Speciation through Entrepreneurial Spin-off:
The Acorn-ARM story

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Abstract

Can the concept of speciation explain evidence on how technologies branch and advance? Can evidence on innovation through spin-off usefully inform the concept of speciation? These questions are addressed through a case study of detailed processes enabling the shift of technology to new domains of application. An innovative IT firm developed its own semiconductor technology to remedy supplier deficiencies but it required a joint venture with a completely new business model to adapt and move the technology into new market domains. We propose the concept of techno-organizational speciation to delineate this phenomenon. Competing perspectives on speciation, (compatibility, niche and lineage approaches) are found to illuminate the evidence, while complementarities between these conceptual dimensions are revealed by the case. Causal processes uncovered include the following: (1) Techno-organizational speciation through spin-off may be needed to launch a dominant technical standard, compatible with multiple applications. (2) This can be achieved through niche creation from which develops a new business eco-system. (3) Inherited knowledge together with organizationally-based learning foster the branching and renewal of technological lineages.

Keywords: spin-off, technological speciation, parent-progeny, technological innovation.

1. Introduction

The branching and diversification of related technologies is a feature of technological advance. The firms that incubate and carry innovations also branch and diversify as new firms are spun-off from old (Klepper and Sleeper, 2005). The idea that these two processes are closely connected is intuitive, but the association has not been explored in detail in the literature on innovation. This study uses the concept of speciation to explain a case where the spin-off process stimulated the branching and advance of technologies. The evidence informed theory by delineating the concept of techno-organizational speciation and illuminating its complementary dimensions.

In ecology, speciation describes the process through which a new natural species may emerge as a sub-population adapts to new ecological conditions (Dupré, 2001). Technological speciation refers to a new technology that emerges as an existing technological form is adapted to a new selection environment (Levinthal, 1998). For example, when the Internet expanded its domain from military and academic applications to the world of consumers in the mid-1990s, it was transformed into the world-wide web (enabled by new standards) reflecting the very different features and attributes demanded by consumers and firms in the new markets. The shift in domain of application allowed a niche technology to become a global phenomenon and stimulated a host of ancillary technologies.

The concept of speciation can be used to trace continuity alongside discontinuity. In the study of technological innovation, continuity has been depicted in terms of path dependence, the cumulative influence of the past on developments (Arthur, 1990). In contrast, discontinuities in technology are highlighted by the concept of the technological paradigm, which points to cognitive and practical disjunctures that set off the path-breaking trajectories in a new technological paradigm (Dosi, 1984). Technological speciation addresses a spectrum rather than disjuncture: in the lineage of a new technological species there is continuity, but application to a new domain results in discontinuity. Over the last ten years research on technological speciation has provided several accounts of innovations stemming from the transfer of specific technological know-how to a new domain (Levinthal, 1998; Adner and Levinthal, 2002; Cattani, 2006). Little is known, however, about the actual processes that underlie the transfer of existing know-how into a new domain and allow subsequent adaptation to the selection forces operating there. What micro-developments and decisions prompt the branching of an existing technical lineage? What transformations are required in order for the existing technological know-how to be adapted to new selection forces? How does this process unfold over time?

In this study we address these questions by moving beyond speciation in the incumbent firm, addressed in the literature, to examine an incumbent company that spun out a new venture into a new domain, where different market forces operate. We found that the inherited technology mutated into a distinctive combination of new technology and business capability. We propose the concept of techno-organizational speciation to depict the emergence of a new species of technology and the concurrent crafting of organizational arrangements that allow its successful exploitation in the new market environment. We investigate this dynamic through the exemplar of Acorn Computers and its offshoot ARM, one of the most successful spin-offs in the history of European technology-based industry. The RISC chip (Reduced Instruction Set Computer Chip) launched by ARM has had a major impact in the semiconductor industry, but its core technology was developed in Acorn Computers as a micro-processor for its PC products. At ARM, this microprocessor was licensed as a core adapted to design needs in new market niches, and came to be a new platform technology.

The paper is organized as follows. After an introduction to relevant concepts and literature, we describe the design of our inquiry and go on to outline our case study, in which we present the antecedents to the spin-off of ARM and its outcome. In the interpretation of the evidence we use the concept of speciation as a pattern-recognition device to identify generic issues raised by the evidence. We offer an explanation of this instance of technological branching and diversification, and identify organizational conditions conducive to the process of speciation through spin-off that are revealed by the case.

