited from the stalemate in access technology development which continued to support substantial installed base of incompatible equipment.

From an economic viewpoint, the increasing technological complexity at the product level has either opened up new sub-segments within an existing market or created completely new markets. The former was the case when two products co-existed because they performed different functions (‘new application effect’) as in the multiprotocol and access routers’ sub-segment. In the latter case the products might not coexist because they both performed the same function and new products brought about new features which the old products did not incorporate (‘complete substitution effect’). During the evolution of the internetworking industry the last pattern repeated both patterns of activity when routers were introduced as substitute for bridges and when switches substituted for routers.[36]

However, the complete substitution did not occur immediately in the case of internetworking devices. Old products continued to perform their function soon after the introduction of potential substitutes. As the substitutes got through different generations

[36] It is important to stress how, in the case of switches, first generation products were more substitutes for bridges than for routers suggesting that the technological upgrade requires a new product to pass through all the previous steps before becoming a perfect economic substitute. One may speculate whether this tendency is linked to the process of winning legitimacy in the market.

usually their prices decreased and their performances improved. This pushed the old product more and more to the boundaries of the market until the complete substitution occurred.[37] As we have seen something different is happening nowadays to routers whose co-existence with switches does not seem to be threatened by the upgrade of switches which, on the contrary, seem to stimulate a convergence of the technology applied to the two equipment.

3.2 The process of lineage

The pattern highlighted above seems to be consistent with the so called 'process of lineage' a pattern the literature has stressed in the case of other technologies when the technological innovation first created new applications and then, once evolved, entered the domain of application of the precedent technology.[38] In these cases the technology seems to evolve gradually and the radical change arises from the application of the technology to new markets.

The point is to understand whether the evolution into other domains is constrained and what are eventually the focusing devices 'channelling' the evolution.

According to the theory two elements drive this process of development. The first element is adaptation since the technology is supposed to adapt to the particular needs and requirements of the market it addresses. From this viewpoint, the impact of the changes on the market depends on how the innovations are valued in terms of existing preferences in already established markets. Since innovations are valued according to established parameters when they hit the market, to enhance their acceptance they are often introduced into new market segments where the preferences are closer to the new characteristics or have to be built up completely.

The second element is the abundance of resources which are required to support and favour the penetration of the innovation into new application domains. With a given amount of resources, the pace of the change usually depends on the kind of

[37] Bridges disappeared completely only when switches entered the market, but at the beginning they coexisted with routers.
[38] See Christensen C. and Rosenbloom R. (1995); Levinthal D. A. (1998); Rosenbloom R. and Cusumano M.A. (1987);

technological change. Given the technological paradigm, changes may occur either in the single component at the detailed design level or throughout the system.[39] This distinction has given rise to a classification of the kind of innovation according both to where it occurs (either at the component or at the architecture level) and to its intensity.[40]

The concepts of adaptation and availability of resources stress how firms' behaviours are shaped according to the kind of technology they are dealing with, the pattern of demand they confront and the structure of the industry they operate in. These influences are dealt in the literature with the concepts of opportunity, appropriability, cumulativeness and knowledge base.[41]

Opportunities are a measure of the incentives to engage in innovative activity and represent the potential source of depletion of the available resources. Appropriability is related to the possibility of profiting from the innovation by protecting it from imitation. Cumulativeness refers to the property of the innovative activity to reinforce itself once occurred either at the single firm or at the industry level. The knowledge base summarises the characteristics of the technology both in 'intensive' terms (the dichotomy tacit vs. codified knowledge) and in 'extensive' terms (when several disciplines must be integrated into the technology).

Usually, if high opportunities combine with high cumulativeness at the firm level and high tacitness of knowledge, appropriability increases and may prevent new firms from entering the industry. In this case incumbents enjoy relatively low competition and can benefit from high profits. Moreover, a first mover's strategy may allow incumbents to seize and keep a good share of the market.

