Failing to disrupt: the case of the Network Computer

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Abstract: In 1995, the future of home computing was in the balance. The dominant technology, the PC, was threatened by the entry of a potentially disruptive technology, the Network Computer (NC). Yet in 2005 almost 200 million PCs were sold globally and the pioneering NC was not to be seen. In this paper we take a co-evolutionary view of the development and attempted diffusion of the NC. We observe that the lack of technological and market complementarities were central to its failure, restricting the adoption of the NC and the growth of its business ecosystem. In competition with the significantly more mature PC ecosystem, in which these complementarities were highly evolved, the NC failed to generate the expectation that it was a viable proposition. This episode provides insight into the difficulties facing new entrants with potentially disruptive technologies and shows why, nevertheless, incumbent technologies that initially overcome such challenges may remain under longer term threat.

Keywords: technological co-evolution; innovation; business ecosystem; complementarities; failure.

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1 Introduction

Episodes of novel technologies challenging an incumbent paradigm have long been of interest. Schumpeter (1928; 1934) identified such challenges as the hallmark of entrepreneurial innovators. In the wake of his pioneering ideas on creative destruction, the topic has been studied not only with respect to the role of new entrants versus incumbents (Henderson and Clark, 1990; Tushman and Anderson, 1986) and the inertia of incumbent technologies (David, 1985), but also from other perspectives on industry evolution (Utterback, 1994), the diffusion of innovations (Rogers, 1995), the role of complementarities (Teece, 1986; Tripsas, 1997) and the nature of disruptive innovations (Christensen, 1997; Slater and Mohr, 2006). The majority of these studies focus on successful challenges; there are fewer detailed studies of unsuccessful attempts to displace a dominant technology. Yet there is much to be learned from cases where the commercialisation and diffusion of emerging technologies did not unseat the incumbent paradigm even where the new technology offered the potential for improvements in cost and productivity.

Networks, alliances and complementarities are invoked in the literature to depict the launch of new technologies, but they are often used as overlapping constructs that draw on disparate theoretical positions. Viewing innovation as a co-evolutionary process can provide a coherent perspective and resolve puzzles around unsuccessful rival technologies. As a higher order conceptualisation, co-evolution of technologies can be brought to bear on entrepreneurial attempts to commercialise technologies in order to provide a broader perspective than do automatic market adjustment theories, deterministic accounts of path dependence or eclectic explanations.

In this paper we ask (1) why early attempts at challenging an incumbent paradigm tend to fail, and (2) what factors operate that make it possible for a technology that fails initially to succeed in the longer term. We do so through examining an unsuccessful challenge by a disruptive technology to an incumbent paradigm, that of the Network Computer (NC) to the PC, which occurred in the mid 1990s. The episode on which we focus saw a direct attack on PC technology that over the previous 20 years had gained acceptance as the design dominating a major business ecosystem, supported by complementary products and services. Our investigation focuses on how technological co-evolution affected the commercialisation and diffusion of the Network Computer and complementary offerings by partner companies.

2 Prior work on technological co-evolution

In the natural world co-evolution operates as a meta-evolutionary process in which interactions of participants contribute to the collective creation of a habitat that shapes their prospects. Selected forms of mutual accommodation or symbiosis can occur without intentionality when blind accommodating responses are rewarded by survival, as where the form of fitness required by natural selection is the capacity to ‘fit into’ a co-evolving ecosystem (Goodwin, 1994). By analogy, the concept of a ‘business ecosystem’ refers to an ecology of firms where, through cooperation and competition, each firm attempts to achieve returns by satisfying related customer needs and providing support to related products; over time these firms incorporate the next round of innovations into the ecosystem (Moore, 1993; 1996).

The concepts of co-evolutionary processes and co-evolving ecosystems are not simply biological metaphors (Metcalfe, 1998). They depict distinctive modes of transformation in such arenas as the evolution of languages, the development of scientific knowledge and the advance of technologies. Across these domains there are common co-evolutionary processes at work, involving the generation of variety, the operation of selection forces and the propagation of those selected variants. Natural variety is generated in Darwinian mode, through random genetic mutation and combination, blind to the selection forces that determine propagation. In the economy, consumer demand, competition and the allocation of investment operate as selection forces shaping advances in technologies (Nelson and Winter, 1982). Variety generation in the economy takes place through learning processes. Intelligent agents are not blind to the operation of selection forces; on the contrary, they can learn to anticipate rewards and sanctions and they respond to perceived incentives so as to adapt to them (Nelson, 1995). What is distinctive about entrepreneurial innovation is the early anticipation of, and response to, selection forces that promise rewards for innovative behaviour. Moreover, the frequent creation of partnerships by entrepreneurs launching new technologies (Gomes-Casseres, 1996) may be seen as representing entrepreneurial attempts to shape a new business environment hospitable to their efforts. By anticipating gains from innovative goods and services under changing and uncertain conditions (Bhidé, 2000), entrepreneurial entrants often initiate changes in business ecosystems.