2. Speciation, technological innovation and entrepreneurial spin-offs

The richness of the idea of speciation is not fortuitous but reflects longstanding research using this concept in biology and ecology (Ayala and Fitch, 1997). Darwin's evidence from the Galapagos Islands fed understanding of the detailed process by which one species can give rise to others through natural selection operating in different habitats. Darwin viewed a species not as an entity but as a category to aid classification of the varieties of life forms (Darwin, 1887). There are inevitable differences of perspective on how best to classify living forms, which has resulted in controversy on species boundaries. These differences have outlived Darwin and are reflected in three main (and to some extent competing) approaches to 'species' in the natural world, and corresponding perspectives on the speciation process (Dupré, 2001). Assigning an empirical instance to a category is an endemic classification problem. Judgement is involved in setting such boundaries, whether of natural species or of technological trajectories (Dosi 1984). We found that three major approaches to identifying natural species also provided relevant criteria for drawing boundaries between types or species of technology[1]. (1) Incompatibilities prevent members of a species' population from inter-breeding with those of other species. Constraints on species' replication are addressed by this concept of species (Panhuis et al., 2001). (2) Ecological perspectives on speciation highlight the selection environment and the niches and ecosystems in which distinctive selection forces operate. (3) The lineage approach categorises species in terms of common ancestry and evolving lineage that splits as a new species emerges (Claridge et al., 1997).

All three perspectives on speciation are relevant for differentiating between technologies (Nelson 2006). (1) Compatibility between technologies is a salient criterion for distinguishing between technological types. Differences are formalised in technology standards that define compatibilities between designs. As a new technology is altered to the point of incompatibility with the originator technology, this brings to an end the design replication process that keeps a technological or other

[1] While we apply the biological framework to understand the nature of the selection environment acting on possible technologies and, in particular, the niche structure of the resource space, we are not assuming a process of blind variation generation. Indeed, the role of intentionality and choice in technology development clearly distinguishes it from processes of biological change. Unlike the blind determinism of natural selection described by Darwin, technology selection processes, when understood by participants, give rise to learning on the part of actors and deliberate efforts to change their selection or opportunity space.

species from extinction (Rohlfs, 2001). (2) Technologies are subject to selection forces in different niches or markets, which operate as forces differentiating between technologies as they evolve. (3) Processes of technological inheritance occur as a design is replicated and adapted in one organization after another, creating identifiable technological lineages in applications and products. All three of these speciation perspectives illuminate our case evidence, which in turn proved to clarify connections between the perspectives.[2]

Over the last ten years a growing number of evolutionary economists have adopted a speciation lens to explain and illustrate the emergence of new technological trajectories in a variety of industries . Technological innovations as diverse as wireless communication (Adner and Levinthal, 2002), the steam engine (Frenken and Nuvolari, 2004), fibre optics (Cattani, 2006) and broadcast radio (Levinthal, 1998) share a common developmental pattern. All these technologies underwent a process of evolutionary development within their original domain of application. At some juncture, however, that set of technologies was applied to a new domain of application in which they evolved in new directions. The technological advance necessitated by this event was not discontinuous. But the different selection criteria and new resources available in the new domain of application resulted in a technology that became quite distinctive, even though path dependence – the strong influence of prior developments – characterized the routes taken from the technology of origin. Research on technological speciation shows that what appear to be radically new technologies have gradual and incremental features when scrutinised more closely (Cattani, 2006).

The literature on spin-offs is clearly relevant to the speciation process that occurs when a new firm endowed with inherited knowledge branches out from its originator and strives to apply that knowledge in a new economic domain (Agarwal et al., 2004). Surprisingly, however, this literature has not made use of ideas introduced by the speciation framework, nor has the stream of work on

[2] To term a technology type a 'species' of technology and the emergence of a new type of technology in new markets a 'speciation process' is not to base reasoning on a figure of speech. It is to tap into a rich analytical vein, highly salient to the analysis of branching and diversifying technologies. Evolving technologies are among a class of systems that are subject, in different ways, to common evolutionary processes (Beinhocker, 2006). It is inappropriate to seek equivalence across these systems beyond generic processes of variety creation, selection and diffusion through which designs are replicated, branch and diffuse over time (Nelson, 2006).

technological speciation explored the micro processes that set off the initial splitting of a common lineage and occasion subsequent adaptation of a sub-group to the new domain. Most spin-off studies have focused on the new venture without tracing evolutionary antecedents in the organization of origin (Mustar et al., 2006). Alternatively they focus on the organizational endowment at founding without a detailed account of the early processes at the spin-off level (Shane and Stuart, 2002). For instance there is an extensive stream of research that emphasizes the effects of spin-offs' origin on their subsequent survival rate and performance (Agarwal et al., 2004; Cooper and Gimeno-Gascon, 1992; Klepper, 2001; Lindholm-Dahlstrand, 1997). However, little attention has been paid to the dynamic relationship between the heritage of a spin-off and the exploitation of its innovative potential through entry into a new market.

