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

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Abstract

This work analyses the case of innovation diffusion in the case of the Local Area Network industry. It focuses in particular on two suppliers of LAN components: the access technology industry and the internetworking industry. Two elements driving the diffusion 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 process of 'branching' of technologies into new application domains are analysed through the dynamics of entry and exit of firms in both industries. We find that the effects on the dynamic are different depending on kind of innovation. These mechanisms may ensure a matching between the two industries and 'excess momentum' when compatibility is maintained. Nevertheless, when an innovation occurs in one of the two industries and the 'match' is disrupted it needs time to re-establish a matching position, and 'excess momentum' may turn into a 'excess inertia'.

Keywords: lineage process, compatibility, excess momentum, excess inertia, Local Area Network

1. Introduction

This paper is concerned with the process of diffusion of innovations into new domains of application in the presence of network externalities with particular reference to the Local Area Network (LAN) industry. Local Area Networks are considered here as an example of technological systems whose components come from two distinct industries, the Internetworking Industry, producing the equipment (bridges, routers, switches) that connects sites on the network, and the Access Technology Industry providing the transmission protocol (Ethernet, Token Ring, Fast Ethernet etc.). Our major concern is to provide some kind of empirical evidence of the effect of the ‘excess inertia’ and ‘excess momentum’ phenomena on the ‘branching’ of a component system technology into new domains of application when both the decisions of the producers to introduce a new technology and the decisions of the users to adopt a new component embodying the technology are affected by the current or expected width of the system installed base.

The branching of a technology into a new application domain is an example of ‘lineage Levinthal, 1998). In the case of component system technology, a lineage process may follow from a technological innovation altering the existing complementarity/ substitutability relationships among system components. Both within the industries and at the system level, components may be either compatible (perfect substitutes) or they may complement each other. When they are perfect substitutes, they compete at the single industry level but not at the system level (Greenstein and Wade, 1998). Competition at the system level may occur when technological innovation in either industry disrupts the existing ex-ante compatibility and turns complementary products into substitutes. We will identify in the history of the evolution of the LAN industry major innovations that define a lineage process.

Once a lineage process has been detected, whether competition among different components actually increase or decrease as a consequence of it, depends on the extent of the ‘excess inertia’ or ‘excess momentum’ effects (Farrell and Saloner, 1986; 1987). In the case of ‘market mediated’ externalities, competition between products occurs only when innovations have changed the technological characteristics of products and hit the market through users’ adoption. As more and more users adopt the innovation, more and more producers are induced to enter the industry and this feeds back onto the decisions of other producers to enter or leave the industry. A measure to empirically capture this dynamics is needed. We shall argue that the increasing legitimacy (Hannan and Freeman, 1989) of both the technology and the products consequent to the reduction in both the technological and the market uncertainty during the lineage process may represent a sensible proxy.

The relationships among components serves to transmit the effect of technological change across component markets and alters the rate of entry and exit of firms in the component industries. The result changes the competitive structure of the industries producing components.

It is found that when innovations preserve compatibility between components, uncertainty is reduced. A higher degree of compatibility preservation produces a greater level of uncertainty reduction. Legitimacy is gained quickly and this speeds up the rate of entry of firms despite the fact that decreasing margins of profit and/ or increasing barriers to entry may discourage firms from entering. This sets the conditions for 'excess momentum' to be achieved but may inhibit the branching of the technology into new application domains. On the contrary, when an innovation alters compatibility at the system level, uncertainty decreases more slowly. Firms are concerned with receiving positive feedback and gaining legitimacy for their new products. This may induce 'excess inertia' and delay the diffusion of new technology when the technology enter new application domains. Both the rates of entry and exit are weakly affected.

The paper is organised as follows. The concepts of 'lineage process', compatibility and complementarity in the case of component system technologies are introduced and discussed in section 2, together with the peculiarities of diffusion of innovation in presence of network externalities. The Organisational Ecology approach is briefly presented in section 3. In the same section the fruitful application of concept of legitimacy is explained. Section 4 is a brief sketch of the history and evolution of the LAN industry so far. In Section 5 some preliminary findings are presented and commented upon in the following Section 6. Section 7 discusses the limits of the analysis and introduces suggestions for future investigations.

2. The ‘lineage process’ and network externalities

The literature on technological change often highlights cases of so called ‘lineage process’ in which technological innovation first creates new applications and then once they have evolved enter application domains of a pre-existing technology. Levinthal’s account of the development of wireless communication technology (1998), and Rosenbloom and Cusumano (1987)case of the VCR industry, are both examples of such lineage process.

While technology evolves gradually, the radical change arises from the application of the technology to new products which, in turns, open up new markets (Levinthal, 1998). Two forces drive this process of development. The first is ‘adaptation’. The new technology is altered to adapt to the particular needs and requirements of the market it addresses. The market effect depends upon how much the newly adapted product is valued by users relative to already established markets. Innovations are evaluated and may be valued according to established parameters when they enter the market. To avoid ill-adapted new innovations (Rosenberg, 1976b), and to enhance their acceptance, they are often introduced into new market segments where the preferences are closer to the new characteristics or where there is little effective competition. In addition, substantial investment is required to promote the penetration of the innovation into new application domains.

Moreover, given the amount of resources to invest, the pace of the change may depend on the kind of technological change. Technological opportunity may result in different options (Clark, 1985). One may choose a strategy of introducing new components that fit within an existing architecture. Alternatively, one may introduce a new architecture *and* key components for implementing that architecture (Henderson and Clark, 1990). The relative pay off of these strategies depends upon the character of demand and the possible competitive response of rivals.

