"…then came Cisco, and the rest is history": a 'history friendly' model of the Local Area Networking industry

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ABSTRACT

We study the role that switching costs, compatibility, and mergers and acquisition, play in influencing the evolution of an industry. By looking at the case of the Local Area Networking, a multi market industry, we propose a 'history friendly model' to replicate the evolution of the industry during the 1990s. Our model explains how a firm can start from a dominant position in one of the existing markets and exploit switching costs and compatibility to enter a new market when it opens. Mergers and acquisitions also play an important role as the new market is pioneered by a new start-up, which is soon acquired by the dominant incumbent. As a result of the acquisition, the acquiring firm becomes leader also in the new market.

Key words: Simulation, History Friendly Models, Switching Costs, Compatibility
JEL classification: 030, L10, L63

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1. Introduction

The aim of this paper is to propose a 'history friendly' model of the Local Area Networking (LAN) industry in the 1990s. LANs are physical infrastructures enabling computers, peripherals and more in general 'end stations', to be linked to form a network connecting different users within an area of narrow extension (i.e. a university campus or different buildings at a company site). The LAN industry is part of the data communication industry that accounts for 30% of the total spending on communications equipment in the US. In the phase of maximum growth of the industry, spending on LAN equipment accounted for 47% of the total for data communications and 14% of the total for telecommunication equipment in US (Doms, 2003).

'History friendly' models (HFMs from now on) are conceived as part of a second generation of evolutionary models of industry evolution. While first generation models (Nelson and Winter, 1982) were abstract and general, primarily aiming at exploring the logic of evolutionary economic processes and at establishing the utility of this new approach, HFMs intend to focus on and to explain the historical evolution of specific industries. The first example of a HFM was proposed by Malerba *et al.* (1999), who also provided a discussion of the HFM methodology.[1] In particular, Malerba *et al.* (1999) argue that one primary goal of HFMs should be to verify the logical consistency of appreciative theorizing put forth by analysts of the history of an industry or a technology. Appreciative theorising is defined as the non-formal explanation of observed phenomena based on specific causal links proposed by the researcher (Nelson and Winter, 1982). Although appreciative theorizing must be seen as 'true' causal theory and a fundamental process of building a theory, it can be difficult to assess if the suggested causal arguments are consistent and sufficient to provide an explanation, in particular if the phenomena under investigation embody non linear and path-dependent processes. In this respect, a first objective of the HFM exercise is to identify a set of 'reasonable' values for the parameters such that the model is able to replicate the actual evolution of the industry. The existence of such a set of values supports the capacity of the formal model, and indirectly of the appreciative theorizing, to be a valid explanation of the empirical evidence. After achieving this aim, the model can then be used to perform counterfactual analysis. Varying key parameters, it becomes possible to study 'what if' histories, assess the robustness of the results, make predictions, and formulate further hypotheses.

[1] Malerba *et al.* (1999) present a model of the evolution of the computer industry. Other sectors which have been studied using this approach include pharmaceuticals and biotechnology (Malerba and Orsenigo, 2002), and the DRAM industry (Kim and Lee, 2003).

Our paper focuses on the structural dynamics and evolution of the LAN industry during the 1990s, an extremely dynamic period in which growth occurred as the consequence of the interplay between technical change and new market creation. The evolution of the LAN industry proceeded in phases, each of them characterized by the presence of several markets (one for each piece of LAN equipment) and each phase characterized by the presence of a 'focal' market. During the 1990's, Cisco Systems was able to become the dominant firm in the LAN industry by extending its dominance from an existing market (routers) into a new market (switches).

The appreciative theory we propose to explain this pattern is based on three elements: switching costs, compatibility, and mergers and acquisitions (M&As). In the industry, switching costs derived mainly from the need to purchase equipment that is compatible with the existing installed base, and from the extra cost customers incurred to learn how to use equipment purchased from different manufacturers. LAN equipment 'work together' on the basis of common and open standards. However, all the major industry leaders developed families of equipment and dedicated software platforms in an attempt to differentiate their offer from those of competitors. In this context, compatibility (or lack thereof) became an important issue to maintain market leadership. M&As of new start-ups where also used by incumbents to restrain competition and gain access to new technological capabilities. In a nutshell, we argue that Cisco was able to become the industry leader by exploiting its installed base, through switching costs and compatibility, while simultaneously acquiring new technological capabilities through a mix of targeted M&As.

Our formal model captures all the distinguishing features of this appreciative theory, and it produces results that are in line with the observed history. In particular, while the historical pattern is qualitatively obtained irrespectively of the level of switching costs and firms strategies about compatibility, the observed high level of concentration and a high market share for the leader in all the markets is obtained only for a significantly high level of switching costs. M&As play a crucial role in shaping the industry evolution, as a counterfactual exercise excluding them produces an evolution of the industry that is rather different from the observed one.

According to Malerba *et al.* (1999), HFMs may (and in a sense they should) provide insights that span beyond the specific industry under investigation. In this respect, our work contributes to a recent stream of literature which studies the co-evolutionary dynamics of related markets, in particular Malerba *et al.* (2006), who developed a HFM of the computer industry which focuses on vertical specialisation and integration, Malerba e Orsenigo (2008), who consider the same issue in a more general model, and by Bhaskarabhatla and Klepper (2008), who, using a different approach, analyze the co-evolution of technology and different sub-markets in the laser industry. We extend this literature by considering the case of demand for complementary goods in presence of 'frictions' such as switching costs and partial compatibility. Other industries (for instance software/hardware in IT) present similar characteristics and some of the dynamics we have described are likely to be observed also in these industries.

The paper is structured as follows. Next section provides the background information on the evolution of the LAN industry. In particular, it identifies those facts of industry evolution on which we intend to focus on, and sets the stage for the development of an appreciative theory in Section 3. The HF model is described in Section 4 Section 5 reports the results from numerical simulations. Section 6 discusses some of the findings. Section 7 concludes.

2. The evolution of the LAN industry

In this section we present an overview of the main events that have characterized the pattern of technical change and the evolution of the LAN industry, with a specific attention to the 1990s. It provides the necessary background information for understanding the model and the analysis that will be carried out in the rest of the paper.

LANs constitute the physical infrastructure for data communication across an area of narrow extension (e.g. a university campus or different buildings at a company site). Over LANs data travel in packets from a possible sender to a data receiver according to some 'rules' defined by standards. Beside standards, the infrastructure of modern LANs is made up of several types of equipment which govern the data traffic at different levels of technological complexity and hierarchy. We focus on three types of equipment: hubs, routers, and switches. Within a LAN, each piece of equipment plays a specific role. Hubs are very simple equipment which are used to extend networks. Routers are technologically complex as they embody the algorithms used to optimally transfer data across users and between separate LANs. Switches are used to accelerate data transfer and processing. They are located between hubs and routers in terms of technological complexity. The wiring of hubs, routers, and switches form a 'system'. LAN firms manufacture and commercialise the pieces of equipment that constitute the system. Each type of equipment is commercialised in a specific market of the industry and LAN manufacturers may or may not be active in every market. During the evolution of the industry, and as a consequence of technical change, the functionality of equipment changed and the boundaries between the markets have progressively blurred.

The diffusion of office LANs started in the second half of the 1970s. Early LANs were essentially 'company' networks based on proprietary technologies (i.e. the Xerox Network and the DEC Network etc.). An acceleration in the diffusion of LANs within office environments occurred during the first half of the 1980s as a consequence of the official definition of Ethernet and Token Ring as LAN transmission standards. Both Ethernet and Token Ring enabled companies to connect the sparse existing 'legacy' LANs by using two types of equipment: bridges and routers. Bridges and routers were mainly used to connect networks running incompatible standards. Hubs were introduced to rationalize cable deployment and enlarge existing networks. At the end of the 1980s, the process of enlargement created congestion problems as new and more performing computers were adopted in company offices and new 'bandwidth hungry' voice and video applications became available. Two possible solutions slowly emerged. The first was the definition of new high speed standards which could enable data packets to travel at higher speed than that provided by Ethernet and Token Ring (10Mbps and 4 Mbps respectively). The second was the deployment of switch equipment that progressively substituted for hubs within high speed LANs (Christensen *et al.*, 1995).