If considered at the industry level cumulativeness is strictly linked to appropriability and the 'intensification' of the knowledge base. Since codified knowledge generates

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[39] See Clark K.B. (1985) and Tushman M.L., Anderson P. (1986);

[40] Handerson and Clark identify four types of innovations. Incremental change reinforcing the expertise both in the architecture and in the component technology; Modular innovation affecting the technology at the component level but not changing the architecture; Architectural innovation changing the way components work together; Radical innovation when a new component technology has a pervasive effect both on the component and on the way they interact together.
See Henderson R. M. and Clark K.B (1990);

[41] See Malerba F. and Orsenigo L., (1993);

externalities which may turn into increasing returns supporting the diffusion of a particular kind of innovation, the dynamic may turn out different from the previous one. In this context of low appropriability, high opportunities, associated with high availability of resources or with the absence of any resource constrain at all, favour the ease of entry of new firms in the industry. A high degree of knowledge codification may reinforce this process[42] and in this case a first mover strategy is not enough to reduce the competitive pressure on incumbents.

This picture changes if the technology displays a high degree of pervasiveness. If the core of technical knowledge can be applied to a range of different alternative solutions, which seems to be a condition to enter different domains of application, then firms may be induced to either diversify or specialise their activity according to a low or high degree of cumulativeness respectively. In this case even the presence of high opportunity and cumulativeness cannot prevent established markets from being invaded by products with a high degree of substitutability. This may induce a coexistence of product at the market level.

This pattern captures the evolution of the internetworking industry from 1993 to 1997. The opening up of the multiprotocol sub-segment with high priced, high performance products had set the basis for product specialisation. The knowledge required to develop the software for routing among different protocols provided the basis for a highly cumulative process. The appropriability increased and rose some barriers to entry. This did not completely prevent firms from entering the segment even if, as both market shares and CR_4 indicate[43], it did prevent new entrants from competing effectively against the leaders. CR_4 increased in 1997 but the market leaders were still the same of seven years before.

In the presence of high technical pervasiveness, which stimulated the competition from the switches industry, these technological barriers are revealed to be weak. This weakness brought about two consequences. Firstly, following the increasing competition from switches, router prices fell and, as a consequence, the incentive to enter the subsegment decreased slowing the rate of new entry. Secondly, it prevented firms in the router market from shifting from a strategy of product specialisation to one of product standardisation. Prices might have declined anyway as the consequence of

[42] See Winter S.G.(1984);
[43] See Tab.8;

falling costs had firms achieved economies of scale in production. This would have allowed firms to keep their margin of profit unaltered while enhancing the competitivity of their products and increasing the quantity of products shipped. Multiprotocol routers, regardless their higher price when compared to access routers, were becoming a commodity but the process of standardisation driven by economies of scale and learning occurred too slowly to allow effective price competition with switches once they were introduced in the market. Unfortunately neither data on costs nor on the margins of profit are available to shed some light on this hypothesis even if the stability of market shares seems to confirm, indirectly, a sort of stability of the margins of profit. Nevertheless the increasing number of firms entering both the switches and the router market at the same time after 1994 is a signal that a reduction in the barrier to entry had occurred as a direct effect of pervasiveness. In this context, specialised firms are vulnerable, especially if they delay in moving toward the exploitation of scale economies.

On the contrary, the establishment of the switches market provides an example of how an aggressive lead in the exploitation of scale economies might represent a good strategy for exploiting the technical pervasiveness and for entering a new application domain for the technology. As we saw, the changes in market shares for switches' producers between 1994 and 1997 reflected a re-shuffle more than a simple consolidation of leaders' position as had happened in the routers' market. New firms entered the market and some incumbents became leaders by acquiring other incumbents. All this happened while a new generation of products was about to be introduced creating a 'window of opportunity' for firms to enter the market. Thanks to the pervasiveness of the technology, new entries were mainly driven by the expectations of future gains coming from the substitution of routers with switches, but to seize the opportunity they needed to be quick in cutting costs and to ship as many products as possible to enhance the substitution process.

The diffusion of ASICs as an alternative to software-based switches helped them to achieve this goal. ASIC-based switches, once developed, offered all the advantages in scaling up production and cost cutting typical of semiconductors. However, to grasp the opportunity new firms could not spend a long time developing their own design, bearing the high costs and facing the high uncertainty. The decision to acquire incumbents seemed to be the best solution to avoid delays.[44] The only problem with this kind of strategy was the eventual product overlap resulting from the acquisition. Because of the cross-substitutability, router manufacturers acquiring switch producers could end up reducing the size of the market and the amount of the rents coming from the existing product lines.[45] By exploiting scale economies suppliers had the opportunity to reduce costs and to practise a policy of aggressive pricing which enhanced the diffusion of the product and offset the falling of the rents.