Within this framework, technology diffusion may be modelled as a sequence of random adoption choices made by users who ‘pick’ goods that embody available and competing technologies. If there is a positive feedback mechanism ensuring that the number of adoptions is influenced by the total number of previous adoptions, a bandwagon effect may be set in motion. If a ‘bandwagon effect’ of this sort can be detected we are in presence of network externalities (Agliardi, 1998). This effect may result either directly from physical network externalities when compatibility among goods enhances one user's value for the good (as in the case of telephones), or in the form of 'market mediated' effects when, maintaining the compatibility within the system, a complementary product becomes cheaper. In the former case the externalities operate directly upon the demand side of the market. In the latter case the externalities impact on the technical performances of the system and this feeds back into costs and profits of component producers *through* the influence of the system's performance and characteristics upon users' demand for it when compared to alternative technologies (Katz and Shapiro, 1985). In this second case both demand and supply side are affected by the process.

Analyses of the introduction of a new technology in presence of an already existing installed base have stressed the likelihood of an inefficient outcome in presence of network externalities. The behaviour of an industry which has already adopted a standard and is considering whether to switch to a new one has been investigated by Farrell and Saloner (1985; 1986) . Network externalities may induce either 'excess inertia' and delay the diffusion of an innovation or 'excess momentum' and speed up the adoption process depending on certain assumptions.

With unanimity and complete information about the characteristics of the technology, excess inertia cannot exist . In the case of incomplete information about the eagerness of the other firms to switch, firms are supposed to differ in their attitude toward change and they form expectations on what other firms will do. These expectations influence their eagerness to switch. Here two kinds of 'excess inertia' may arise: symmetric inertia if the firms have the same preferences over the technologies (all would switch) but they have a low attitude to switch. Asymmetric inertia when firms have different preferences on whether to switch or not. Improving communication (through a public announcement of switching) would reduce uncertainty and might solve the problem of symmetric inertia but it exacerbates the problems of asymmetric inertia.

Depending on firms' preferences and expectations on other firms' behaviour 'excess momentum' may also arise. This occurs in three cases. If the benefit for a single firm from combined shifting of technology is negative but higher than staying alone with the old technology. If the benefit from combined shifting is negative but a firm prefers to introduce a new technology if competitors have done it (even if *ex ante* it would have preferred competitors not to have done it). If the benefits form switching alone are negative but the bandwagon starts in the hope that the others will follow.

This paper is an attempt to analyse the process of lineage in the case of component system technologies when ‘market mediated’ network externalities[1] play a crucial role. This demands a new understanding both of the evolution of the technology and of the evolution of the preferences. Achieving a matching between users and producers seems crucial (Mangematin and Callon, 1995), to enhance the penetration of a technology into new applications domains. However, this matching is hardly achieved because in the lineage process technological characteristics and product characteristics evolve according to separate dynamics. Although producers may be less uncertain about the characteristics of the technology in a lineage process, they are highly uncertain about whether the products embodying the technology will match the preferences of the users allowing for the positive feedback to operate.

Moreover, for network externalities to be an effective driving force behind the diffusion of the technology, the establishment and maintenance of compatibility among the components must be assumed. However, when an innovation is introduced into new application domains it may challenge the present status-quo compatibility between the system components. If the innovation disrupts the compatibility, the interplay between producers’ strategies aimed atseizing the market by catering to users’ preferences, although still important, become less relevant as a mechanisms to explain how the lineage process gains momentum. What is required for the lineage process to occur is that compatibility must be re-established among the components. This is a necessary (although not sufficient) condition for the diffusion process to gain enough momentum and become self-reinforcing. Within this perspective, although it may not result from a technological breakthrough, the disruption of the compatibility increases the level of technological uncertainty. Producers’ decisions whether to experiment with new technologies become strictly inter-dependent and they might influence the outcome of the lineage process more than the interplay between users and producers.

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[1] From now on we will intend market mediated network externalities when using the term ‘externalities’.

If we incorporate this mechanism into the dynamics of the lineage process, the range of possible outcomes of the lineage process is enlarged. From the likely mismatch between the producers of system components, distinct dynamics may originate at different levels. The mismatch may induce 'excess inertia' to such an extent that the technology is prevented from branching into a new application domain. Another possibility is for the mismatch to induce excess inertia at the system level while at the same time it 'enhances' the lineage process at the industry level. We will analyse in Section 6 all these possible outcomes.

3. Legitimacy, Uncertainty and Network Externalities

In the previous section we have identified the features of the lineage process, recognised the need to distinguish between technologies and products, highlighted the peculiarities of the process in presence of network externalities and delineated possible outcomes of the process. To analyse those outcomes we need to introduce some measures to empirically detect them. The presence of network externalities have stressed the importance of re-establishing the compatibility between system components as a necessary condition for the lineage process to occur. We have pointed out how compatibility results from 'matched' decisions of the producers. In this section, we shall argue that this matching depends on the extent of the 'legitimacy' acquired by the technology and we will use this concept as a 'measure' both of the extent of the excess momentum/ inertia and of the width of the lineage process.

The concept of legitimacy is borrowed from the Organisational Ecology approach (Hannan and Freeman 1977). In the Organisational Ecology framework '(...) (an organisational) form receives legitimacy to the extent that its structure and routine follow the dictates of the prevailing institutional rules (...) an organisational form is institutionalised or legitimated to the extent that it has a taken for granted character' (Hannan and Carrol,1992: 33-34). The 'birth' and 'death' rates of firms are related to the density of the industry measured by the number of incumbent firms. Given a current total amount of resources available within the industry (carrying capacity) the dynamics of births and deaths depends on the evolution over time of the distance between the current density and the maximum sustainable number of firms defined by the given carrying capacities. When the density is low with respect to this frontier, entries (exit) are positively (negatively) correlated to density. The dynamic exhibits the so called 'legitimacy effect'. As the frontier of existing carrying capacities is approached, the legitimacy effect is offset by the increasing competition among firms for the still available resources and the relationship between density and rate of entry (exits) becomes negative (positive) (Hannan and Freeman, 1989).[2]

Here we want to extend the concept of legitimacy from the case of an organisational form to the case of a 'technology' embodied in system components. In extending this analysis, the units of analysis used will still be the firms but their rates of entry and exit will be investigated according to the relevant component niche they are present in and they will not necessarily coincide with the births or deaths of the firms themselves. Both the case when the innovation does not impact on legitimacy at the system level (i.e. it preserves the existing compatibility) and the case in which legitimacy *between* the industries is impacted (case of a 'systemic' shock) will be considered.