The definition and commercialization of high speed standards that occurred in the first half of the 1990s saw initially the competition between different alternatives (Fast Ethernet, FDDI, 100VG-AnyLAN and ATM) and ended in mid-1990s when Fast Ethernet became dominant (Fontana, 2008). The diffusion of new standards and the opening up and evolution of new markets were not disjointed. The definition of new standards at high speed represented for LAN users a possible solution to congestion problem but, at the same time, a new source of possible bottlenecks when the implementation was not accompanied by changes in the design of the equipment. During the 1990s, technical change in hub equipment mainly consisted in changes in the hardware design in response to the introduction of high speed standards. This dynamic sustained the growth of the market. A further evolution consisted in the development and introduction of switch equipment. Switches embodied many of the functionalities played by hubs and threatened their existence. This happened during the second half of the 1990s which witnessed the progressive decline of importance of the role of hubs within LANs and the fast diffusion of switches while the router market stood still. The changes in revenues reported in Figure 1 below reflect the events just summarised.

[Insert Figure 1 about here]

We now analyze more in detail the dynamics of the two key markets in the 1990s, routers and switches.[2]

2.1. The router market

Starting in 1989 the router market has passed through three phases, each opened up by some kind of technological innovation (either radical or incremental). The introduction of the 'multi-protocol function' was the event that opened up the market and engaged router manufacturers in close competition. The market then entered a diversification phase (1992-1994) in which incumbents started to offer 'scaled down' versions of previous products (i.e. remote-access routers) following mainly two different innovative strategies, software-only routing or hardware-based routing.[3] A new phase started in 1995 when router manufacturers felt progressively threatened by new entrants coming from the switch market (Miller, 1996).

During all these phases the structure of the router market did not change much. Entry and exit combined with decreasing prices occurred. Market shares and firms' ranking, considering also M&As, remained relatively stable though a look at the changes in market shares for the overall market between 1990 and 1996 (see Table 1) reveals a tendency toward a growing concentration.

[Insert Table 1 about here]

Contrasting this relative stability there was much more turbulence at the sub-market level (i.e. multi-protocol and remote-access router). During the period of diversification total revenues in both sub-markets continued to grow and average prices to fall, but at different rates in each sub-market. Prices of multi-protocol routers decreased relatively less than in the remote-access sub-market.

Competition was less effective in the case of the multi-protocol sub-market because of higher barriers to entry represented by both the high capabilities required to provide the software responsible for the multi-protocol routing function and the presence of demand side switching costs. Most of new firms which entered the sub-market during the diversification stage could not provide the routing function in their products which had to be handled by PCs. Multi-protocol

[2] Existing contributions have provided detailed evidence on the early history of the industry (von Burg, 2001) and on the events that have characterized the most recent period especially concerning the optical networking market of the data communication industry (Carpenter *et al.*, 2003).

[3] Multi-protocol routers embody several algorithms and support several communication protocols to intelligently deliver data packets to their destination. Access-routers provide customers with an interface between their end stations and the network.

incumbents responded to the challenge of new entrants with new products that contained proprietary software and hardware thus rising demand side switching costs and barriers to entry (Miller, 1994). Prices for remote-access routers fell both because of competition from multi-protocol incumbents, and because of new entrants from the switch market.

In 1993, when the switch market took off, some switch manufacturers challenged existent incumbents also at the low-end of the router market. Thus, new entries in the remote-access sub-market continued to increase fuelled by new manufacturers. As a result, within the router market the multi-protocol sub-market was systematically more concentrated than the remote-access sub-market (see Table 2).

[Insert Table 2 about here]

Competition in multi-protocol sub-market increased as the result of new entrants which, however, failed to challenge the leaders. A mix of technological advantage and the presence of switching costs partially sheltered incumbents from increasing competition. The remote-access sub-market instead suffered the consequences of two types of competition. Increased competition from outside the market was as effective as intra-market competition in disrupting technological barriers.

2.2. The switch market

The first LAN switch was introduced in 1990 by a US start-up company: Kalpana. From the technological viewpoint, early switches were an incremental innovation with respect to bridges.[4] Thus when they first appeared in the market they engaged in a direct competition with bridges rather than with routers. Second generation switches incorporated technological improvements which enabled them to perform more sophisticated data communications thus challenging what until then had represented exclusive application domains of routers.

From an economic viewpoint, the introduction of the LAN switch had a great impact on the structure of the 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 a typical switch was priced (on average) only 35% more than a remote-access router. The price premium was even smaller as switches could ensure higher data speed and performance. The commitment of suppliers to address demand came together with a change in the structure of

[4] Bridges had been used during the 1980s to interconnect LANs using different proprietary standards.

the market, although changes were different from the ones experienced by routers (see Table 3 below).

[Insert Table 3 about here]

The arrival of the switch impacted deeply on the sales of the other LAN products. The LAN switch was a definite hit for LAN bridges and routers sales slowed down. Also, switches represented a window of opportunity for a swarm of new firms to enter the industry, try to undermine, for the first time since its foundation, the growth of the router market, and to lay foundations for future changes in the entire industry.

The structure of the switch market has always been concentrated, although less than that of routers. In 1994, the four biggest firms in the market (Cisco Systems (Kalpana), 3Com (Synernetics, Alantec and Chipcom)) accounted for 94% of revenue share. In the 2nd quarter of 1999, the share of the four biggest companies had fallen to 81%, with Cisco maintaining the lead at 47%, followed by 3Com, Nortel Networks (Bay Networks) and Cabletron. Contrary to what had happened in the router market where there were no major changes in firms' ranking, here the market experienced a marked shuffle. This difference is the result of the different dynamics underpinning entry and exit in this market when compared to routers'.

Entry in the switch market was driven by three types of manufacturers. First, there were incumbents from within the LAN industry (both from the router and the hub market). Cisco Systems, the future dominant firm in the switch market, was originally a router maker and was among the first firms to enter. More hesitant incumbents in the hub market (3Com, Bay Networks, DEC) were constrained by their previous investments as well as by the risk of cannibalizing their installed base. Second, there were incumbents from outside the industry but with previous experience either in the telecom industry or in the semiconductor industry. Third, there were start-ups searching for new opportunities.

Consolidation occurred mainly because of two reasons. First, incumbents strengthened their position through a mix of targeted M&As. Cisco Systems, soon to extend its dominance from the router into the switch market, entered by acquiring Kalpana the market leader and pioneer of the technology. In 1994, SynOptics (a hub maker) merged with Wellfleet (a leader in the router market) to create Bay Networks. Indeed entry by acquisition soon became one of the main features of the LAN industry and several recent works have investigated both the economic (Fontana and Nesta,

2009) and the managerial/organizational (Mayer and Kenney, 2004) implications of this strategy of growth.

Second, incumbents leveraged on their existing leadership in related LAN markets to become dominant in the new switch market. This strategy was facilitated by the peculiar nature of the switch market which soon became polarized. Indeed, the growth of the switch market was accompanied by developments in the equipment design (i.e. transition to Application Specific Integrated Circuits based hardware). As a result of these events, in the second half of the 1990s, two sub-markets opened up. High-end switches, characterized by high performance, were targeted to customers with large networks. Low-end switches were low cost and generally less performing, supported only one standard and were targeted to customers with small networks (Fontana and Nesta, 2006).

3. Towards an appreciative theory

The previous sections have summarised the main events and facts that have characterized the structural dynamics and evolution of the LAN industry during the 1990s. The aim of this section is to highlight these facts and to develop an appreciative theory to be formally represented in a HFM.

The first fact emerging from the previous section is that the evolution of the LAN industry proceeded in phases each of them characterized by the presence of several markets (one for each LAN product) and each phase characterized by the presence of a 'focal' market. The opening up and subsequent growth of the 'focal' market was usually the consequence of the interplay between technical change and changes in customers' needs which led to the progressive redefinition of the LAN structure through time. In each phase major firms competed to become dominant in the 'focal' market.