3.3 What difference does it make?

Beside those elements, in the case of LANs, network externalities and compatibility issues deriving from the 'systemic feature' of the product have acted as a major focusing device in the process of lineage. This peculiarity influenced the process more than the resources availability and the adaptation envisaged by the theory. As we have seen in the previous chapter, the shift in the carrying capacity was essential to favour the diffusion of the switches innovation in the case of the internetworking industry, but because of the lack of a 'reinforcing mechanism' coming from the access technology side the equilibrium between demand and supply could not be restored at the system level.

3.3.1 The supply side

Network externalities are usually intended as 'positive consumption externalities' and, so defined, they are mainly considered to be a 'demand side phenomenon'. In the presence of network externalities, the value received by the single user depends positively on the total number of users consuming the good via either a direct or a mediated effect.[46] As the scope of the network increases, the utility of the single user increases leading other users to enjoy a higher benefit.

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[44] For an attempted analysis of the acquisition strategy in the case of Cisco Sys. see: Fontana R. (1998);

[45] This trade off between being lock-in to an existing technology and the 'cannibalisation' of the existing product lines based on previous technologies is common in presence of high opportunity and cumulativeness and it is worsen by the compatibility issue which may delay the substitution as we have seen above.

[46] See Katz M.L. and Shapiro C. (1985);

For this process to operate as a dynamic mechanism, compatibility among the different products should be assumed. If this assumption is made we can also assume that the extent of the installed base, when it becomes larger than a ‘critical mass’, operates as an almost automatic adoption-inducing mechanism.[47] If we drop this assumption, then network externalities become relevant from the producers’ point of view too. When compatibility is not assumed to be ‘ex-ante’ producers may display different strategies for influencing the decisions of the users in the hope of reaching the critical mass that makes the process self-reinforcing and allows them to seize the market. They can support an existing standard in the hope of benefiting from an already existing installed base but in this case they have to sustain the competition of existing incumbents. They can introduce a new incompatible technology and enjoy all the benefits coming from being the only sponsors but in this case they cannot rely on an already existing installed base.

Existing products shape the needs and set the parameters driving the selection process on the demand side but also both the depth of the installed base, especially for the access technology, and the need to preserve the compatibility with the existing devices, especially in the internetworking market, limit the number of new specifications available and constrain the strategies of producers. Because of the past history of the market and of the technology, the new domains of application for the technology are not all equally likely.[48] The effect on the development of the new technology may be varied and the diffusion of the innovation into other domains of application might be either enhanced or retarded.

The history of the LAN diffusion has provided many examples of this. In the router market the multiprotocol function, which in 1989 opened up a new, more concentrated and highly priced sub-segment, represented a sort of ‘gateway technology’[49] the system needed to overcome the bottlenecks which might have inhibited its further expansion. Because of the expectations of a widespread adoption of the product and the lure of high profits ensured by the peculiarity of the status of ‘gateway innovation’ many firms entered the sub-segment irrespective of the high technological barriers to entry which demanded a relevant effort in terms of resources availability to prospective entrant.

[47] See Arthur W.B. (1989);
[48] The process is non-ergodic or path-dependent. See Arthur W.B. (1987), David P.A. (1988);
[49] *”they* (gateway technologies*) make it technically feasible to utilise two or more components/subsystems as compatible complements or compatible substitutes in an integrated system of production”*. See David P.A. and Bunn J.A. (1988), p.172;

Adoption was quick irrespective of the high price and the new segment grew up beside the old one of the access routers.

The case of switch is different. Switches were adopted very quickly at the beginning because of their low price resulting from high competition in the market. Despite this, their effect on the router market became 'tangible' only four years after their first appearance in the market, when as we have seen, in 1994 new entries in the multiprotocol sub-segment started to decrease very quickly together with the average price. The impact due to the cross-substitution effect was weaker in the less concentrated access router sub-segment. Both the timing and the evidence seem to suggest that the combination of technological characteristics and market structure ended in delaying the substitution of routers with switches. Switches represented cheap substitutes for routers, but the substitution might have occurred faster had the multiprotocol routers not been such an expensive and widely adopted 'gateway technology'.