The outcomes of co-evolutionary processes impact on further activities in iterations that generate recurrent feedback processes. The role of negative feedback in restoring equilibria has long been promulgated in the economic literature. That positive feedbacks also operate in the economy has been highlighted relatively recently (Arthur, 1989; 1990; David, 1985). In these accounts, positive feedbacks are manifested as increasing returns created by consumption and production externalities. In particular, their effects are significant in networked industries characterised by interactive products where common standards and interoperability are highly valued (Shapiro and Varian, 1999). For networked technologies, positive consumption externalities arise directly from the number of users on the network, and indirectly from the availability of complementary products and support services (Katz and Shapiro, 1986). New entrants to networked industries enter complex dynamic systems that may be disrupted, but may also, alternatively, be immune to such perturbations as a result of strong interlinkages.

Positive production externalities arise when core product architectures provide an enabling function to which agents in the ecosystem can contribute complementary technologies and services. These complements contribute to the growth of the ecosystem, increasing the value of these externalities to producers and consumers alike. As an ecosystem grows, another set of information feedbacks, collectively described as 'bandwagon effects', become prominent (Rohlfs, 2001). Joining a leading or growing ecosystem is more likely to yield returns than is joining competing ecosystems that are rapidly losing market share. Thus the commercialisation of a networked product follows an 'S-shaped' curve, with very rapid growth at the point where it becomes recognised that critical mass in a given technology offers access to the largest consumer base, tailing off as marginal returns from further adherents fall (Rogers, 1995).

Self-reinforcing mechanisms of this kind imply that, for networked technologies, positive feedbacks create close linkages between selection processes and the process of propagation of selected variants, leading to tensions between diversity and uniformity in business ecosystems. While core architectures can facilitate variety generation in complementary technologies (which may themselves become core architectures for future technological co-evolution), they may also introduce path dependence, lock-in and switching costs that obstruct diversity (Arthur, 1989). Path dependence provides one explanation as to why some ecosystems of firms and their technologies, despite attempts to create alternative ecosystems with greater potential, continue to favour incumbents. But since technological co-evolution is ongoing, along with continually shifting costs, provision and demand, new conditions in which the challenging breakthrough can prevail may yet re-emerge when circumstances alter. Technologies advance not only through automatic market adjustments but also as a result of contributions to technological progress from factors such as defence policy, strategic R&D alliances and university research. In the emergence of the PC, for example, the unintended impact of defence policy played a major role in providing complementary technologies in the public domain ready for entrepreneurial commercialisation (Fong, 2001).

3 New entrants and incumbents

Incumbent and new firms face different obstacles to innovation. On the one hand, new firms are often incubators and carriers of new technological competencies (Rosenberg, 1982). Existing firms can also operate as entrepreneurial innovators if they are particularly adept at the forms of opportunity detection and resource creation required to envisage and design new technologies, though incumbent inertia may prevent commercialisation.[1] On the other hand, fast moving entrepreneurial entrants are often resource-constrained by their lack of accumulated capital, as Schumpeter pointed out in 1928. One way of diffusing a new technology despite capital constraints is to license a technology into a network of partners. But new entrants who do not have influence over partners may be over-dependent on partner cooperation in one form or another. They need to enhance the attractiveness of their emergent ecosystem to potential complementary players by bringing down price and improving performance within the window of opportunity offered by vulnerabilities in the dominant technology. But even if they can offer significant advances to the core architecture, they may still be unable to foster or position the complementary products and services needed to commercialise and diffuse their innovation.

When a novel technology is first released on the market its performance/cost ratio is often far inferior to that of the incumbent technology it is seeking to displace. When the technology is further developed and economies of scale realised, the attractiveness of the technology is increased (Christensen, 1997). But the incumbent technology is also improving concurrently. In some instances, with sudden bursts in improvement from the incumbent. Such was the case when the challenge of steam ships prompted improvements in sail technology, when electrical lighting provided the stimulus for advances in gas lighting, and when optic fibres were developed as an alternative to copper wires in telecommunications. In what follows we demonstrate the operation of these causal factors in the case of the NC, which initially offered a lower performance/cost ratio to the PC but had the disruptive potential to offer a greater value proposition to the consumer. Our aim is to view networks, alliances and complementarities from a co-evolutionary vantage in order to specify conditions in which attempts at challenging an incumbent paradigm and its associated ecosystem are likely to fail. From this analysis it will be possible to infer more about the inadequacies in the incumbent paradigm that may subsequently bring about a reversal of fortunes.

4 Methodology

Interviews with seven participants were conducted. Retrospective bias in recollections was adjusted by cross-comparisons between interviewee accounts and comparison with contemporary archives and documentary evidence. The history of the NC, though neglected in innovation literature, is an appropriate case for co-evolutionary analysis because it was sufficiently recent for participants to have shown good recall during interviews, access to company archives was available, and it was also relatively well documented in the trade press.