The second fact is that dominance was usually achieved through two types of competition. First, there was inter-market competition which led LAN incumbents to enter into related markets of the industry. This is the competition that occurred along the 'vertical structure' of the industry and was facilitated by technical change that made products more and more similar in terms of functions. We define this type of competition: *'technological competition'*. Second, there was the competition that occurred within a specific market (i.e. intra-market competition). The aim of this type of competition was to differentiate equipment within each market in order to make the demand increasingly inelastic. We define this type of competition: *'demand competition'*. While technological competition blurred the functional boundaries across products, demand competition led to fragmentation with technological variety that increased both horizontally (i.e. inter-firm market distance grew) and vertically (i.e. the variance of distance from frontier grew as markets became polarized).

The third fact is the role played by new entrants vis-à-vis incumbents in shaping the industry structure. The opening up of a potential 'focal' market triggered a swarm of new entrants, initially start-ups, who could supply new equipment, improve upon an existing one, or compete with incumbents by mean of differentiation first and then price competition. Confronted with the entry of new firms, incumbents reacted in different ways. In particular, a mix of *targeted M&As* was one of the strategies pursued by incumbents to obtain the needed technological capabilities. In the period our model aims to represent, the 1990s, the switch market emerged as the new focal market. Kalpana, a start-up, pioneered the technology and become the market leader; soon, however, it was acquired by Cisco Systems, which was able to extend its dominance from the router into the switch market.

Cisco Systems was by no means the only LAN manufacturer who grew through M&As. What we suggest is that Cisco's M&As' strategy turned out to be successful for the concurrent presence of *switching costs* and *compatibility strategies*. In the LAN industry, switching costs derived mainly from the customers' need to purchase equipment that was compatible with their existing installed base, and from the extra cost of learning to use equipment purchased from different manufacturers. Manufacturers exploited the presence of high switching costs to lock-in customers and to compete against rivals in several ways, for instance by strategically setting the timing of new product introduction to force customers to buy upgrades. In their analysis of the determinants of switch equipment choice by users, Chen and Forman (2006) present evidence that the presence of an installed base of equipment from a particular manufacturer increases the likelihood of repurchasing from the same vendor if the customer decides to buy again. These issues become particularly important in the case of technologically sophisticated equipment such as high-end switches used in large networks of hundreds or thousands of users.

As far as compatibility is concerned, LANs developed in an environment characterised by open and common standards. In this context, customers in theory can mix-and-match equipment from different manufacturers in the same network. In practice, firms adopted several strategies to 'close' their system. First, switches need software program to function and manufacturers often designed proprietary software that made their equipment incompatible with that of other manufacturers. For this purpose, Cisco Systems developed the 'Cisco Fusion' architecture first and then the

'Internet Operating Systems' (IOS) software (Gawer and Cusumano, 2002).[5] Second, manufacturers introduced families of products that worked well together. These families typically spanned across different categories of users so as to be able to target the entire demand spectrum (i.e. going 'end-to-end') and/or to prevent rivals from entering. In 1994, Cisco Systems offered the first product of its Catalyst line of Switch equipment that was enriched in the following years by other high-end as well as low-end equipment.[6]

Both switching costs and compatibility (or lack thereof) provided incumbents a comparative advantage in terms of installed base, to be exploited once technological capabilities were acquired through targeted acquisitions. As an alternative strategy to maintain leadership, incumbents could try *vertical differentiation* (i.e. pushing forward the technological frontier). Since the blurring of functional boundaries across equipment represented a limit to the growth of a specific market, the technological frontier in the specific 'focal' market has to be moved forward for the firm to continue to gain rents. However, data suggest that incumbents were able to maintain their leadership without necessarily competing at the technological frontier. For each market in selected years, Table 4 below ranks manufacturers in terms of their location with respect to the technological frontier.

[Insert Table 4 about here]

Seen from a different perspective, Table 4 suggests also that being at the technological frontier does not seem to be sufficient for becoming dominant in the industry. Cisco Systems in both the router and the switch market is the most striking example. This evidence suggests also that new entrants lacked other distinguishing features to challenge the leader: the possibility to leverage upon demand side switching costs and 'system closure' strategies.

The formal model we will develop in the next section captures all the essential elements of the appreciative theory outlined above. Innovation takes the form of new product introduction, both within existing markets and in new ones. New products are introduced both by incumbent and new firms. On the demand side, customers incur switching costs when changing suppliers, and products produced by different suppliers may be partially incompatible. Finally, M&As between

[5] In a similar move, Cabletron Systems introduced the 'Spectrum' network management software.

[6] Again major competitors did not stand still. 3Com responded with the Superstack and Office Connect line of equipment, the former targeting big users, and the latter customers with smaller networks. Bay Networks and Cabletron Systems, marketed an entire new product line: the BayStack and Smartswitch, respectively.

firms that are complementary in terms of their product portfolio are another distinctive feature of the model.

4. The model

The set up of the model can be described as follows. There are two categories of agents: *customers* and *producers*. Customers are firms that buy products (i.e. LAN equipment) to build their system. Producers manufacture and sell the products that constitute a system. Simple rules drive the changes in the product line of manufacturers over time.

4.1. Products

Over the simulation horizon, we consider three types of products, *type 1, type 2, and type 3*. Each product is described in terms of its quality level ($q > 0$). Products are used to build systems. Each system is described by an architecture, which consists in a set of products and weights associated to each product. We consider two possible architectures, *A* and *B*. The quality of the system, which is determined by the quality of its constituent products and weights, enters into the utility function of customers. Formally, we use y to denote a generic system, and Y to indicate the set of all the systems available at a given moment in time. We denote with $q(y)$ the quality of the system, and $q_k(y)$ the quality of the product of type k in system y.

Architecture *A* consists of one product of type 1 and one product of type 2. The overall quality of the system can be expressed by a Cobb-Douglas function with weights a and $(1 - a)$.[7]

$$q(y) = (q_1(y))^{\alpha} (q_2(y))^{1-\alpha} \tag{4.1}$$

Architecture *B* is constituted by three products, one by each type. In this case, the weights of the Cobb-Douglas function are β_1, β_2 and $1- \beta_1- \beta_2$:

$$q(y) = (q_1(y))^{\beta_1} (q_2(y))^{\beta_2} (q_3(y))^{1-\beta_1-\beta_2} \tag{4.2}$$

At time 0, only architecture *A* is feasible (i.e. manufacturers cannot produce type 3 products). At time $\bar{t}$ manufacturers can produce type 3 products and therefore architecture *B* becomes available. Our assumption is that architecture *B* is better than architecture *A*, in that it allows reaching

[7] This formulation is consistent with Malerba *et al*. (1999) who assume that the quality of the final product is a C.E.S. function of the quality of different products.

quality levels that are impossible to reach under architecture *A*. Architecture *A* resembles early LANs in which buyers could combine only two types of equipment (i.e. routers and hubs). Architecture *B* becomes viable when also switches are commercialised. The mechanisms determining products quality are described in Section 4.2.2 below.

4.2. Manufacturers

The number of manufacturers is exogenously given and fixed at the beginning of the simulation horizon. At the beginning of each period, each manufacturer has a product portfolio made of several products (this portfolio is assumed to be empty at $t = 0$). In each period, product portfolios are modified following two simple rules concerning:

1. Mergers and acquisitions;
2. Innovation (i.e. the introduction of new products).

4.2.1. Mergers and acquisitions

At the beginning of each period, M&As may occur according to a two steps procedure. In the first step, pairs of potentially merging manufacturers are formed. In the second step M&As can occur with certain probabilities. To understand how M&As occur, we proceed backward and assume that the pairs of potentially merging manufacturers have been formed. Denote with s_{ki} and s_{kj} manufacturer's *i* and *j* market share (in physical units) in the market for type *k* product. The probability that the two manufacturers merge is given by:

If $t < \bar{t}$

Pr (merger)= 0 if $(s_{ki} - s_{kj}) > 0 \forall k$ or $(s_{kj} - s_{ki}) > 0 \forall k$

Pr(merger)= $\theta \,|\max(s_{0i} - s_{0j}, \Delta s_{\min})|^{\alpha} \,|\max(s_{0i} - s_{0j}, \Delta s_{\min})|^{1-\alpha}$ otherwise.