In the access technology industry, the technological stalemate which occurred at the beginning of the 90's has provided another example of how the combination of adaptation, scarce resources, and, mainly, lack of positive feedback from within the system, retarded the adoption of alternative technologies and their penetration into new domains of application. Fast Ethernets, FDDI, ATM were all viable[50] substitutes for Ethernet. All could provide the increased in bandwidth to overcome the existing bottleneck represented by the low speed in transmission. In particular ATM was, and it is still considered, the 'ultimate' access technology in terms of performance both in terms of speed and in terms of integration of video and audio within data transmission. The presence of so many alternatives and the official endorsement as standards of three of them puzzled both the producers and the adopters and ended up (accidentally?)[51] with enhancing the adoption of Fast Ethernet which could not provide

[50] *"A new technology will be viable if it out-competes existing technologies on some performance criteria, whether an element of functionality or cost."*Levinthal D.A. (1998), p. 242;

[51] This strategy of endorsing 'de jure' several alternative standards at the same time is quite common in the standardisation making process by official committees. It responds to the need of these organisations to study alternative nascent network technologies in order to understand which kind of dynamics the system will display whether one or another alternative would prevail. The rationale behind this is to try to favour the emergence and the establishment of the most efficient alternative. But this strategy could become counter-productive if it limits itself to favour the proliferation of alternatives and to a passive wait-and-see. A passivity state would allow for network externalities to play a lead role in supporting the solution which is more

the integration of data, audio, video. To support the entry into a new domain of application the official endorsement of three alternatives at the same time induced firms to spread their already scarce resources on several technologies and increased the uncertainty about which one might have prevailed in the market. In this context, the chance of sponsoring one technology which could reveal itself as the least efficient in the market both lowered the expected benefits and increased the opportunity costs for firms. The expected benefits decreased since the presence of incompatible access technologies reduced the width of the potential installed base. The opportunity costs increased because the need to recoup the 'sunk-costs' of the investment might induce the firm not to switch to the sponsorship of another technology had the one supported not been adopted.

Moreover the introduction of the switch, which addressed the same needs more cheaply, while had major chances of being adopted and which released the network communication from the 'slavery' of protocol compatibility, lowered further both the incentives to engage in the competition in the access technology market and the reinforcing feedback coming from the network externalites. In the presence of such high competition and uncertainty the technology with higher compatibility with the existing installed base prevailed and the invasion of another application domain such as video-voice-data transmission was delayed.

3.3.2 The demand side

The problems highlighted above resulted mainly from the combination of scarce resources and network externalities. In the presence of network externalities and compatibility issues, even if the increase in the capacity provided by each innovation is bigger than the capacity demanded by the new domain of application where the technology is applied before invading the mainstream market[52] and even if there is a high degree of pervasiveness of the technology, the induced demand from the new application may be influenced either positively or negatively by the presence or absence of feedback coming from within the system.

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compatible with already existing deep-installed base technologies which does not necessarily represent the most efficient among the available alternatives. See David P.A. (1987), p.228-236;

[52] This is the case in the account provided by Christensen and Rosenbloom of the disk drive industry.
See Christensen C. and Rosenbloom R. (1995);

Nevertheless, once we allow for the above effects to take effect, we should consider that the process of lineage may be delayed also by retardation and mismatches in the process of adaptation. Usually the theory tends to assume that the adaptation process occurs automatically since for given needs "a technology *naturally* adapts to the niche to which it is being applied".[53] Actually for a given technological paradigm we should talk more of the convergence of two distinct processes rather than simple adaptation underlying the lineage process. The state and evolution of product performance demanded is on one side. The evolution of the improvements in performance supplied by firms is on the other side. Both are driven by different determinants and there is no reason for them either to be identical or to converge automatically.

A LAN is a technical system made of different components but from the economic viewpoint it is also a final product whose final performance depends on the *characteristics* of its components.[54] Users' demands depend on the relationship between their individual preferences and the products' final performance but this performance is the result of the evolution of the relationships between the products and their characteristics. This weakens the link between individual needs (as expressed by firms preferences) and final choices. As a consequence of this, the assessment of the final good may not change, but the final choice might change because some of the characteristics which are considered relevant have changed.