5 The case: launching the Network Computer

In September 1995, Larry Ellison, co-founder and Chairman of Oracle, voiced the view of many critics of the PC as the vehicle for mass market digital provision at the European IT Forum in Paris. He criticised the PC as ‘a ridiculous device’ and suggested that a simpler technology was necessary if computing was to gain mainstream acceptance by consumers. He proposed the concept of an NC, a simpler device that would deliver computing applications to the home over a network rather than hold all data locally, and which would cost less than $500 (Southwick, 2003).[2] By 1995, the internet (still quaintly termed the ‘Information Superhighway’) had been extended from the scientific and security communities to commercial applications and was opening up new possibilities for complementary technologies. Ellison’s suggestion that the future lay in low-cost digital devices connected to a centralised network providing access to the internet and application software did not appear unreasonable. But the problem for Ellison was that Oracle’s core capabilities were in the development and implementation of large scale enterprise databases; they had no experience in consumer electronics. So Ellison set about finding a firm that could deliver a solution to his vision. His search lasted until December 1995 when he made contact with a British firm, Acorn Computers.

5.1 Acorn Computers

Founded in 1978, Acorn had initial success during the early 1980s in the UK and Europe with its innovative microcomputers. But as the IBM PC became the dominant microcomputing paradigm, Acorn’s share of the personal user market was eroded, putting it in a perilous financial situation that resulted in its acquisition in 1986 by Olivetti, the Italian IT corporation (Fleck and Garnsey, 1988). However Olivetti did not attempt to assimilate Acorn but allowed the Cambridge company to retain its operational autonomy and entrepreneurial culture. Acorn remained as resource-constrained as most young enterprises once the Italian company paid off the debts that had threatened the acquired firm’s survival in 1984.

Although Acorn lost its market share of the home computing market, a move into 32-bit Reduced Set Instruction Computing (RISC) processors helped maintain its competitiveness in the UK education market until the end of the 1980s. However, during the development of the RISC processor it became apparent that Acorn was unable to take full advantage of the expertise of its Advanced Research and Development (AR&D) team. The spinout of Advanced Risc Machines (ARM) Holdings Ltd followed in 1990, a joint venture led by Acorn and Apple in which Acorn provided the intellectual capital and Apple provided £1.5 million of funding.

As the PC was adopted in schools, Acorn's market share further dwindled. The rising stock of its daughter company ARM and its own worsening trade performance prompted Acorn to reassess its business strategy. In 1994 the emerging interactive online multimedia market was seen as an opportunity for the firm to exploit its existing technologies and skills. So it followed that in July 1994 Acorn established its Online Media (OM) operating division.

5.2 Acorn Online Media

Online Media's first move was to develop a digital Set-Top Box (STB) based around the ARM 7500 processor. The operation was headed by Acorn's Director, Malcolm Bird, who decided that a local trial would prove a good showcase for Acorn's technology. To this end, OM collaborated with four firms local to the region, ICL, SJ Research, Cambridge Cable and ATM Ltd, in the Cambridge Interactive TV (CiTV) trial. Run on a shoestring and the goodwill of those involved, the trial began with only ten homes in September 1994 but was extended to over 100 by its end in January 1996. The availability and provision of unused cable capacity ('dark fibre') by Cambridge Cable was critical to this project, as was the cultivation of a service nursery that included the BBC, Anglia TV, Tesco and the Post Office.

The trials caught the attention of Prime Minister John Major, who visited Cambridge following recommendations from his aides that the technology being tested was 'the next big thing'. This was also consistent with some US opinion; Time Warner was conducting its own interactive TV trial in Orlando, Florida. But while the Cambridge trial was being run on a meagre budget thanks to the cooperation of the firms involved, rollout of Time Warner's trial to an ambitious 3000 homes was costing tens of millions of dollars. When Time Warner executives visited the Cambridge trial, they were astounded at the level of system integration on such a limited budget.

The success of the Cambridge trial prompted OM to participate in further trials, in Ipswich with Oracle and BT, and in Westminster with BT. But problems became apparent when it came to taking the next steps toward commercialisation. Bird had recognised from the start of the CiTV trial that the dark fibre provision by Cambridge Cable was unique and that the same business model could not necessarily be replicated on a larger scale. But he knew that the installed broadband network in the UK was significantly under-utilised and that an application which would use this capacity should attract interest from UK cable companies. But a problem emerged as a result of the foreign ownership of the larger UK cable companies. CableTel, Telewest Communications and Comcast UK Cable were all owned by US firms. The message from US headquarters was that research was only conducted in the USA and that, as implementation factories, UK subsidiaries 'should stop messing about'.[3] At one of these subsidiaries, support was gained from an ambitious young manager and a collaborative project was planned. However, the manager's recall to the USA led to the project being abandoned.

The failure to gain support from the cable companies proved an insurmountable obstacle for OM and a significant impediment to the diffusion of interactive TV in the UK. Despite this, a huge order for 10 000 set-top boxes was won with US firm Lightspan, after the OM team demonstrated the superiority of their set-top box technology over that of Apple. After the contract was signed, OM set about adapting the STB to incorporate a coaxial connection that would make it suitable for the US market. But as they were engaged in this technical challenge, Lightspan cancelled their order. The deal would have made OM profitable within the year but the ensuing financial wrangle and the inability to win any other major orders once again left Acorn Computers in a difficult financial position. It was at this point that Larry Ellison appeared on Acorn's radar.