It is argued that a technological innovation in presence of network externalities gains legitimacy through two mechanisms (Choi, 1997). First as a consequence of the reduction of the uncertainty when producers experiment with the innovation and generates new information about its performance which can be appropriated by other producers (Cowan, 1991; Choi, 1997), or when the innovation conforms to institutional rules in the case of official standardisation (Farrell and Saloner, 1988). Second, when its installed base widens as the technology is embodied into a new product, introduced in the market, bought by users and generates positive feedback to producers. The scope of this 'adjustment' process is determined by the extent of the technological inter-relatedness (compatibility) within the system components (Rosenberg, 1976a; Katz and Shapiro, 1986). Innovating firms have major chances to enlarge these boundaries by reducing the extent of uncertainty surrounding the technology itself or by widening the installed base.

We argue that the two mechanisms impact on the rates of entry and exit in the following ways. Producers estimate the benefits deriving both from market mediated network externalities and from uncertainty reduction. However, these mechanisms impact differently on the decision whether to sponsor the technology and entry into the market. In the early stages of diffusion, the reduction of technological uncertainty, subsequent to the experimentation by the early producers, sustains the rate of entry at low density levels.

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[2]Together with these determinants, we believe that patterns of growth at the individual firm level are also

Producers confront the benefits in terms of acquired information from experimenting with the new technology with the fear of being 'stranded' if eventually the technology they sponsor is not adopted by users (David, 1987; Choi, 1997). This interplay determines both the rates of entry and exit. The effect of network externalities on the rate of entry is weak since is 'expected' more than actual (Katz and Shapiro, 1986; Habermeier, 1989). On the contrary, this absence of current positive feedback from users may increase the exit rate.

As uncertainty declines and network externalities become effective, rates of entry increase and rates of exit declines. In the late stages, when uncertainty about the characteristics of the technology is weak, the decreased uncertainty continues to impact positively on the entry rates but producers now balance the positive benefits of joining an existing network of users against the drawbacks of competing effectively with incumbents to decide whether to enter the market (Matutes and Regibeau, 1988; 1989). The presence of barrier to entry may offset the installed base effect. As a consequence, entry rates are low and exit rates may increase.

4. The Technological Evolution of the LAN Industry

This section takes a first step toward applying the above framework to the study the Local Area Network industry. Local Area Networks (LANs) are technological systems resulting from the match of many components coming both from the electronic and the communication technology field. 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. The evolution of the LAN industry highlights some of the typical features of technical systems. As LANs are made of several different components coming from different markets, the technological evolution of each component influences the diffusion of LANs through the effect of technological and economic complementarities.[3] We will focus here on two distinct 'industries' producing system components. The Internetworking Industry, producing the equipment (bridges, routers, switches) that

important determinants of the structure of the LAN industry. However we will not deal with this issue here.

[3]Technological complementarities are due to features of the computer hardware used in the network . 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.

connects sites on the network, and the Access Technology Industry providing the transmission protocol (Ethernet, Fast Ethernet etc.).

When trying to assess technically and economically the evolution of LANs' performance over time both the 'systemic' and the 'complex' feature of the network should be considered. The 'systemic' nature points 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 increases the complexity of the system as the network continues to grow. The 'complex' nature of LANs implies that, like in any electronic system, their fallibility is proportional to the number of their components. The technical trade-offs between those two dimensions have been shaping the evolution of the technological trajectories overtime.

Two phases of this evolution can be distinguished. An early phase (1985-89) in which the diffusion of LANs is pushed by the economic benefits of linking computers together. In this period the 'technology push' coming from both the evolution of the access technology and the improvement of computers' performance introduced new opportunities but also set new technological constraints. A following period where the exploitation of these new opportunities and the attempt to overcome the technological constraints set new economic priorities for firms and opened up a second phase (1990-97) of the evolution of the industry with the creation of the internetworking market and with the introduction of new access technologies.

4.1 The first phase (1985-1989)

Within each of the two phases two major innovations can be identified. In the first phase the endorsement of Ethernet as an official standard access technology in 1985 gave a decisive push to the industry. [4]

[4] 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 '
(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 in the December 1982 when the IEEE working group ratified the adoption of Carrier Sense Multiple Access

The standardisation of Ethernet represented a turning point in the diffusion of LANs because the adoption of a common transmission protocol, instead of the proprietary ones of the early corporate networks, changed the priority of the firms from the need to connect standalone computers and share applications to the need to connect existing LANs. To connect different LANs new devices called bridges were introduced. Bridges connected different networks by performing a 'store and forward function'. Due to their low processing capabilities they could not differentiate between addresses and they could not support more than one path to each destination. In the presence of 'mesh topologies' they became incapable of handling the increasing traffic.

Reducing the complexity of the network and increasing reliability and its ability to be managed so as to avoid additional costs became the new priority for users. Moreover, the increased performance of computers demanded more bandwidth availability to transmit the higher quantity of the data needed to be processed. Producers coped with this priority by introducing the multi-protocol router in 1989. 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 within a network. To perform this task, a multi-protocol router is capable of interpreting the different network communication protocols to detect both the sender and receiver addresses with streams of data in order to forward the data. With the introduction of the multi-protocol function, which opened up the internetworking market, the first phase of the evolution of the LAN industry ended.