If $t \geq \bar{t}$ (4.3)

Pr (merger)= 0 if $(s_{ki} - s_{kj}) > 0 \forall k$ or $(s_{kj} - s_{ki}) > 0 \forall k$

Pr(merger)= $\theta \,|\max(s_{0i} - s_{0j}, \Delta s_{\min})|^{\beta_1} \,|\max(s_{1i} - s_{1j}, \Delta s_{\min})|^{\beta_2} \,|\max(s_{2i} - s_{2j}, \Delta s_{\min})|^{1-\beta_1-\beta_2}$ otherwise

where $\theta > 0$ and $\Delta s_{\min}$ >0 and 'small'. The rationale underlying Equation (4.3) is that M&As are more likely to occur between manufactures with high shares in different markets. M&As are strategies of external growth, in which firms acquire new technological capabilities 'embodied' in products. This is in fact the role they played in the industry. $\Delta s_{\min}$ sets a lower bound for positive probability of M&As. In particular it allows M&As to occur when the relevant architecture is *B* and manufacturers are not active in all the markets.

To describe how M&As occur in our model, we employ a rule similar to the one adopted by Cowan *et. al.* (2006) to describe the formation of bilateral strategic alliances in a model of knowledge creation. In the first stage, pairs are formed according to the following algorithm. The first pair of manufacturers is given by those manufacturers for which, according to Equation (4.3) the probability of merger is the highest. The second pair of manufactures is given by those manufacturers maximizing probability in Equation (4.3), *excluding the manufacturers in the first pair*. The third pair is formed by those manufacturers that maximize probability of merging according to Equation (4.3), excluding the manufacturers in the first two pairs and so on.[8]

4.2.2. Innovation

In each simulation period, after M&As have possibly occurred, each manufacturer may change its product portfolio. With an exogenous probability *p*, the firm introduces a new product. The probability that the product is of a certain type *k* is:

$$\Pr(type = k) = \frac{\exp(\lambda_1 n_{ik})}{\sum_k \exp(\lambda_1 n_{ik})} \tag{4.4}$$

where λ_1 is a positive parameter[9] and n_{ik} is the number of products of type *k* offered by manufacturer *i*. According to equation (4.4), firms are most likely to innovate in the markets in which they are already most active. This form of cumulativeness can be justified on the basis of idiosyncratic technological competences with specific products. The quality of the new product is drawn with uniform probability in the interval (0, $frontier_k$), where $frontier_k$ is a time invariant technical frontier for product *k*. We assume that $frontier_3 > max(frontier_1, frontier_2)$, which is the reason why architecture *B* (which includes type 3 products) can achieve relatively higher quality levels.

[8] In those cases in which there is a 'tie' (i.e. we observe the same probability of mergers for all pairs in a subset of manufacturers), the first pair is formed by the manufactures with the highest indexes associated to each of them. The second pair is composed by the manufactures with the highest indexes associated to each of them, excluding the manufacturers in the first pair and so on. This 'tie-breaking' rule is adopted to save on computational time. Since ties basically occur when the probability of mergers is 0, the tie-breaking rule is almost irrelevant.

[9] The parameter λ_1 is known as the *discrimination rate* in the probabilistic choice rule.

The assumption that p is exogenous may appear too extreme. Indeed, in most evolutionary models it is common practice to assume that the probability to innovate is endogenous and depends (positively) on previous innovativeness, profits or firm size. However, we believe that in our case it can justified on several grounds. First, from a purely theoretical view point, incentives for product innovation depend less than process innovation on firm size (Cohen and Klepper, 1996). Second, making this assumption allows us to focus on other specific mechanisms that have driven firms' growth in this industry such as M&As on the supply side, switching costs and imperfect compatibility on the demand side. Indeed, our account of the industry suggested that several firms (especially new start-ups) have played an important role as innovators, but their internal growth has been halted due to subsequent acquisitions by leading firms (Cisco Systems in particular), whose expansion was mainly a consequence of M&As, and product innovation.

A manufacturer enters a market when it introduces its first product of a specific type. If the manufacturer's product portfolio is initially empty, entry into a specific market coincides with *overall entry*. If the firm is the first one to introduce a product of a certain type, firms' entry also coincides with the opening up of a new market.

4.3. Customers

The number of customer firms is exogenously given and fixed at the beginning of the simulation. In each period, with probability η, each customer is drawn from a distribution to purchase a new system. For simplicity, we assume that, once drawn, a customer simultaneously changes all the products constituting her system. $\bar{q}(y)$ denotes the 'actual quality' of the purchased system. This quality is the one described by Equations 4.1 and 4.2 only if: (i) the system is composed entirely by products supplied by the same firm or (ii) all products are supplied by firms that do not produce all the products which are feasible in a given moment in time. In all other cases, the 'actual quality' is given by $\bar{q}(y) = \gamma q(y)$, with $\gamma \leq 1$. γ captures the extent of compatibility across products. The idea is that manufacturers supplying customers with a full line of products can 'close' the system, as happened in the LAN industry through proprietary software.

y_{it} identifies the system bought by customer *i* at time *t*. y_{it-1} indicates the system bought by the customer in the previous period. The utility customer *i* benefits from buying *y*, when she had y_{it-1} in place is described by: [10]

$$U(y_{it}, y_{it-1}) = D_{it}\bar{q}(y_{it}) - \frac{1}{2}\bar{q}(y_{it})^2 - \sigma_{itt-1}, \tag{4.5}$$

where σ_{itt-1} denotes a product switching cost which is equal to $\sigma\chi_{tt-1}$, where χ_{tt-1} is the number of products that are present in system y_{it} but not in system y_{it-1}, and σ is a positive parameter. D_{it} is a variable that represents the extent to which a customer is responsive to quality. In particular, it is easy to verify that it corresponds to the 'ideal quality' level for a specific customer, since it corresponds to the quality level that maximises *U*. D_i increases over time according to the following expression:

$$D_{it} = D_{i0} + \overline{D}(1 - \exp(-g * t)) \tag{4.6}$$

where D_{i0} is uniformly distributed on $[0, \underline{D}]$ and *g* is a positive parameter. The fact that D_i grows over time is the reason why architecture B becomes attractive, first for consumers with high D_{i0} and then to the rest of customers.

The probability that y_{it}=*y* (i.e. the probability that a customer buys an available system *y*) is then given by:[11]

$$\Pr(y_{it} = y) = \frac{\exp(\lambda_2 U(y, y_{it-1}))}{\sum_{\tilde{y}\in Y}\exp(\lambda_2 U(y, y_{it-1}))} \tag{4.7}$$

[10] This particular utility function borrows from Adner and Levinthal (2001), and many others, the idea that consumers differ in their marginal evaluation of quality. Differently from Adner and Levinthal, however, we do not explicitly consider prices. It can be noted, however, that equation (4.5) can be considered as a reduced form of a case where price is determined by a fixed mark-up over cost, and unit cost of production is quadratic in quality.
[11] The exponential rule for representing consumer choices has been often used in models of industrial and market dynamics (Weisbuch *et al.*, 2000).

5. Results

In this section we report the results from our numerical simulations. Initially we vary only two parameters, the level of switching cost σ and the degree of compatibility γ.[12] For each parameter, we consider three possible values. For σ, the values are 0 (no switching cost), 1.5 (low switching costs) and 3 (high switching costs). For γ, the values are 1 (full compatibility), 0.6 (high compatibility) and 0.2 (low compatibility). High values of γ indicates that the system is 'open' and products from different manufacturers can actually be mixed-and-matched. Low values of γ indicates instead that products from different manufacturers cannot be combined (i.e. each system is 'closed'). We create nine combinations, each of them identifying one possible scenario. For each scenario we considered 50 runs with different random seeds. Each run lasts 200 periods. Product 3 (i.e. Architecture *B*) becomes feasible at $\bar{t} = 100$. Table 5 below summarizes the nine possible scenarios thus created.