5.3 Acorn Network Computing

It was not until December of that year, while collaborating with Oracle on interactive TV trials in Ipswich, that Acorn heard about Ellison's need for a technology developer. Quick to recognise an opportunity, entrepreneurial managers at OM saw the similarities between their digital set-top box and Ellison's Network Computer vision. Hermann Hauser, by now a serial entrepreneur and director of Acorn, instigated a series of meetings between Oracle and Acorn, culminating in Ellison visiting Cambridge. By this point, Ellison was satisfied that Acorn could deliver what he wanted and he left the Cambridge meeting saying "I've got a presentation in nine weeks or whatever it is and you've got the contract. I want a reference design for the Network Computer."[4]

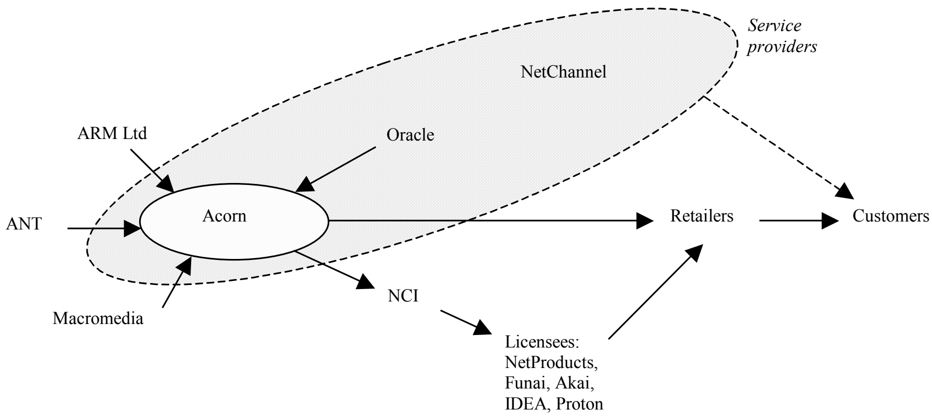
The Acorn Network Computing division was formed to respond to Ellison's challenge and adapt their set-top box to provide the functionality desired for the Network Computer. Malcolm Bird once again led the Acorn engineering team. In collaboration with firms such as ARM, Macromedia and ANT they put together a complete hardware and software package. So, at the Oracle Developer Conference in February 1996, less than two months after he jetted out of Cambridge, Ellison was able to demonstrate the first operational NC reference model. It was a moment of glory for Ellison when he paraded his PC-beater to his audience. And, after the troubles of Online Media, it appeared that the decision of the Acorn board to pursue the development of hardware for interactive TV had finally been vindicated.

The NC's formal introduction to the world followed three months later in San Francisco. Oracle launched the NC by announcing that fellow industry heavyweights, Apple, IBM, Netscape and Sun, would be joining it in an alliance to develop NC devices. These devices would all be based on the architectural specification that Acorn had devised for Oracle, an open standard called the NC Reference Profile (NCRP). It was on the basis of this standard that Ellison hoped to triumph over the PC. For Acorn, it represented a means by which it could diversify away from the education market and strategically reposition itself as a technology licensor.

Ellison also announced the launch of a new Oracle subsidiary, Network Computer Inc. (NCI), which would be responsible for handling the licensing of the NCRP. According to the terms of the contract between Acorn and Oracle, Acorn could not seek revenues from licensing the NCRP, as this was NCI's role, but could manufacture its own NC devices. So, along with designing the specification, Acorn engineers worked towards the development of their own NC, the NetStation, for release in August 1996.

As the NC alliance emerged as bandleaders and the NetStation took shape, Hermann Hauser approached the Acorn board with a proposal: "We should bet the company on the NC".[5] His plan was that Acorn would commit to an expenditure plan that would see thousands of NCs manufactured for the Christmas market. Wary of entering such an unproven market and fearing a repeat of the sales disaster of Christmas 1984 that had almost doomed the company, MD David Lee and his board dismissed Hauser's proposal. Instead, they suggested that he license the technology. So, with £800k of his own money, Hauser founded NetProducts and NetChannel as NC device manufacturer and service provider, respectively. Players in the emergent NC business ecosystem are depicted in overview in Figure 1.

Figure 1 Product and service delivery in the emergent NC ecosystem



5.4 The fall of Acorn Computers

Although the Acorn NetStation was successfully released on schedule in August 1996, with it came the first signs that all was not going to plan. During the Cambridge trial of its set-top boxes Acorn had set up a service nursery to provide consumers with necessary applications. For the NC, Oracle was supposed to be leading on service delivery, but its servers were frequently offline for maintenance. For a computing system that was dependent on always being connected to a central server, this was unacceptable. Nevertheless, Acorn pressed on with the development of new NC designs, demonstrating four new models at Oracle Open World in November 1996.