4.2 The second phase (1990-1997)

In the second phase (1990-97), both in the access technology and in the internetworking industry technological innovations tried to cope with a new technological priority: the so called 'total and node throughput issue'.[5] As new high performance PCs and applications were linked over Ethernet LANs and as more and more functions (voice and video

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with Collision Detection (CSMA/CD) as access method for Ethernet. In 1985, after the '
had accepted the new specifications, the official publication of Ethernet as a standard was made world-wide.

[5]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.

transmission) were to be integrated into data communication, producers had to face a constantly increasing demand for bandwidth.

In 1990 Kalpana, a US based company, introduced the switch as an attempt to respond to this priority. The idea behind the switch is to bring into networking a principle employed by telephone technology where the connection of the stations to a switch ensures 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 viewpoint a logical development of bridges.[6] 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 (Layer 3 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,[7] challenging what until then had represented the exclusive technological domain of routers. This entry into routers' technological field was the consequence of technological improvements which affected the forward capabilities of the CPU both at the software (RISC architecture) and at the hardware (ASICs) level (Hein and Griffiths, 1997).

However, the 'switch revolution' is very much related to the events in the access technology industry. In 1990, a swarm of alternatives to Ethernet was introduced in the market to

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[6] Bridges were early devices used to connect existing 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 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.

[7] 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.

become standards.[8] This proliferation of alternatives was the consequence of specific strategies of the producers 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
setting processes which would officially endorse one of the alternatives. Quite soon producers concentrated on FDDI and Fast Ethernet.

FDDI had been the first alternative to be officially standardised. However, Fast Ethernet although it was a second comer was immediately recognised as the most viable and profitable by the producers. 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. 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.

However, FDDI could ensure better performances 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 out-competed 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, the introduction of the switch in the internetworking market, which revitalised

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[8]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).

the segment of previously adopted access technology such as Ethernet, focused the development of innovations in access technology upon alternatives compatible with the existing ones. Fast Ethernet became more adopted than FDDI.

The great impact of the switches was also a consequence of this stalemate in the access technology field. It became clear that switches represented not only another solution to boost bandwidth, but also an alternative which de-coupled, 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 technologies at the same time without re-cabling changed the priorities for both producers and users. 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 producers to supply switches in their product lines and to make them compatible with Ethernet-based products.

It seems clear that, because of 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 routers substituted for bridges 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.[9] We will try to detect empirically the effects induced by innovations on the dynamics of the lineage process starting in sections 5.

5. Preliminary Findings on Legitimacy

Our main concern is to assess whether either excess inertia or excess momentum have occurred as a consequence of technological innovation, and whether legitimacy can be considered relevant as the main mechanism behind these dynamics. To detect the relevance

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

of legitimacy, we will confront the dynamics of the access technology industry from 1985 to 1989 and of the internetworking industry from 1993 to 1997.

The choice of these two periods is not accidental. As briefly sketched in section 4, between 1985 and 1989 the access technology industry was relatively stable after the endorsement of Ethernet. Major technological innovations did not occur until the end of 1989 with the multi-protocol router. Between 1993 and 1997 the LAN industry has been impacted by the introduction of the switch in the internetworking industry and the shift from the shared to the switched network architecture. Since they experimented different events, we expect to find different dynamics of firm growth and entry in the two industries for these two cases. A comparison will allow us to draw some conclusions on the relevance of the legitimacy mechanisms in explaining these differences.

5.1 Legitimacy in the access technology industry (1985-1989)

Table 1 reports the analysis of the dynamic of the access technology industry between 1985 and 1989. This is a period of consolidation for Ethernet after the official standardisation in 1985. New entries and exits increase 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. 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.

The patterns of entry, exit and persistence in the industry seem to be related. Both the number of new entries and the number of the total incumbents is small at the beginning when new entry represents a high percentage of the total incumbents. They both increase but when the number of new entrants levels 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.

Tab. 1: US LAN industry: Density, Entry and Exit (1985-1989);

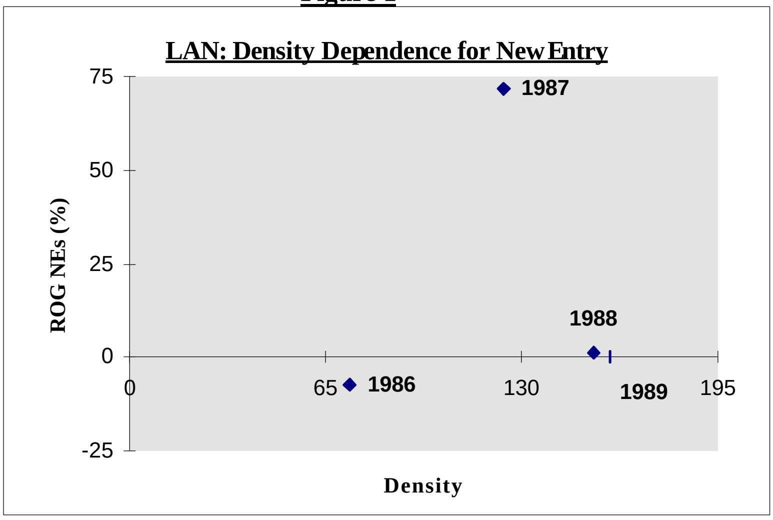
YEAR	TOT. INC. (ROG)	TOT. NE. (AS A % OF INC.)	ROG FOR NE	TOT. EXITS (AS A %OF INC.)	ROG FOR EXITS
1985	47	47	-	-	-
1986	73(55%)	43(91%)	-8%	17(36%)	-
1987	124(70%)	74(101%)	72%	23(31%)	35%
1988	154(24%)	75(60%)	1%	45(36%)	96%
1989	159(32%)	75(48%)	0%	70(45%)	55%
AV.	111(42%)	63	16%	39	62%

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

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.

The scattergram in Figure 1 suggests that the increase in the number of new entries begins soon after the standardisation of Ethernet and Token ring. This seems to highlight a strong legitimacy effect.