[Insert Table 5 about here]

In the next section, we report the average value (across runs) of a set of indicators measured at period 100 (when a new type of product is introduced) and at period 200 (when the run stops). As a methodological point, we observe that our results can be commented along two lines. First of all, we may wonder under which parameter configurations our model can be consistent with histories ('history friendly'). Second, we can look at comparative dynamics exercises resulting from parameter variations. Both types of comments will be presented in the next sections.

5.1. Results for concentration and market leadership

Table 6 reports the values of the Herfindahl Hirschmann Index (HHI) across markets over time.

[Insert Table 6 about here]

Results in columns (1) and (2) summarize the HHI for market 1 at the end period 0 and at the end of period 200 respectively. It can be noted that, in each scenario, there is a tendency towards greater concentration over time, consistently with the observed history. The same dynamics is observed in the second market (columns (3) and (4)). This tendency is mainly driven by M&As. In each market innovators and market leaders seek to exploit existing complementarities across products. One way to pursue this goal is through M&As. The opening up of a new market creates

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[12] The values of parameters that remain constant across simulations are reported in the Appendix.

new opportunities for exploiting complementarities and further triggers waves of acquisitions. As a result, firms increase their shares also in other markets.

This general dynamics notwithstanding, differences seem to exist across markets. In particular, for a given scenario, HHIs are usually higher for market 1 than for market 2. In the case of market 3, HHIs are instead relatively lower. In the case of markets 1 and 2 the result depends on the fact that the weight associated to product 2 in determining overall quality is higher (0.7 vs. 0.3). This implies that quality is relatively more important than other determinants of choices (i.e. switching costs and compatibility) for market 2 than for market 1. As a consequence, market 2 is more competitive. As long as market 3 is concerned, the explanation for the difference lies in the different way in which purchases occur. While customers simultaneously purchase products from markets 1 and 2, purchase of type 3 products occurs sequentially provided that the marginal benefits in terms of quality are sufficiently high. The main consequence is that in the initial phase of market evolution, 'new' (i.e. without an installed base) customers continuously enter the market and 'second mover' manufacturers can cater for them. As a result competition level stays relatively higher than in the other two markets. Interpreting market 3 as the market for LAN switches, this result is in line with the observed evolution of the LAN industry (see Section 2.2 above).

Concerning the impact of switching costs and compatibility on HHI, it can be noted that an increase in the level of switching costs (i.e. higher values of σ) leads to an increase in concentration in both market 1 and 2 irrespective of γ. This results follows from a switching cost related first mover advantage that impacts on the concentration level in two ways. On the one hand, there is a direct effect. Higher switching costs reduce competition and therefore increase concentration. On the other hand there is an indirect effect. Higher switching costs tend to favour M&As also in the initial stages of industry evolution since, by assumption, mergers are more likely between firms with high shares (in different markets). As a result HHI increases.

In terms of capability of our model to replicate the reality we can notice that, *qualitatively*, the pattern actually observed is obtained irrespective of the level of switching costs and firms strategies about compatibility. However, in order to reproduce *quantitatively* the high level of concentration and to obtain a high market share for the leader, we need to set *positive* switching costs.

For given values of switching costs, changes in the degree of compatibility impact unevenly across markets. In particular, an increase in compatibility (i.e. higher values of γ) has no evident effects on concentration levels in markets 1 and 2. However, it increases concentration in market 3. This is an important result that can be explained in terms of the interplay between firms' strategies, demand heterogeneity, and complementarity among products.

Because of heterogeneous demand, customers will purchase those products that reflect their desired quality. When firms pursue a 'close' strategy they can increase the appeal of some of their products that otherwise would remain unsold by 'bundling' them together. As a result, demand for these products would increase together with manufacturers' profits. However, pursuing this strategy reduces the extent to what customers can mix and match products. This is likely to reduce demand for other products which can potentially cater for a larger share of customers. Going into opposite directions, the two effects tend to cancel out and, as a result, concentration level in the two markets remains largely insensible to changes in γ.

Different is the case of market 3 in which pursuing a 'close' strategy ends up reducing concentration. This result follows from the dynamic of entry into the new market embodied in our model. Indeed, one feature of our model is that start-ups are among the early entrants in the new market. Being first movers they are likely to exploit their advantage and grow. Incumbents can react to new entrants either by acquiring the new firms (see below) or by 'closing' their system. By reducing compatibility across firm, a 'close' system strategy allows incumbents to leverage upon their installed base in the other two markets and establish their share in the new one. As a result, the concentration level remains relatively low.

The market shares of the leader firm across periods and markets are reported in Table 7 below.

[Insert Table 7 about here]

These results generally mirror those just discussed. For a given scenario, leader's shares increase over time in both market 1 and 2. Moreover, increasing switching costs and lower levels of compatibility are generally associated to higher shares for the leader firm. An important difference with respect to the previous case is market 3 in which, the share of the leader firm tends to increase as compatibility increases.

5.2. Results for industry dominance

It is interesting to understand whether market concentration and leadership in one market is accompanied by leadership in a related market and to what extent this relationship depends on switching costs and compatibility. We report this information in Table 8 below. In particular, columns (1) and (2) report the frequency of runs in which *a specific firm* achieves the highest shares in every 'active' market (i.e. the markets in which at least one unit is sold) after 100 and 200 periods respectively. This is an indication of the 'dominance' of a specific firm in the LAN industry. This frequency can be interpreted as the probability that the real pattern (i.e. dominance) emerges out of the simulation. Columns (3) and (4) instead report the average (across firms) dispersion in firms' market shares. Dispersion was computed as the variance of shares across active markets.

[Insert Table 8 about here]

Table 8 shows that history replicating runs have a non negligible probability to be observed under all parameter configurations, but the values of σ and γ do have an impact on the level of such probability. In particular, the probability is significant lower in the absence of switching costs. These results, while providing support for the validity of our appreciative theory, confirm the importance of switching costs in our model.

As for the effect of parameters variations on the probability of industry dominance, the following considerations are in order. First, for a given level of switching cost, a decrease in compatibility (i.e. lower γ) is generally accompanied by an increase in the probability that a single firm dominates the industry at period 100 (column 1). This result is expected. The lower is γ, the 'closer' (i.e. firm specific) is the system. The average quality of a system depends positively on its 'closeness'. To the extent that firms pursuing a close strategy supply relatively higher quality products in each market, the likelihood of observing firms' dominance in the industry increases as γ decreases. Second, we also observe that average probabilities are generally higher for intermediate values of switching cost than for higher values. The reason for this result is that for high level of switching cost, innovators in each market benefit from greater first mover advantage, and M&As are less likely to occur within a relatively short period of time.

The same probability tends to increase with γ at the end of the simulation horizon (column 2). This result indicates that, for a given level of switching costs, firms pursuing an 'open strategy' are more likely to achieve industry dominance after the new market opens up. At first sight this result is surprising. When firms pursue an open strategy, customers can easily mix and match products in their system and manufacturers are likely to confront with a much higher level of competition. As a consequence, we should expect a decline in the market shares and consequently a reduction in the probability that one firm achieves industry dominance. However, in this context firms can also benefit from a relatively higher level of demand which allows them to grow and eventually try to enter into the new market when it starts (provided they have the capabilities to innovate in the full range of qualities). In other words, a scenario with full compatibility is consistent with the presence of several firms with similar shares in each market. In our setting, firms with relatively high but similar shares in different markets are more likely to merge. M&As are therefore the way to go to achieve industry dominance in a context of full compatibility. When products are not fully compatible (i.e. γ is low) instead, firms operating in different markets are less likely to become similar in terms of shares. This follows from the fact that the relatively smaller size of the overall market makes firms less likely to survive and grow. As a consequence M&As among 'equals' across different markets are less likely to occur. Finally, we also observe that average probabilities are now generally higher when switching costs are high. The reason for is that, as time goes by, there is a high probability that leading firms end up merging.

The above explanations are consistent with the values of the average dispersion index. The higher the index is the more dissimilar tend to be the firms' shares across markets. Our results show that after opening up a new market (see column 4) the average dispersion is the higher the lower is compatibility (i.e. as γ gets lower) suggesting that firms tend to differ in terms of market shares. Before the start of the new market instead, lower values of dispersion are generally associated to low compatibility with exception of the case in which switching costs are null (see column 3).