But there were further setbacks. Conflicting interpretations of NCRP and a lack of cooperation between the five alliance members did not help matters either, leading to market uncertainty. Price wars in the memory and hard-disk drive industries, along with the rise of Dell's direct marketing strategy, were pushing PC prices below the $1,000 mark, making the NC's price tag of $500 appear increasingly less attractive. Further competition came in October 1996, when Microsoft and Intel announced that they were to lead a rival consortium that would develop an alternative network computing system, the NetPC. Although this group did not release any hardware until a year later, this announcement introduced more uncertainty into the market, further benefiting the incumbent PC technology.

Meanwhile, Hauser's two NC ventures had failed to make any headway in the market. NetChannel had been set up to provide a service to those with NC devices but was failing to attract subscribers. By early 1998 it had attracted 10 000 subscribers in the USA whereas its main competitor, WebTV (which was providing internet access and services through a proprietary set-top box technology), had a subscription base of 300 000. Sell offs followed in the middle of 1998, with AOL purchasing the US operation and NTL picking up the European subsidiary.

As provider of the technology on which NCRP was founded, Acorn's future was tied to the ability of NCI to gather revenues from licensing. While East Asian firms, such as Akai, Funai, IDEA and Proton, were signed up, these were not the big name consumer electronics manufacturers necessary to spearhead the rollout of NC devices into homes. Without any significant income from licenses, Acorn was again in a perilous financial position. The interactive TV market had proved to be a non event in the UK and Acorn's market share of the UK education market had continued to be eroded. It was only its 43% stake in the successful spinoff ARM that was maintaining Acorn's market valuation. When Acorn's valuation dropped below the value of this stake, a share exchange was arranged in the spring of 1999. Prior to the exchange, the Online Media set-top box division was bought by Pace Micro Technology for £200,000; after the buyout the core Acorn Computers team was recast as Element 14, with its attention focused on the development of digital signal processors, software tools and applications.

6 Insights from a co-evolutionary perspective

The launch of the NC came amid great fanfare and press attention. But only three years later this variant was already forgotten by all but the participants in the project. In what follows we adopt a co-evolutionary perspective on those features of the case study that provide insight into why the commercialisation and diffusion of this product proved unsuccessful. We identify the presence of a number of factors that constituted barriers to entry for those promoting the potentially disruptive technology in view of the strong interlinkages in the incumbent technology.

6.1 A lack of user involvement

As a new paradigm in computing, Ellison's Network Computer concept represented a form of technological mutation, being conceived as a simpler distributed device than the PC but with its roots in the centralised mainframe terminal. The NCRP represented further evolution of the technology as its blueprint had been determined through Acorn's adaptation of its digital set-top box. But the NC paradigm had not been developed in an environment in which user involvement shaped the characteristics of the final device. It was conceived in the mind of Larry Ellison and Acorn had adapted its set-top box to provide the NCRP on the basis of Ellison's requirements, without establishing the level of functionality that potential users would require of this technology. This 'top-down' approach to development stands in stark contrast to the 'bottom-up' emergence of the microcomputer. Hobbyists had formatively shaped the functionality of the microcomputer until its commercial potential was recognised, first by hobbyists themselves, Steve Jobs and Steve Wozniak at Apple, and then by industry giant IBM (Langlois, 1992). Growth had come from a resource-rich niche that had expanded over time. Touted from the start as a PC-beater, the Network Computer had no such niche from which to grow and it lacked the user involvement that has been identified as crucial in the history of successful technologies (Bijker *et al.*, 1987; Bijker, 1995).

6.2 The failure to stimulate partners into producing NC technologies

Open standards can enable replication and mutation of core technologies, along with enabling the creation of complementary technologies when the standard promotes interoperability. For an interactive innovation there is a requirement for a certain level of standardisation so that other actors can participate successfully. This explains part of the success of the PC: its modularity facilitated competition across a disaggregated value chain, promoting innovation in performance improvements and cost reduction (Curry and Kenney, 1999). In theory, as an open standard, the NCRP would provide such an architectural blueprint. But NCI, the Oracle subsidiary charged with gaining licensees, only managed to interest a handful of East Asian firms. Acorn itself developed a product, the NetStation, which it then licensed to one of Hermann Hauser's new ventures, NetProducts. Of the NC consortium members, only IBM set about developing its own NC, also called the NetStation. This lack of licensed manufacturers meant that it was difficult for the NC consortium to sustain the expectation that the NC could rival the PC, and led to few actual products being seen on retailer's shelves.

6.3 A lack of complementary hardware and software

Disruptive technologies, and new technologies in general, are often released with significant improvements still to be made in their design for successful commercialisation. Such was the case with the NC. The initial Acorn design had at its core the ARM 7500 processor, which was designed primarily for handheld devices. But despite the lower processing requirements of the NC, it was initially underpowered. These hardware issues were resolved in later NC models but the NC retained its earlier image as an underpowered technology. This lag in positive perceptions of the NC was particularly damaging because the applications used in the NC were also seen as inferior to those available for the PC.

Acorn did however integrate smart card technology into their NetStation. This smart card acted as a personal access card so that anyone could insert it into an NC device and gain access to their own desktop and file space from the central servers. Highly advanced for its time, the smart card was one complementary product that would have provided significant added value, had the NC become more widely diffused.