Figure 1



The endorsement of Ethernet as an official standard reduced the uncertainty of the producers about the characteristics of the technology and reinforced the advantages it already enjoyed as a consequence of having been experimented and introduced in the market before the only available alternative (Token Ring). 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.

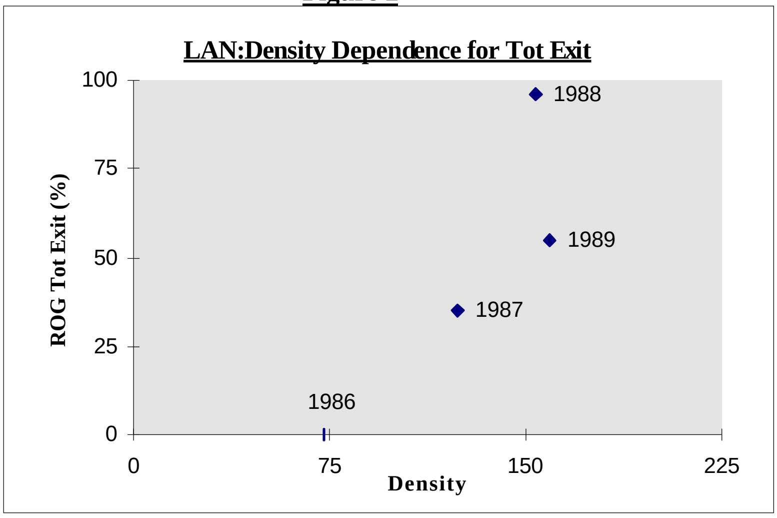
The flow of entries was probably reinforced by other factors. An increase in total revenues parallel to the increase in production might have induced some firms to enter attracted by the lure of profits. For this to be effective, the profit margins should not have been eroded by the decline in prices. 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.[10] The main point is that the endorsement acted, through the reduction of the uncertainty, as a source of legitimacy encouraging more firms to experiment mainly with *that* existing standard instead of the alternative one.

The reduction in uncertainty had a positive effect on legitimacy until 1987. By that time, also positive feedback generated by market mediated network externalities attracted new producers into the industry. In 1987 the number of incumbents in the industry had reached the point where the benefits in terms of decreased uncertainty new firms could get from the addition of other ‘experimenters’ were offset at the margin by the increase in density brought about by the presence of more producers attracted by the increasing demand. Moreover, the increase in density multiplies the number of possible interactions among producers and the number of possible results firms have to consider as a consequence of their strategic behaviours. This might have prevented more firms from entering the market.

The scattergram in Fig. 2 depicting the relationship between density and the ROG of exits may either fit a linear positive relationship or a non-monotonic relationship (increasing up to 1988 and then decreasing). As we pointed out in section 3 legitimacy exerts opposite effects on firms entering and leaving the industry.

[10] 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.

Figure 2



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 1 third column above), then a high rate of exit *within* new entries (a ‘churn’of the new entrants pool), 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 legitimacy is not affected by market mediated network externalities. 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 2 and 3 seems to confirm this hypothesis.

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). A smaller number of incumbents seems to leave in the early years than subsequently because total exits are boosted by the increasing number of new firms which enter and leave the industry immediately.

Tab. 2: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. 3: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

Soon after the standardisation of Ethernet which 'legitimised' the technology and set the pace for the early entries, incumbents enjoyed the benefits deriving from decreasing uncertainty and low competition thanks to still low (but increasing) 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 from the reduction of the uncertainty and had quite similar low rates of exit.

When also market mediated network externalities started their positive feedback on the decisions of producers, incumbents continued to further strengthened their position but the incentive for new firms to enter increased. As a result new entries peaked but early incumbents might have benefited more than new firms from this effect because the already established installed base had created an entry barrier *within* the industry between them and the new firms. 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.

5.3 Legitimacy in the internetworking industry (1993-1997)

The dynamic of the internetworking industry between 1993 and 1997 is different from the one analysed in section 5.2. In this period the industry shows the consequences of the introduction of the switch which opened up a new market. The patterns for incumbents, total entry and total exit (Tab. 4 next page) is not monotonic but fuzzy.

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 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.

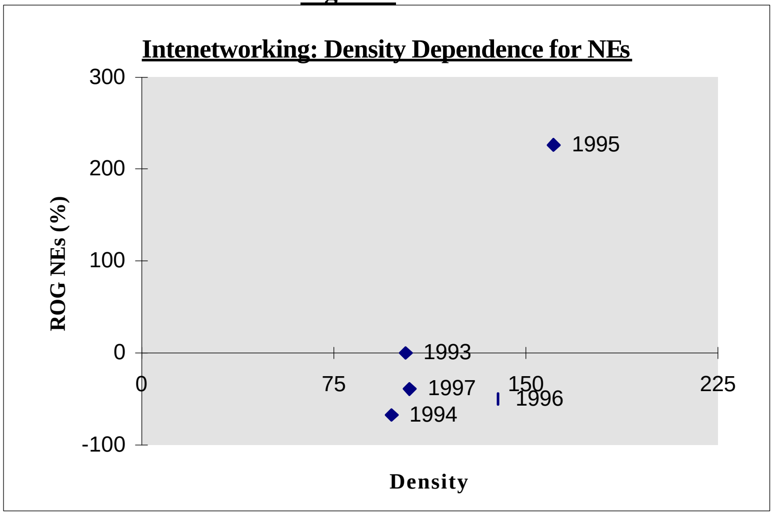
Tab. 4: US Internetworking Industry: density, entry, exit (1993-1997);

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, ROG stands for Rate of Growth, NE for New Entrants, AV for Average;

In the case of the access technology the pattern clearly displayed a non-monotonic relationship between density and the rate of entry. This seemed to result from the evolution over time of the effects of the two components of legitimacy on increasing density. The same pattern does not seem to fit our data on density and rate of entry in this case. The scattergram in Fig. 3 seems to highlight a positive but linear relationship between density and rate of entry as if it captures only one component (the reduction of uncertainty) of the legitimacy effect.