5.3. Further results

We now move to consider the effect of our scenarios on another set of aspects that are relevant for describing the evolution of the LAN industry. These results are reported in Table 9 below.

[Insert Table 9 about here]

Column (1) reports the frequency of runs in which the firm that was the first to introduce a product of type 3 was a start-up (i.e. no products in markets 1 and 2). Frequencies range between 60% and 84% with peaks of 88% and 96%. In our model the fact that start-ups firms are those most likely to open a new market follows from the assumption that competing in the new market requires new and specific capabilities and that the probability that a firm introduces a product of a an existing type is increasing in the number of products of that type already offered by the firm. As a consequence, incumbents are more likely to exploit their capabilities in markets they are already active in rather than exploring new ones.

Column (2) reports the frequency of runs in which the start-up that pioneered a product of type 3 ends up being acquired and/or merged. Our results indicate that this event happens in almost every run independently of the scenario we are considering. Indeed, the very high probability that a type 3 product pioneer firm is later acquired is a consequence of the start-up being almost a monopolist in the market. Being among the few firms with specific capabilities to supply the new product, start-ups became likely targets for acquisitions especially for those incumbents with high shares in the other markets.

Column (3) reports the frequency of runs in which the start-up that starts the new market becomes the leader of the market at the time of the simulation horizon. This statistics includes the cases in which the start-up was acquired. Our results indicate that leadership is almost always achieved in every scenario. Incumbents enter the new market by acquisition and exploit their strength in at least one of the existing markets to extend their leadership also to the new market.

Finally, column (4) reports the total number of M&As occurring during the simulation horizon. It can be noted that M&As happen more frequently in scenarios characterized by absence of switching costs and their number increases as compatibility decreases (i.e. in the presence of 'close' systems). Indeed, the presence of switching costs is an important source of first mover advantage for those firms that innovate early. Exploiting the presence of switching costs is the way these firms gain market shares. Few M&As among the leading firms are then needed to create dominance. With full compatibility, the 'best' firms in each market become the leaders and, once again, few M&As among them lead to consolidation. In the absence of switching costs and compatibility, M&As become the main way for firms to gain dominance. However, this process is likely to take time and generate a 'wave' of M&As.

6. Discussion

In the previous sections we have proposed a model of the evolution of the LAN industry in the 1990s. Our results seem to well replicate the dynamics of innovation, entry and growth that have characterized the evolution of the LAN industry. When the switch market started as a result of technical change, start-ups firms were among the early entrants. These firms were usually mono product firms with high R&D intensity and highly specific capabilities. Few of them, however, survived and were able to make it to the next round. Acquisition of new start-ups provided incumbents with the required knowledge to compete in the new market as well as with the necessary products to extend their portfolio. Once entered in the new market, incumbents used their dominant position in other markets to become dominant also in the new one.

Altogether, these results are consistent with some of the events highlighted in Section 2 and in line with the history friendly nature of our model. Moreover, the history can be qualitatively explained by 'supply driven' mechanisms, as the results hold irrespective of the level of switching costs and firms strategies about compatibility. This is in line with the explanation of the evolution of the industry put forward by Carpenter *et al.* (2003) who pointed to the role of corporate stocks in the accumulation of the innovative capabilities necessary to compete in the optical networking industry during the second half of the 1990s. Though insightful, this explanation is however partial as it lacks an explanation of how Cisco Systems rose to dominance in the data networking systems for enterprises before challenging existing incumbents in the optical networking industry.

In this respect, our review of the main events in the evolution of the industry during the 1990s, and the appreciative theory, has highlighted the important role played by the presence of switching costs and compatibility strategies. Results from our model further confirm the appreciative theory and highlight the important role played by switching costs in reproducing the high level of concentration and the dominance of a single firm. All in all, this result suggests that supply side factors alone seem able to explain the qualitative dynamics of the industry, but good calibration (i.e. 'history friendliness'), seems instead to require also demand side factors (i.e. switching costs).

Concerning the role of compatibility, the results are less clear-cut. Our model suggests that firms' strategies to 'close' the systems should combine with firm expertise in order to achieve high market shares and leadership. Indeed, in the absence of strong economies of scope among different products, as it is the case in our model, a strategy to 'close' the system *alone* does not provide any comparative advantage, since firms' lack of expertise and capabilities in one market makes the strategy ineffective.

As mentioned in Section 1, HFMs can also be used to carry out counterfactual analyses. In our specific case for instance one may wonder to what extent M&As, which we did observe in reality, played a crucial role for the consolidation of the industry into a tight oligopoly. In their case study of Cisco Systems' acquisition strategy, Mayer and Kenney (2004) argued that the development of an 'acquisition and development' strategy was essential for the survival and growth of the company and that acquisitions played an important role in its overall competitive strategy. To gain a better understanding on whether M&As are crucial vis-à-vis other mechanisms we have performed a counterfactual analysis excluding by assumption the possibility to merge and setting intermediate levels of for switching costs and compatibility (i.e. σ =1.5 and $\gamma = 0.6$). The results of this exercise are summarized in Table 10.

[Insert Table 10 about here]

A comparison between these results and Scenario 5 highlights several important differences. The first difference concerns the concentration levels (see upper panel). In this case, concentration does not grow when market 3 starts and it even decreases for market 2. The second major difference concerns some of the statistics reported in the lower panel. In this case the average dispersion index (AV. DISP. T = 200) is significantly higher than the one reported in Table 10 suggesting that, in the absence of M&As, dissimilarity across markets tends to grow. Finally, no dominant firm in the industry seems to emerge at the end of the simulation runs. All in all, this counterfactual exercise suggests that our model is able to produce 'history divergent' runs to the extent that it describes an evolution of the industry that is rather different from the one observed in the reality.[13] In the light of these results, we can conclude that M&As seems to play a crucial role both in determining the competitive strategy at the firm level, as argued by Mayer and Kenney (2004), and in shaping the industry evolution.

Counterfactual analysis can also be used to investigate further the role played by demand heterogeneity. In our model we assume that customers have heterogeneous preferences and that, as a consequence, sub-markets exist within each market corresponding to the specific needs of customer firms. This is what we observed in reality both in the case of routers (i.e. multiprotocol vs. access-routers) and in the case of switches (high-end vs. low-end). To understand the implication of this assumption for industry level dynamics we run a second counterfactual exercise, assuming homogenous demand. In particular, in equation (4.6), we fix $D_{i0} = \frac{D}{2}$ for each *i*. The other parameters values remain set as in Scenario 5. The results of this exercise are reported in Table 11.

[Insert Table 11 about here]

[13] The strongest similarity being the frequency of runs in which the start-up firm that opened up the new market becomes the market leader at the time of the simulation horizon (INN3LEADER).

Assuming homogeneous demand does not substantially change the main results of industry evolution with respect to Scenario 5 (see bottom panel). However, as in the case of an increase in switching costs, the level of concentration within each market slightly increases (see top panel).

7. Conclusion

This paper has proposed a history friendly model of the evolution of the LAN industry in the 1990s. Our model embodies some key features of the industry: competition in product innovation with demand heterogeneity, switching costs, the possibility of supplying 'close' systems, the emergence of new markets, and M&As. Our results are able to reproduce some stylized facts of the industry. In the model, as in the 'real world', we observe a tendency towards the creation of a dominating firm (Cisco Systems in the reality). This firm starts from a dominant position in one of the existing markets (i.e. routers) and reinforces its position when a new market (i.e. switches) emerges. The new market is pioneered by a new start-up (Kalpana in the reality), which is soon acquired by the dominant incumbent (Cisco Systems). As a result of the acquisition, the acquiring firm becomes the leader also in the new market.