As regards software, the initial set available for the NC was limited to just a handful of applications, much of it developed by Acorn, and possessed lower functionality and aesthetic quality than comparable PC software. The NC's internet browser, developed by Acorn, is a case in point. It needed to be downloaded from the servers quickly so was coded to be as compact as possible. HTML code had been standardised by this time and Acorn developers were able to develop a lean browser that could read this code. But the problem was that a high proportion of webpages had 'broken' code where the code did not conform to the standard. The sophistication of the browsers available for the PC, Netscape's Navigator and Microsoft's Internet Explorer, was in their ability to interpret and present what was intended when broken code was identified. This level of sophistication would arrive much later to the NC as, despite being part of the NC consortium, Netscape did not adapt their browser for the NC launch. Instead, Netscape created a spin out company in August 1996, Navio Communications, to adapt the Navigator browser for consumer devices such as the NC. However, it was not until early 1997 that a sophisticated browser became available for the NC when Navio began licensing the Navigator variant to NC developers, including IBM and Sun (Cusumano and Yoffie, 1998).

6.4 A lack of adequate infrastructure and complementary services

The lack of an enabling network infrastructure was a serious impediment to the uptake of the NC. In 1996, telecommunications networks were of insufficient bandwidth to supply a computing experience of comparable quality to that of the PC. The latency between NC and server meant that applications and internet pages took much longer to load on the NC than the PC. For those consumers who had broadband this latency was less noticeable, but problems remained.

Even where network infrastructure was adequate, lack of access to applications themselves represented a major factor in the adverse selection process experienced by the NC. Applications were hosted on Oracle's servers but these servers were frequently offline for maintenance and testing. Yet the service was unforgivable for a service that was entirely dependent on the servers for its operation. NC services were also available from Acorn's test server, although these were never intended to be operational commercially.

Recognising the necessity for this service and the opportunity that NC content provision afforded, Hermann Hauser set up NetChannel. But this amounted to little more than a pilot venture and failed to attract a significant number of subscribers. Delivering software applications over a network was still novel at this time; the concept of Application Service Provision (ASP) was still in its infancy. The new business model required for the NC had significant technical hurdles to overcome. Along with the limitations of the networks on which it would operate, there was also the challenge of creating a scalable database capable of hosting on-demand applications and that of developing applications with a similar level of aesthetic to that of the PC.

6.5 A lack of incentives for partners to develop and promote the NC

It would have required an ecosystem made up of collaborating partner firms to commercialise and diffuse the NC successfully. But the composition of the NC alliance (Apple, IBM, Netscape, Oracle and Sun) represented a motley opposition to Microsoft, Intel and the PC. Apple had seen its position as the leading PC manufacturer usurped following the release of the IBM PC, but then IBM itself had lost control of its own PC architecture to Microsoft and Intel. Netscape was involved in an internet browser war with Microsoft, while Sun and Oracle were looking for new markets for Java and its enterprise databases, respectively. These five companies were unified by their strong anti-PC stance. But none of these firms released a NC device based on the original reference profile. Instead, Sun developed its JavaStation and IBM its NetStation based on a later reference profile. As developers of the original NCRP, Acorn was the only firm whose success was tightly coupled to that of the NC.

An ecosystem will grow through the deliberate efforts of the parties involved only if these parties see their success as being bound up with the success of the overall ecosystem (Iansiti and Levien, 2002). For the alliance firms, the NC was a diversion from their primary activities and they were not reliant on its success for their own progress. Lacking commitment, each firm pursued its own agenda. The uncertainty this generated, along with that caused by the introduction of the rival network computer, the NetPC, left both producers and consumers bewildered, ultimately to the benefit of the PC.

6.6 A restrictive licensing agreement

Acorn was the entrepreneurial system architect for the NC. But under the terms of their contract with Oracle they could not seek licensees for the NC themselves. Instead they were reliant on the ability of Oracle's subsidiary NCI to gain licensees for their revenue stream. That NCI was only able to generate a handful of licensees meant that Acorn was not sufficiently rewarded for its efforts in further developing the reference profile or new NC devices. Acorn engineers understood the technology better than anyone else and could have played a more prominent role promoting the NC within the industry. In another successful licensing initiative, engineers from Acorn employed in a joint venture with Apple at ARM (founded in 1990) were active in assisting the CEO to promote the licensing of ARM's RISC chip in a business model that was to make ARM world leader in the design of microprocessor cores for the mobile device sector. The success of ARM, an entrepreneurial entrant that created a new business ecosystem using a new licensing model, differed on every feature listed above from the NC case (Garnsey *et al.*, 2005).