Figure 3



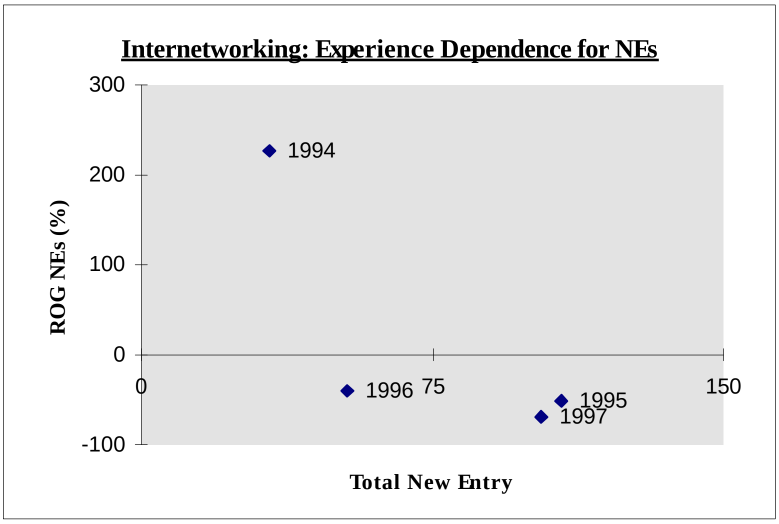
We need to identify what was the source of legitimacy in this case. The increase in the rate of entry between 1994 and 1995 is so sharp that it points to a strong effect of the decreasing uncertainty. However, contrary to what happened in the case of Ethernet, no official endorsement of the product as a standard has occurred to justify such an impact.

What contributed to reduce the uncertainty in this case was the previous ‘experimentation’ with switches as substitutes for bridges four years before they boomed in 1995. This helped to reduce the technological uncertainty and to enhance further their acceptance once their improvement had made them potential technological substitutes for routers.

Had the density exerted a positive effect on the rate of growth of entry only by decreasing uncertainty we should observe a positive relationship between the rate of new entry and the total number of new entrants since it can be 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.[11]

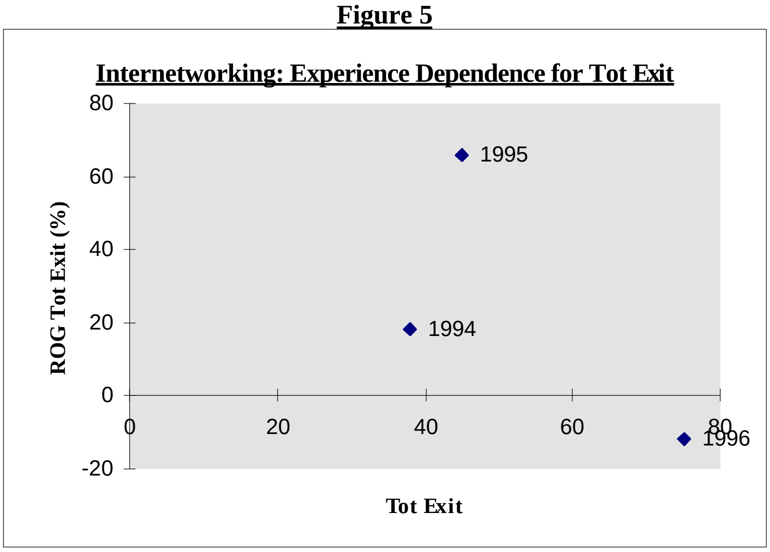
It can be noticed instead (Fig. 4), that there does seem to be a negative relationship between total new entry and the ROG of new entry. The wave of entry in 1994 attracted new firms immediately but their entry did not seem to trigger any signalling effect to further entries. The quick drop in the prices of switches, which had made them an economic alternative to routers for users, to such a point that many producers entered the market with the perspective of facing such a high demand, induced actually perspectives of low profits and restrained firms from following the early entrants. This seems to follow from the second mechanism of legitimacy: market mediated network externalities.

Figure 4



However, we should expect the weakness of the signalling to be confirmed also for the rate of exit (Fig.5).

Figure 5



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. We should expect a

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[11] This is the 'experience effect' of the Organizational Ecology (Hannan and Freeman, 1989: 205);

positive relationship between the number of recent exits and the current rate of exits.[12] In our case a negative relationship, seems to fit better than a positive one.

We argue that the main reason is represented by the peculiar technological nature of the switch. The introduction of the switches impacted upon the technological frontier both at the component and at the systemic level and started a lineage process. At the component level, it allowed firms in the industry to obtain scale economies in the production and relaxed some of the constraints which had previously prevented routers producers from achieving those economies. By spurring competition within the industry it reshaped the boundaries among the segments within the internetworking industry.

Nevertheless, the switch incorporated also new functions. The possibility to gain bandwidth by shifting from the shared architecture to the switched architecture made the switch a direct competitor of the current access technology. This changed the relevant parameters affecting consumers'choice. The opportunity to address this additional portion of the demand restrained incumbent from leaving the industry regardless the decreasing profits brought about by the increasing competition.

After the analysis of both the industries we can sum up and comment upon the findings. The two industries differ both in their dynamics and in the relevance of the mechanisms underlying and explaining it. The evidence from the access technology industry highlights the two mechanisms behind the legitimacy. The density of the incumbents would seem to be the relevant dimension to study to capture the role of network externalities and decreasing technological uncertainty. The evidence from the internetworking industry is different. Density seems to be still relevant but the legitimacy effect seemed to have been weaker than in the previous case mainly because innovations impacted both at the industry and at the systemic level. We are now going to use these results to draw some conclusions on the characteristics of the lineage process in the LAN industry.