Our model builds upon and extends previous contributions in the HFM tradition which studies the co-evolutionary dynamics of related markets (Malerba *et al.,* 2006; Malerba and Orsenigo, 2008) by explicitly incorporating switching costs, compatibility strategies and M&As. Moreover, though they refer to the case of a specific industry during a limited time period, our results bear some general implications for the literature on industrial organization. First, they throw new light on some typical results of the literature on switching costs (Klemperer, 1987; Matutes and Regibau, 1988 among others). Looking at firms strategic interactions and relying upon strong assumptions in terms of rationality, this literature predicts that in the presence of switching costs convergence in market shares is usually achieved, since incumbents have interest in keeping the price high in order to exploit their installed base, leaving 'unattached' consumers to new firms (Beggs and Klemperer, 1992). Our model, who considers the presence of switching costs in a context of uncertain innovation, suggests instead that new firms may lack the technological capabilities to reduce the gap, and the incumbents may use M&As to consolidate their position when compatibility is partial.

Second, our model qualifies some of the results put forward by the existing literature on the market effects of compatibility. This literature traditionally posits the presence of a dichotomy between fully compatible (i.e. open) systems and fully incompatible (i.e. closed) systems. As we have argued in our appreciative theory, this dichotomy is hardly found in practice as firms may strategically ‘close’ their systems even in the presence of common or open standards. Within this context our results have shown that industry concentration depends on the degree of compatibility rather than mere presence (or lack thereof).

Third, our results that the presence of demand heterogeneity tends to mitigate market concentration are consistent with some recent works on the dynamics of some industries characterized by the presence of sub-markets and absence of shake-outs (Klepper and Thompson, 2006; Bhaskarabhatla and Klepper, 2008). When demand is heterogeneous, each product can find its own demand and competition turns out to be less intense. In the absence of heterogeneity firms compete for the same customers and concentration tends to increase.

These implications notwithstanding, our model is not without important limitations. First of all, innovation is modelled as an exogenous event. While this is a sensible choice on both theoretical and empirical grounds, a more complete treatment would probably require modelling the probability to innovate as a function of firm’s R&D investment and, possibly, spillovers by other firms similarly to what is done in Silverberg and Verspagen (1994). Second, the model does not explicitly consider the dynamics of entry and exit in the industry. While this choice is motivated mainly by the fact that studying the demography of the sector was not the main aim of our analysis, looking at this aspect may also provide further interesting insights. Finally, in our model switching costs and compatibility were not firm specific. One possibility would be to introduce firm-specific levels of switching costs and compatibility by allowing simple (i.e. myopic) strategic reasoning in the model. All in all, these extensions suggest future avenues to pursue for our work in the search for a reduced-form or a ‘non history friendly’ version of the model.

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LIST OF FIGURES

FIGURE1. LAN INDUSTRY. REVENUES BY MARKET

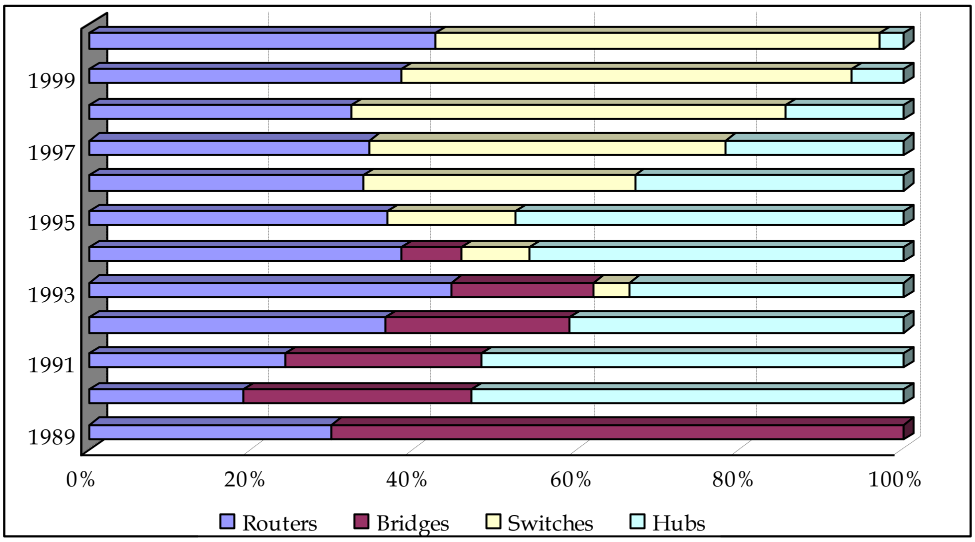

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TABLE 1. ROUTER MARKET: REVENUES' MARKET SHARES

1990		1993		1995		1997	
Vendor	%	Vendor	%	Vendor	%	Vendor	%
Cisco Systems	35.2	Cisco Systems	50	Cisco Systems	48	Cisco Systems	63
DEC	20.3	WellFleet Comm.	16	Bay Networks	17	Bay Networks	10
3Com	13.2	IBM	7	Motorola	6	3Com	4
WellFleet Comm.	8.7	3Com	6	3Com	5	Motorola	3.5
Proteon	7.8	DEC	4	IBM	3	IBM	2.2
Others	14.8	Others	17	Others	21	Others	17.3
TOTAL	100	TOTAL	100	TOTAL	100	TOTAL	100

SOURCE; AUTHORS' ELABORATION BASED ON DELL'ORO GROUP REPORTS

TABLE 2. ROUTER MARKET: REVENUES' MARKET SHARES BY SUB-MARKET

MULTI-PROTOCOL SUB-MARKET				REMOTE ACCESS SUB-MARKET			
1996		1997		1996		1997	
Vendor	%	Vendor	%	Vendor	%	Vendor	%
Cisco Systems	64	Cisco Systems	58	US Robotics	26.1	3Com Corp.*	34
Bay Networks	10	Bay Networks	12.7	Ascend	22.7	Ascend	27
3Com Corp.	4	Motorola	5.5	Cisco Systems	11.4	Cisco Systems	18
IBM	2	3Com Corp.	4.6	Shiva	8.2	Shiva	5
Motorola	2	IBM	2	3Com Corp.	6.2	US Robotics	-
Others	18	Others	17.2	Others	25.4	Others	16
TOTAL	100	TOTAL	100	TOTAL	100	TOTAL	100

* 3COM CORP. ACQUIRED US ROBOTICS IN 1997

SOURCE; AUTHORS' ELABORATION BASED ON DELL'ORO GROUP REPORTS

TABLE 3. SWITCH MARKET: REVENUES' MARKET SHARES

1994		1999 (2qt)	
Vendor	%	Vendor	%
Kalpana	53	Cisco Systems Inc.	46.7
3Com Corp. (Synernetics)	29	3Com Corp.	13.1
Alantec Corp.	7	Nortel Networks	11.1
Chipcom Corp.	5	Cabletron Systems Inc.	9.8
Lannet	3	IBM	4
TOTAL	100	TOTAL	100

SOURCES: 1994: THE YANKEE GROUP; 1999: DELL'ORO GROUP REPORTS

TABLE 4. TOP 5 COMPANIES IN TERMS OF DISTANCE FROM TECHNOLOGICAL FRONTIER

	ROUTERS			
RANK	1993	1995	1997	1999
1	Wellfleet Comm.	Newbridge Networks	Newbridge Networks	Juniper Networks
2	RAD Network Devices	3Com Corp.	Xyplex Whittaker	Cisco Systems
3	Cisco Systems	Network Systems Corp.	Cisco Systems	3Com Corp.
4	ACC	Cray Communications	3Com Corp.	NeoNet-works
5	Andrew Corp.	CrossComm Corp.	Network Systems Corp.	Cabletron Systems
	SWITCHES			
RANK	1993	1995	1997	1999
1	Fore Systems Inc.	Newbridge Networks	Newbridge Networks	Cisco Systems
2	DEC	3Com Corp.	Plaintree Systems	3Com Corp.
3	UB Networks Inc.	Hughes LAN Systems	Hughes LAN Systems	Fore Systems Inc.
4	Grand Junction Networks	Cabletron Systems	Optical Data Systems	Lucent Networks.
5	Hewlett-Packard Co.	IBM	Cabletron Systems	Foundry Networks