Again the point is how does this change occur over time because this will influence the adaptation process leading eventually to the entry into another application domain. Here it is the *reaction* of firms to the change of different characteristics rather than their assessment of the characteristics which is important in determining the outcome of the process.[55]

In the specific case of internetworking technologies, the penetration into a new application domain has been the consequence either of a reduction in the price of the final product via a cost reduction at the component level or of an enhancement in the quality of the final product through the improvement in the functions displayed. The reaction to the changes depended on firms expectations about future changes in these

[53] Levinthal D. A. (1998), p.221 (emphasis is mine);
[54] We use the term characteristic for *"those objective properties of things that are relevant to choice by people"*.See Lancaster K. (1971), p.6;
[55] Lancaster K. (1971), p.7;

dimensions. In particular expected product obsolescence and expectations of future price changes seemed to have played an important role.

The alternative between the adoption of software and hardware-based switches illustrates this point. As we have seen both the adoption of a RISC processor and the implementation of an ASICs could ensure the improvement in the store-and-forward mechanism of the switches, allow them to operate at layer three and challenge the routers' application domain. In a context of both high market and technological uncertainty surrounding the introduction of new products, to choose one of the two options might constrain both users and producers' future choices about the technology and eventually affect the entry into new application domains.

From the producer's viewpoint, developing an ASIC-based switch is very expensive and risky and suppliers will engage in the project only if they can reduce the uncertainty concerning the adoption of the product. This implies an evaluation of users' reaction based on an assessment of how the product will fit with the other components within the system. The habit of introducing into the market product samples to test consumers' reactions is a way to reduce market uncertainty.[56] The commercialisation of a product compatible with the existing installed base is an attempt to enhance the adoption by 'adapting' to existing needs as expressed by the final preferences.

However this entails two risks for producers. The first one is that it exposes suppliers to increasing competition from other incumbents. The second one is that the users' adoption will depend also on the evaluation of how the relevant characteristics will change in the future. For instance ASIC-based products ensure high performance at high price but low flexibility when compared to software-based alternatives.[57] Adopters may be more concerned with high performance than with flexibility or low price at the moment of the adoption, but the relevance of these characteristics may be upset by a future change in the 'objective properties' of the product. In the presence of fast obsolescence[58] of the products, due both to the introduction of substitutes and to the upgrading of existing product lines, flexibility and not high performance becomes a priority but the presence of high sunk-costs to recoup would force adopters not to

[56] This practice is common in the semiconductor industry. See Steinmueller W.E. (1987) for an analysis of the economic consequence of it.
[57] See Tab.8 for a summary of the trade-offs.
[58] See Rosenberg N. (1976);

change their products were a substitute to appear in the market. Moreover, switching could even be more unlikely if the product achieved a wide compatibility within the system because a single user would switch only if all the other would do the same.[59] These considerations could lower the expectations of adopters to such a point that they might offset the expected gains from adopting the new product. As we have stressed above, switches became viable substitutes for routers only four years after their first introduction regardless of the fact that they had already acquired legitimacy as substitutes for bridges and regardless of the continued fall in their price over time. Probably such considerations delayed the application of the technology to the mainstream domain.

3.3.3 The system

Considering how demand and supply are matched in the process of lineage means, in this systemic context, to analyse how the dynamic of the system is affected by the process of lineage. The analysis in the previous chapter has stressed the importance of the matching between the two industries to achieve an equilibrium between demand and supply and to enhance the penetration into new applications domains. Moreover it has also stressed how difficult is to achieve this matching in presence of innovations changing the carrying capacity of the system and setting new resources constraints.

In presence of network externalities, when an innovation is introduced in new application domains it may challenge the present compatibility status-quo, as the switches challenged the compatibility between routers and the shared architecture of Ethernet. In the absence of a new ex-ante compatibility producers' strategies to seize the market, and users' preferences become strictly inter-dependent in the sense that the matching between them was necessary for the process of lineage to acquire momentum. Nevertheless this matching is hardly achieved and it is more likely that the mismatching delayed the introduction of the technology into new domains of application.

The matching depends on the legitimacy acquired by the innovation and on the extent of competition because they influence, through the density of firms in the industry, the process of entry and exit of innovators. Nevertheless, at the level of the system the

[59] See Farrel J. and Saloner G. (1986);

concepts of legitimacy/ competition and adaptation/ resource availability overlap. Adaptation is easier when the technology enters new domains of application just by satisfying existing needs based on established preferences (i.e. when it has already acquired legitimacy in some other markets). The penetration into new domains is enhanced when resources are available (i.e. when competition is low). This creates a link between the process of lineage and the evolution of supply and demand which affects the evolution of the system.