[12] In the Organizational Ecology framework, 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. (Hannan and Freeman, 1989: 272).

6. Legitimacy and the Lineage Process

The analysis of the technological evolution of LANs in section 4 has highlighted two regularities. 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. We stressed the case of switches which were substitutes for bridges and only the application either of RISC architecture or the use of ASICs gave them the opportunity to substitute for routers in high speed applications.

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"). 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 when routers were introduced as substitute for bridges and when switches substituted both for routers and for the access technology.[13] However, the complete substitution did not always occur immediately. Old products continued to perform their function soon after the introduction of potential substitutes. As the substitutes got through different generations 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.[14]

[13] 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.

[14] Bridges disappeared completely only when switches entered the market, but at the beginning they coexisted with routers.

In Section 5 the influence of network externalities and of the reduction of technological uncertainty on legitimacy have been ‘identified’ behind the technological evolution and their impact on the rate of growth of each of the industries producing system components discussed. We want now to sum up the findings of the previous sections, to make some preliminary guesses about the structure of the causation between these mechanisms and the lineage process. Four cases can be identified according to whether the inter-industry or the intra-industry effect of the innovation is analysed.

Inter-industry effects of the innovation (1). Excess momentum in presence of a lineage process: the case of the switches and the access technology (FDDI)

The introduction of the switch, lowered both the incentives of producers to engage in experimentation with new alternative access technologies and the feedback from the market mediated network externalities. From their introduction, 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 together with the high technological uncertainty, prevented competitors from entering the FDDI market. The opportunity to adopt a switched network architecture contributed to speed up the diffusion of the switch as a substitute both for the router and for the access technology. This ‘excess momentum’ delayed the diffusion of new and more efficient alternative access technologies (e.g. ATM).

Inter-industry effects of the innovation (2). Excess inertia with (?) lineage process: the case of the access technology (Ethernet) and the multi-protocol router

As we have analysed in Section 5.2, the legitimacy mechanism through which the endorsement of an access technology as a standard impacted the market was mainly induced by the reduction of uncertainty. The standardisation of Ethernet induced such high expectations to producers that the diffusion was accelerated. 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. Nevertheless, it introduced new bottlenecks. It took time, from 1985 to 1989, before the introduction of the multi-protocol router overcame these bottlenecks. Multi-protocol routers did not substitute for Ethernet so they did not start a ‘lineage process’. However, they represented a sort of

Bunn, 1988), at the system level which reinforced, after the initial inertia, the diffusion both of the access technology and of the internetworking equipment.

Intra-industry effects of innovation (1) . Excess inertia without a lineage process: the case of the multiple endorsement of access technologies

In the access technology industry, the technological stalemate which occurred at the beginning of the 90's has provided an example of how the combination of high uncertainty and lack of positive feedback from within the system, induced excess inertia and delayed the adoption of alternative technologies. Fast Ethernet, FDDI, ATM were all viable substitutes for Ethernet and were candidates to gain legitimacy. All could provide the increase in bandwidth to overcome the existing bottleneck represented by the ‘total and node throughput issue’. In particular ATM was, (and it is still considered to be), the ‘ultimate’ access technology in terms of performance both for speed and for the 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 with increasing the ‘excess inertia’ leading to the adoption of the less efficient Fast Ethernet. 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’ and the consequent impossibility for the firm to switch to the sponsorship of another technology increased the fear of being ‘stranded’ and becoming ‘angry orphans’ (David, 1987), had the one supported not been widely adopted.

Intra-industry effects of the innovation (2) . Excess momentum without lineage process: the impact of switches on the router segment

The change from a shared system architecture to a switched system architecture represented by the introduction of the switch impacted on the structure of the internetworking industry through the router segment. The technological barriers to entry raised by the introduction of a gateway technology such the multi-protocol router, revealed to be weak in the presence of competition from a potential substitute. 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 to generate excess momentum even in the absence of a lineage process. New entries were mainly driven by the expectations of future gains coming from the substitution of routers with switches, but to seize this opportunity producers needed to be quick in cutting costs and to ship as many products as possible to enhance the substitution process through the network externalities mechanism.

The diffusion of ASICs as an alternative to software-based switches helped producers to achieve this goal. The development of the ASIC based switches present the interplay of the two mechanism we identified as responsible for the legitimacy. From the producers' 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 experimentation with the product. This implies an evaluation both of producers and of users' reactions 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 was a way to reduce market uncertainty. The commercialisation of a product compatible with the existing installed base was an attempt to enhance the adoption by 'adapting' to existing needs as expressed by the final preferences. ASIC-based switches, once developed along these premises, offered all the advantages in scaling up production and cost cutting which allowed them to gain 'excess momentum' as substitutes of routers. Table 5 (next page) summarises the four cases.

As can be seen from the table, on the one hand there is no lineage process when innovation preserves the compatibility within the system but this may induce either excess inertia or excess momentum. On the other hand, when the innovation disrupts the compatibility at the system level, both excess inertia and excess momentum may occur but this may not configure a 'lineage process'. Therefore, no clear-cut conclusions can be drawn about the relationships between the lineage process, the level of inertia and the extent of compatibility disruption within the system. Excess momentum and excess inertia seem to depend on the two mechanisms behind the legitimacy instead. The former is linked more to the decreasing in technological uncertainty and the latter to the network externalities effect. However, this conclusion requires a much more deep investigation.