6.7 The continuing co-evolution of the incumbent technologies

Advances in the PC ecosystem represented a significant barrier to the diffusion of the Network Computer as the constituents of the PC ecosystem were continuing to co-evolve at a significant rate. In the early 1990s, Microsoft and Intel had emerged as the platform leaders of the PC and they had managed to lead the development of the PC architecture (Cusumano and Gawer, 2002). The modularity of the PC promoted competition and innovation across a disaggregated value chain, simultaneously increasing the performance and decreasing the cost of hardware (Curry and Kenney, 1999). These advances, coupled with the periodic release of more sophisticated operating systems and application software, meant that the market continued to grow and existing users were compelled to upgrade their systems every three to five years. Complementary products and services added value to the PC, locking-in users as they made investments and learned how to use the PC's applications. The firms that were part of this ecosystem were rewarded for their efforts through the PC's continuing growth of market penetration. But they too were ultimately locked-in because their success was tied to the success of the PC. Through Moore's Law, firms were able to project the approximate rate at which advances would take place and could plan their strategies accordingly. The technological co-evolution in the PC ecosystem served to increase the fortunes of its members. In addition to this, the emergence of Dell and the effect of its direct sales business model on reducing retail prices meant that there was little need for the PC ecosystem to respond to the threat of the NC.

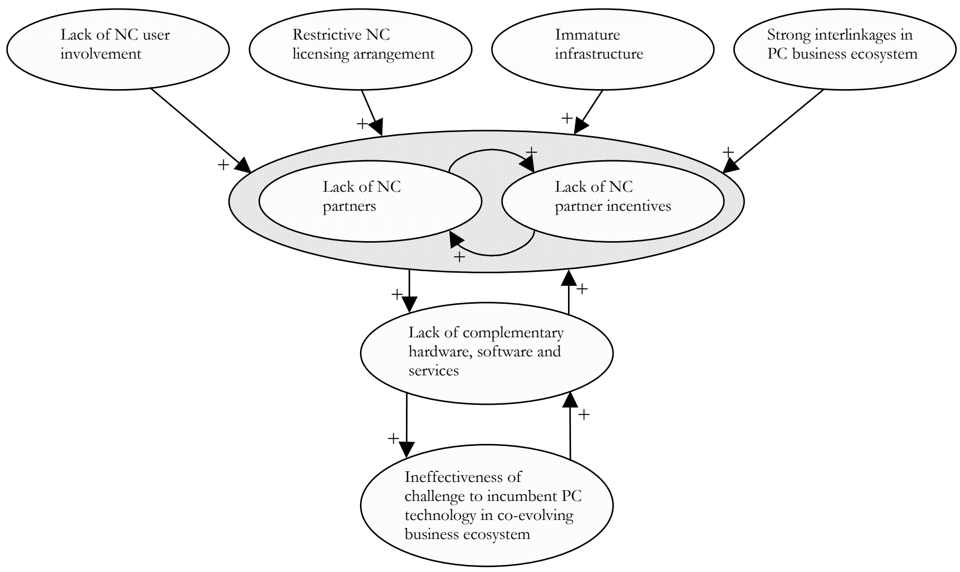
But as events unfolded, the PC ecosystem did react to the threat of the NC in October 1996. It was announced that a rival consortium led by Microsoft and Intel would produce an alternative vision of an network computing device, the NetPC, which would be based around an Microsoft operating system and Intel microprocessor. The announcement of this consortium came more than a year after Ellison announced his vision, but only two months after the launch of the first NC, the Acorn NetStation. This announcement had a ‘vaporware’ effect in increasing the uncertainty amongst producers as to whether the NC, the NetPC or the PC represented the future of computing.

The PC industry was sufficiently concerned about the need to improve the interconnectivity of its systems to make network integration simpler, both in office Local Area Networks (LANs) and in connecting to the internet in the home. Again the modular architecture of the PC meant that the industry was able to respond when users began to demand this functionality. This was initially done through the release of separate modems or network cards, then later through the integration of these components onto the motherboard.

7 Complex dynamic feedbacks

On simple inspection it may appear that NC failed to challenge the PC effectively simply because its technology was inferior. But most disruptive technologies appear inferior at the time they emerge (Christensen, 1997). To dismiss its failure in such terms is to overlook the interplay of causes that contributed to the NC’s weakness. Figure 2 depicts the combination of specific factors that led to the ineffectiveness of its challenge.

Figure 2 Factors contributing to the failure of NC



This figure synthesises analysis from the previous sections to illustrate how the lack of complementarities restricted the technological co-developments that the NC needed in order to challenge the incumbent business ecosystem. In particular, the lack of partner incentives prevented the development of complementarities and inadequate licensing arrangements restricted the expansion of the partner network. Prior developments, including the close interlinkages in the incumbent PC technology, were able to close out the NC in the absence of counter developments.

The successful selection and propagation of a business ecosystem can be partially attributed to the effective harnessing of positive feedback effects. Complementary products and services have the potential to add value to the ecosystem and the technology, but potential participants must first be convinced that they should partner in the development of these complements. Providing potential partners with the perception that the future prospects of the technology are attractive is a key element in growing a business ecosystem where further innovative behaviour develops complementary technologies of mutual benefit. But such an outcome was not effected in the case of the NC. The uncertainty surrounding the NC led to a vicious cycle in which the business ecosystem failed to grow and facilitate the development of complementary technologies.