These considerations, together with the comments we made above about demand and supply, change the perspective from the theoretical viewpoint. In presence of network externalitites and compatibility issues, adaptation does not occur automatically and the availability of resources might not be a great constraint to the process of innovation diffusion into new domains of application. If the process of adoption becomes self-reinforcing once it has gained enough momentum, the real problem is to match demand and supply in the early stages of the process to acquire critical mass. One of the possibilities is to create a large installed-base by shipping as many products as possible. The problem with this solution is that it still emphasises the availability of resources as a major constraint. Moreover it does not solve the problem, which is both analytical and practical, of the existence of the demand to be met by the supply in the earliest stage of the process. One of the possible solutions is to stress, beside the mentioned elements, the role of producers and users' expectations in shaping the path of lineage by *creating* a pattern of demand which conforms to the characteristics of the product whose objective properties are determined by the existing technology. In the case we have analysed, the introduction of switches has lowered users' expectations on the opportunity of adopting a new access technology (FDDI) and has also delayed the diffusion of new more efficient alternatives (ATM). Nevertheless, there is no intrinsic reason for this mechanism to turn out to be vicious and the endorsement of an access technology may induce such high expectations that the process of innovation is accelerated as happened in the first phase with Ethernet and the routers.

So far, the existing literature has limited itself to analyse the role of expectations in the diffusion of innovation either in presence of compatibility (rational expectations case)[60]or in context of comparative statics where the final state of the system is assumed and only the effects of departures from the equilibrium position, are analysed.[61] As some

[60]See Katz M.L. and Shapiro C. (1985) and Farrel J.and Saloner G. (1985);
[61]See Ireland N. and Stoneman P. (1986);

authors have stressed, it is important to investigate the role of expectations in shaping the path toward the final state.[62]

Conclusion

This chapter aimed to fullfill the last requirement of the Schumpeterian advice we mentioned in the introduction. To interpret the historical account and the empirical findings of the previous chapters we needed to relate analytically the evolution of the technology to both a theory of the demand and a theory of the supply. Moreover, we needed to stress a possible mechanism relating both to the dynamic and to the evolution of market structures.To frame the diffusion of the technology in new domains as a process of lineage has seemed to provide a good starting point to achieve this goal.

By considering the interaction between economic and technological dimensions during the process of innovation, but by distinguishing clearly between the economic and the technological effects of an innovation, this approach allowed us to understand how it is possible for an innovation to have a revolutionary economic impact despite the stability of its 'technological core' over time. Moreover, by stressing the adaptation and the availability of resources as the two main elements behind the process of lineage the approach was revealed as useful for relating the process of lineage to the evolution of market structure. However, we have argued that the presence of network externalities and required product compatibility within systems might blur the distinction between adaptation and resources availability, as mechanisms underlying the process of lineage, and beteen legitimacy and competition as mechanisms behind the dynamic of industries. In this context demand and supply become so interdependent that the dynamic of the system might be strongly affected positively or negatively by factors other than the simple availability of resources necessary to sustain the process of lineage. Expectations on the future technological evolution of the components of the system have proved to be one important factor in the case of Local Area Network.

[62]See Arthur W.B. (1987), David P.A. (1988);

CONCLUSION

We can now provide answers to the questions we introduced at the beginning and also make some brief considerations on the methodology we have used throughout this work.

The historical account is valuable for identifying both the technological and the economic mechanisms behind the evolution of the LAN industry. From the technological viewpoint, innovations at the single component level triggered further innovations in other components. This occurred both in the first phase, when improvements in the computer performance and the standardisation of the access technology allowed the expansion of LANs' installed base, and in the second phase when the adoption of routers and the diffusion of Ethernet over twisted-pair, by segmenting the network but potentially extending it at the same time, highlighted the problems of bandwidth shortage and eventually led to the introduction of the switches as a solution of this problem. Cross-substitution and compatibility issues mirrored this pattern from the economic viewpoint. Nevertheless, they exerted uneven and contradictory effects on the evolution of the system according to the different phases, the different market segments, and the presence or absence of innovation. As long as both Ethernet and Token Ring were not challenged by any alternative, compatibility was a relatively 'irrelevant' issue and new, most viable substitutes, both terminal equipment and networking products (routers as substitutes for bridges), were quickly introduced in the market and enhanced the expansion of the overall system.