Table 5: Relationships between the extent of inertia and compatibility

		Inertia	
		High (excess inertia)	*Low (excess momentum)*
Compatibility within the system	*Maintained*	The case of multiple endorsement of access technologies (No lineage process)	The impact of switches on the router segment (No lineage process)
	Disrupted	The case of Ethernet and multi-protocol routers (Lineage process?)	The impact of switches on FDDI (Lineage process)

7. Conclusion

This paper has represented a first attempt to provide some empirical findings on the phenomena of excess inertia and excess momentum in the diffusion of component system technologies (Farrell and Saloner, 1985; 1986). The analysis has been framed within the boundaries of a lineage process (Levinthal, 1998), to recognise the need to capture two distinct mechanisms driving the diffusion of innovation: decreasing technological uncertainty as producers experiment with the new technology and market mediated network externalities as users adopt the components embodying the technology (Choi, 1997; Katz and Shapiro, 1985). These two mechanisms have been summed up in the concept of legitimacy borrowed from the Organizational Ecology approach (Hannan and Freeman, 1989), and an empirical analysis was attempted. The approach has revealed to be fruitful to capture some sector dynamics of entry and exit which, combined with a reconstruction of the technological evolution of the industry, offered some sensible insights into the impact of those mechanisms on the extent of the lineage process.

However, this analysis has been just a start and further empirical investigations and further elaboration of the theoretical framework are required. First, there is the question of the source and of the robustness of these findings for explaining the lineage process. One possibility is that legitimacy merely reflects the effect of the innovation. A second one is that the dynamics of entry and exit followed the innovation but was not directly related. At this stage of the analysis, and because of lack of data, we could not discern more between the two hypotheses but this is an important issue to deal with as soon as possible. Second, there is the need to elaborate more on the distinction between technologies and products. How useful is it to capture the two mechanisms behind the dynamics of diffusion? Are those mechanisms suitable to explain the dynamics? Here an analysis of the determinants of the evolution of the technological frontier and an analysis of the evolution of the markets niches should be combined to provide an answer to these questions. Third, descriptive statistics on market shares and concentration indexes could be helpful to analyse whether there is any relationship between those mechanisms and the evolution of competition both within and between the industries. We are aware that further advances along these directions depend to a great extent on the availability of data which, given the rapid changes and the extreme fluidity of the industry, are neither easy to find nor easily ready in large data sets. However, we are confident that a combination of historical investigation, statistics and economic theory might be helpful to overcome these drawbacks.

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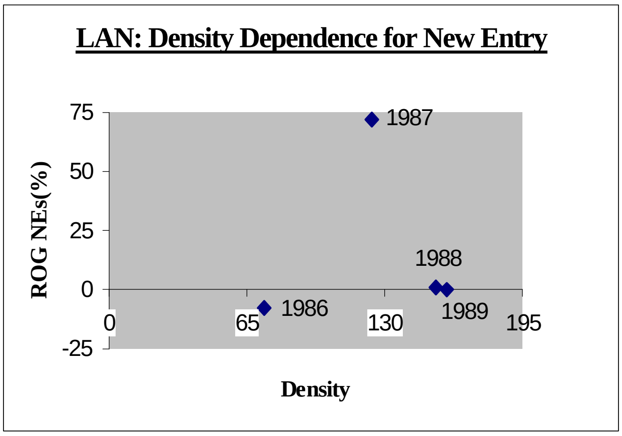

Figure 1

Figure 2

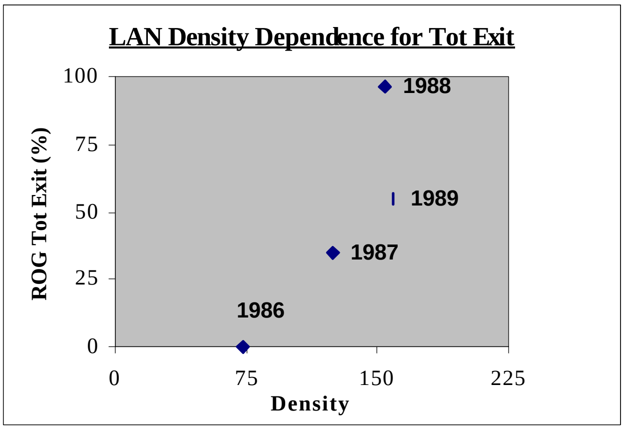

Figure 3

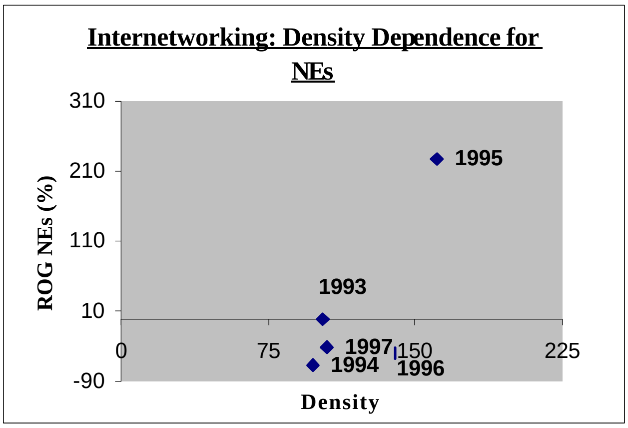

Figure 4

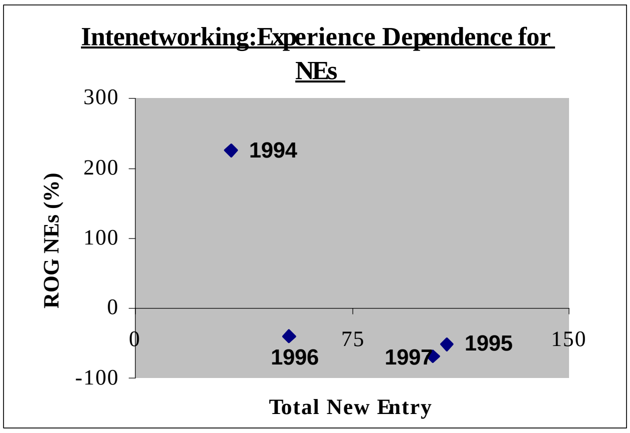

Figure 5