SOURCES: PREDICTED PRICES FROM HEDONIC REGRESSIONS BASED ON AUTHOR'S PRODUCT DATABASE

TABLE 5. POSSIBLE SCENARIOS

		SWITCHING COSTS	COMPATIBILITY
1	$\text{SCENARIO}_{(0\text{-}1)}$	Null ($\sigma = 0$)	Full ($\gamma = 1$)
2	$\text{SCENARIO}_{(0\text{-}0.6)}$	Null ($\sigma = 0$)	High ($\gamma = 0.6$)
3	$\text{SCENARIO}_{(0\text{-}0.2)}$	Null ($\sigma = 0$)	Low ($\gamma = 0.2$)
4	$\text{SCENARIO}_{(1.5\text{-}1)}$	Low ($\sigma = 1.5$)	Full ($\gamma = 1$)
5	$\text{SCENARIO}_{(1.5\text{-}0.6)}$	Low ($\sigma = 1.5$)	High ($\gamma = 0.6$)
6	$\text{SCENARIO}_{(1.5\text{-}0.2)}$	Low ($\sigma = 1.5$)	Low ($\gamma = 0.2$)
7	$\text{SCENARIO}_{(3\text{-}1)}$	High ($\sigma = 3$)	Full ($\gamma = 1$)
8	$\text{SCENARIO}_{(3\text{-}0.6)}$	High ($\sigma = 3$)	High ($\gamma = 0.6$)
9	$\text{SCENARIO}_{(3\text{-}0.2)}$	High ($\sigma = 3$)	Low ($\gamma = 0.2$)

TABLE 6. MARKET CONCENTRATION (HERFINDAHL HIRSCHMANN INDEXES)

	$HHI_{(1-100)}$	$HHI_{(1-200)}$	$HHI_{(2-100)}$	$HHI_{(2-200)}$	$HHI_{(3-200)}$
$SCENARIO_{(0-1)}$	0.137	0.197	0.136	0.191	0.363
$SCENARIO_{(0-0.6)}$	0.142	0.202	0.139	0.209	0.360
$SCENARIO_{(0-0.2)}$	0.134	0.204	0.130	0.189	0.294
$SCENARIO_{(1.5-1)}$	0.435	0.593	0.410	0.561	0.374
$SCENARIO_{(1.5-0.6)}$	0.478	0.605	0.433	0.545	0.339
$SCENARIO_{(1.5-0.2)}$	0.430	0.545	0.444	0.554	0.245
$SCENARIO_{(3-1)}$	0.491	0.671	0.443	0.622	0.354
$SCENARIO_{(3-0.6)}$	0.498	0.636	0.441	0.589	0.338
$SCENARIO_{(3-0.2)}$	0.508	0.672	0.480	0.623	0.258

TABLE 7. LEADER MANUFACTURER (MARKET SHARES)

	$LEADER_{(1\text{-}100)}$	$LEADER_{(1\text{-}200)}$	$LEADER_{(2\text{-}100)}$	$LEADER_{(2\text{-}200)}$	$LEADER_{(3\text{-}200)}$
$SCENARIO_{(0\text{-}1)}$	0.230	0.331	0.230	0.322	0.464
$SCENARIO_{(0\text{-}0.6)}$	0.248	0.340	0.240	0.347	0.468
$SCENARIO_{(0\text{-}0.2)}$	0.232	0.321	0.217	0.309	0.399
$SCENARIO_{(1.5\text{-}1)}$	0.564	0.710	0.543	0.682	0.504
$SCENARIO_{(1.5\text{-}0.6)}$	0.619	0.727	0.565	0.670	0.464
$SCENARIO_{(1.5\text{-}0.2)}$	0.575	0.673	0.585	0.682	0.366
$SCENARIO_{(3\text{-}1)}$	0.625	0.781	0.572	0.736	0.493
$SCENARIO_{(3\text{-}0.6)}$	0.631	0.745	0.567	0.705	0.515
$SCENARIO_{(3\text{-}0.2)}$	0.641	0.787	0.613	0.738	0.379

TABLE 8. INDUSTRY DOMINANCE (FREQUENCY) AND AVERAGE MARKET SHARE DISPERSION

	DOM. T = 100	DOM. T = 200	AV. DISP. T = 100	AV. DISP. T = 200
$\text{SCENARIO}_{(0\text{-}1)}$	0.28	0.42	0.25	0.28
$\text{SCENARIO}_{(0\text{-}0.6)}$	0.38	0.38	0.28	0.30
$\text{SCENARIO}_{(0\text{-}0.2)}$	0.34	0.32	0.32	0.33
$\text{SCENARIO}_{(1.5\text{-}1)}$	0.66	0.72	0.47	0.23
$\text{SCENARIO}_{(1.5\text{-}0.6)}$	0.88	0.76	0.26	0.26
$\text{SCENARIO}_{(1.5\text{-}0.2)}$	0.8	0.54	0.27	0.33
$\text{SCENARIO}_{(3\text{-}1)}$	0.64	0.88	0.40	0.22
$\text{SCENARIO}_{(3\text{-}0.6)}$	0.76	0.76	0.37	0.23
$\text{SCENARIO}_{(3\text{-}0.2)}$	0.76	0.68	0.35	0.39

TABLE 9. ADDITIONAL STATISTICS

	INN3NEW	INN3MERGE	INN3LEADER	MERGERS
SCENARIO$_{(0\text{-}1)}$	0.8	0.94	1	15.54
SCENARIO$_{(0\text{-}0.6)}$	0.84	1	1	15.56
SCENARIO$_{(0\text{-}0.2)}$	0.96	0.98	1	16.62
SCENARIO$_{(1.5\text{-}1)}$	0.6	0.94	1	9.12
SCENARIO$_{(1.5\text{-}0.6)}$	0.76	0.96	0.96	9.28
SCENARIO$_{(1.5\text{-}0.2)}$	0.88	0.92	0.96	9.82
SCENARIO$_{(3\text{-}1)}$	0.84	0.96	0.96	8.96
SCENARIO$_{(3\text{-}0.6)}$	0.72	0.94	1	9.26
SCENARIO$_{(3\text{-}0.2)}$	0.76	0.98	1	9.56

TABLE 10. COUNTERFACTUAL #1: NO MERGERS

COUNTERFACTUAL NO MERGES	$HHI_{(1-100)}$	$HHI_{(1-200)}$	$HHI_{(2-100)}$	$HHI_{(2-100)}$	$HHI_{(3-100)}$
	0.360	0.362	0.442	0.370	0.286
	INN3NEW	INN3LEADER	$LEADER_{(3-200)}$	AV. DISP. T = 200	DOM. T = 200
	0.80	0.92	0.418	0.76	0

TABLE 11. COUNTERFACTUAL #2: HOMOGENEOUS DEMAND

COUNTERFACTUAL HOMOGENEOUS DEMAND	$HHI_{(1-100)}$	$HHI_{(1-200)}$	$HHI_{(2-100)}$	$HHI_{(2-100)}$	$HHI_{(3-100)}$
	0.481	0.654	0.442	0.628	0.344
	INN3NEW	INN3LEADER	$LEADER_{(3-200)}$	INN3MERGE	DOM. T = 200
	0.80	0.92	0.470	0.98	0.76

APPENDIX

TABLE A1. NUMERICAL VALUES FOR INVARIANT PARAMETERS

PARAMETER	SYMBOL	VALUE
Max responsivess to qualty	$\overline{D}$	0.6
Growth in responsiveness to quality	G	0.01
Min responsivess to qualty	$\underline{D}$	0.3
Probability of changing LAN	μ	0.1
Number of customers	N° customers	1000
Discrimination rate in consumer choice	λ_2	20
Weight of product 1 in architecture A	α	0.3
Weight of product 1 in architecture B	β_1	0.1
Weight of product 2 in architecture B	β_2	0.2
Technological frontier for product 1	$frontier_1$	0.4
Technological frontier for product 2	$frontier_2$	0.4
Technological frontier for product 3	$frontier_3$	1
Probability of innovation	p	0.015
Discrimination rate in product type choice	λ_1	0.3
Propensity to merge	θ	0.2
Min probability of merger	$\Delta s_{\min}$	0.1
Number of manufacturers	N° manufacturers	30