When alternative technologies or products appeared the picture changed and compatibility and substitution started to collide. Maintaining the compatibility with the existing installed base became the main concern behind firms' decisions and this ended up in delaying or even preventing the substitution of existing products with new technologically viable alternatives. This happened both in the case of access technologies, where the presence of the more compatible Fast Ethernet delayed the diffusion of FDDI, and for the internetworking devices where the status of 'gateway technology' of routers delayed the introduction of switches as their substitutes and instead started a process of technological convergence of the two products. Beside these effects which occurred *within* each industry, changes affected also the relationships *between* the industries at the system level. The introduction of the cheaper switches further delayed the development and diffusion of an alternative and viable ‘switched’ access technology (ATM). The persistence on the practice of developing a ‘shared’ alternative access technology to maintain compatibility did not reinforce the diffusion of switches in use and their impact on the market was further delayed.

To highlight the effects of compatibility and cross-substitution we chose to analyse changes in the dynamic of the industries and of the system over time. To pursue this goal we applied the ‘second technique’ suggested by Schumpeter, statistics, within the theoretical framework of the Organisational Ecology approach. Within this framework, the rate of entry and exit of firms are linked to the number of incumbents (density) in the industry through the concepts of legitimacy and competition. Moreover, the dynamic of entry and exit depends on the amount of resources available (carrying capacity) within the industry or the system. Carrying capacities, and the dynamic of entry and exit, may be altered if an innovation occurs. For the purpose of our analysis we took legitimacy and competition as proxies for compatibility and cross-substitution respectively. In our analysis of the access technology industry (1984-1989), we found out that in absence of innovation challenging the existing technological compatibility (i.e. given the carrying capacities and in presence of high legitimacy), the pattern conformed to the theory and displayed an increasing ‘competition effect’ as density increased and the exhaustion of the available resources was approached. In this case the presence of high cross-substitution effect in the internetworking market did not negatively affect either the dynamic of the access technology industry or of the matching between industries at the level of the system. On the contrary by investigating the dynamic of the internetworking industry (1993-1997), our findings showed that when an innovation has altered the existing carrying capacities, the pattern does not conform to the theory but displays a weak ‘density effect’ both on legitimacy and competition. Since, in this case, firms were mainly concerned, in the access technology industry, with gaining legitimacy for new products the issue of compatibility became relevant. Both the dynamic of the internetworking industry and the dynamic of the system were negatively affected.

The last step was to provide a ‘theory’ consistent both with the historical account and with the assumptions made in the empirical investigation and at the same time provide hints and starting points for further analysis. To portrait the ‘branching’ of the technology into new application domains as a process of lineage allowed us to capture the trade-offs in the technological evolution between the increasing complexity at the component level and the decreasing complexity at the system level. Nevertheless, this introduced the problem of consistency, at the analytical level, between the assumptions behind this process and our assumptions. The process of lineage describes the introduction of technology into new domains of application in the presence of enough resources to sustain penetration. The process of adaptation to existing needs, which is the required mechanism on the demand side, is considered by earlier writers employing the lineage concept, to follow almost automatically. Our empirical analysis has shown that the matching between demand and supply, as we can consider the access technology and the internetworking industry at this level of abstraction, does not occur automatically but the theory, by stressing mainly the supply side or by assuming the compatibility ex-ante, does not seem to consider this possibility. However, the assumption of ex-ante compatibility is both unrealistic, since producers can gain higher benefits by sponsoring a proprietary technology and trying to have it accepted by the users, and theoretically demanding, since we must assume an instantaneous matching between producers' decisions and users' needs. We stressed that, in a context of network externalities, we can drop that assumption if we assume, more realistically as our historical account has shown, that producers endogenously create the demand for their products. Nevertheless if we assume that, then producers' decisions will be a function of their expectations on users' behaviour. Only when expectations are matched at the beginning, will the process of diffusion into another domain occur evenly and reach momentum as users' decision will depend, as usual in a context of network externalities, on previous decisions of other adopters. We can still assume that producers maintain rational expectations about users' decisions, but again this seems to be an exception rather than the rule as we tried to show in our analysis of the LAN industry.

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