Given the choice between joining the NC ecosystem and remaining part of the PC ecosystem, the majority of firms remained in the PC ecosystem. It was as co-developers for the PC that these firms had become successful; to continue to support the PC was a less risky strategy and it made better sense to have a small percentage of this large market rather than a large percentage of a small market. That there were few licensees meant that the scale on which NC devices would become available would not be as large as anticipated. They were far from achieving a critical mass of licensees and the associated market awareness that would be generated by licensees growing the ecosystem. The promoters of the NC were therefore caught in the classic loop of higher prices associated with the failure to scale up, and were unable to promote the product in niches where it might have been viewed as attractive.

Thus the PC ecosystem had no real need to adapt in response to the threat of the NC even though the emergence of the internet, with its promise of connectedness and content, was in principle more favourable to the NC than the PC, whose proponents had not anticipated the advent of the internet. But the ensuing pressure to improve the interconnectibility of the PC to networks resulted in innovations that, together with price wars and price reductions, eroded the perceived advantages that the NC could have had over the PC.

8 Concluding remarks

In the 1990s when the PC's costs and connectivity were less attractive to buyers than they later became, the idea of a low cost Network Computer, delivering software directly from the internet to terminals that would require much less servicing and support than PC networks, had a more compelling logic than today. Retrospectively, it may seem inevitable that the PC technology would continue to experience improvements in performance, productivity and cost, and that such advances would outpace any rival paradigm. Challenging the PC would require a transformation of the technological paradigm that had taken root over the previous two decades. What prevented this was neither the operation of autonomous market forces (Liebowitz and Margolis, 1994) nor irreversible path dependence (David, 1994). Asynchronies that result from prior developments and chance events sometimes stimulate compensatory self-organisation among participants, or coordination through market leadership. Neither of these occurred in this instance, despite the efforts of those at the technological centre of the endeavour.

The co-evolutionary perspective provides insight into why this vision of low cost digital access for the masses was not realised at this point in time. We have traced the failure of synchronisation of the technological and marketing complementarities that would have been required to bring Acorn's Network Computer product to reality. Backed by government support for micro-computing in schools, Acorn Computers was a pioneer in the personal computer market in Europe and a central player in the UK debate over the future of home computing. Olivetti, a major player in international IT, was a supportive though not a munificent owner. Acorn's experience illustrates how difficult it is for a resource-constrained entrepreneurial firm to achieve the complementarities required to change a technological paradigm through market and partnership relations in the face of incumbents with market power and of improvements in the incumbent technology.

Our case study details why it is that once critical mass has been established in a core interactive product, the co-evolutionary forces that brought about this result may continue to operate, locking-out competitors who are unable to build the kinds of complementarities that favour the expansion of the dominant paradigm. But this case also shows that such attempts are not in vain, as they nurture new technologies and competencies that later exert an impact in unexpected ways.[6] The defeated technology may experience a resurgence, albeit in a new manifestation. In the case of network computer devices, this will require further technological co-evolution, for example, through open source software and government backing on the scale that underlay the emergence of the PC in the USA (Fong, 2001). In the past, competing technologies that faced an initial struggle have not been permanently locked-out. Over time their capacity to meet currently unmet needs has been recognised and the new business ecosystem has been backed by new investment, marketing and institutional support (Nairn, 2002).

Although the PC has extended its functionality and market reach by an order of magnitude, Ellison's criticisms ('the PC is a ridiculous device') still carry resonance some ten years after the launch of the Network Computer. The PC remains an overly complicated and sophisticated device for most users. Its relatively high upfront cost, the continual obsolescence and upgrading of hardware and software and high maintenance costs prevent its adoption by those with lower incomes in both developed and developing countries. Moreover, the contribution of the PC's technology paradigm to environmental problems is considerable (Kuehr and Williams, 2003).

When the internet age arrived in the mid 1990s, the NC had been part of the battle to decide whether home computing would be PC- or TV-centric. While that competition was won decisively by the PC, the fluid and continually changing nature of competing technological paradigms and user requirements make it certain that the PC will face further threats from rival business ecosystems promoting other kinds of networked electronic devices. The success of such challenges will be determined by the rival ecosystem's ability to deliver value through aligning technological complementarities supported by an effective infrastructure, and so provide a genuine alternative to the tight interlinkages of the PC paradigm.

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Notes

1 Witness the notorious failure of Xerox to commercialise the developments made at its Palo Alto Research Centre, such as the first microcomputer (Smith and Alexander, 1988).

2 A typical PC cost in the region of $1,500 dollars in 1995.

3 Reported by Malcolm Bird, formerly Acorn Director and Chief Executive of the Online Media and Acorn Network Computing divisions.

4 Reported by Malcolm Bird, formerly Acorn Director and Chief Executive of the Online Media and Acorn Network Computing divisions.

5 Reported by David Lee, formerly Managing Director of Acorn.

6 Acorn's set top box spin out was sold to Pace and became the vehicle for the diffusion of digital TV in the UK. Over 20 other companies originated in Acorn, several of which have become market leaders.