A key benefit of looking at the speciation process through a dyadic (parent-progeny) lens is that it illuminates issues of both continuity and discontinuity. The development of a lineage is continuous in that the initial form of technology in the spin-off bears a close relationship to the antecedent technology in the source domain; however, the technology may develop a quite a distinct form as a result of the spin-off entry into domain with distinctive selection criteria and resource pools, as well as deliberate organizational efforts on part of the actors to change their opportunity space (Cattani and Levinthal, 2005). In what follows, we present a case study of the emergence of a new species of technology, enabled by an organizational form more adept at exploiting the new opportunity space than was its parent company.

3. Method of Inquiry

3.1 Research Setting and Design

We sought a case for which we could track key processes in a parent-progeny transition in considerable detail, one recent enough to enable us to interview people who were directly involved in the transition.

Acorn Computers, founded in Cambridge England in 1978, had a unique record in spinning out high tech ventures, one of which, ARM, became a world leader in microprocessor design. Acorn Computers was not a commercial success, but it gave rise directly or indirectly to more than thirty start-ups and has been compared to Silicon Valley's Fairchild Semiconductors (Athreye, 2004). In 1984, Acorn ran into serious difficulties and was acquired by Olivetti, but retained its operational autonomy. Among the reasons for Acorn's problems had been delays and defects in the microprocessors supplied by Ferranti. To avoid recurrence of these difficulties, Acorn set out to develop in-house expertise in microprocessor design in its Advanced R&D department, which was to be the basis for the 1990 spin-off of Advanced RISC Machines Ltd (ARM).

A study of Acorn and ARM had been undertaken in real time, providing us with contemporary evidence from interviews dating back to the 1980s (Fleck and Garnsey, 1987; Garnsey and Fleck, 1988). This together with contemporary documentation reduced the risk of retrospective meaning being imposed on events from knowledge of outcomes (Golden, 1992; Yin, 1994: 92). To gain a longer term perspective we conducted follow-up interviews with key personnel involved in the transition process and those responsible for developing RISC technology in ARM. Interviews included those listed in Table 1. Repeat interviews were conducted with those closely involved in the transition. [3]

Table 1 about here

New product development is allocated resources according to selection pressures within firms (Bower, 1970; Burgelman, 1994), whereas the market constitutes an external selection environment for the firm's innovations. To operationalize the concept of the firm providing an internal selection environment, we used information from respondents on how decisions about resource allocation to new projects were taken. To operationalize the concept of external selection environment, we asked in interviews about market conditions affecting the firms' technologies. To uncover how the competence

[3] Semi-structured interviews lasted between one and three hours. Interviews before 1995 focused on Acorn and those after 1995 focused on the spin-off and ARM's development.

developed at Acorn was furthered at ARM, we asked informants about ARM's technological base and how the ARM business model was devised. Extensive archival and secondary data helped to clarify the internal as well as environmental conditions under which the spin-off driven speciation process unfolded. Other sources provided background information on the role of Olivetti in rescuing Acorn from the severe financial crisis that befell the company in the mid-1980s (Ciborra,1994; Piol, 2005) and on how ARM came to provide the leading architecture in low power consumption embedded processors (Atack and van Someren, 1993).

3.2 Rationale for a dyadic case history

A longitudinal case study design across the two organizations was appropriate for studying speciation through spin-off (Yin, 1994). A dyadic approach, rare in both spin-off and speciation literature, was essential to uncover antecedents and micro-processes of innovation. A rationale for presenting the evidence as a chronology detailing antecedents and outcomes of the spin-off is provided by the cognitive scientist Jerome Bruner, who showed that narrative is uniquely suited to capturing the complexities of change as experienced by human actors (Bruner, 1990). We applied constructs from the speciation perspective to facilitate pattern recognition of interconnected factors and generic processes that shaped this instance of innovation.

A single in-depth case does not aim to be representative but to delineate concepts and identify connecting ideas, using evidence from a detailed empirical exemplar to inform theory. A single case has provided a new perspective on wider issues in key studies that include Penrose's Hercules Powder case (Penrose, 1960), the inspiration for her *Theory of the Growth of the Firm* (1959), Burgelman's account of strategic change at Intel (1994) and Schein's work on Digital Equipment Corporation (Schein, 2003). The Acorn-ARM case helps us delineate a framework and identify recurrent causal mechanisms in the continuities and discontinuities that shape technological advance.

4. Summary of the Case Study

Acorn Computers was among the first European companies to design and market a microcomputer. The spin-off from Acorn occurred through the coincidence of pressures from within Acorn and the needs of a leading US company, Apple Computers, which required a microprocessor for a new hand-held product. Apple's managers had identified the potential of Acorn's RISC chip technology, but did not want to license directly from Acorn as a competing PC company. Apple Computers proposed a new joint venture. A group of engineers from Acorn's microprocessor development team who had outstanding hardware, software, system and integrated circuit expertise, provided the personnel for the newly founded Advanced Risk Machines. Although the expected market for the Newton notepad did not eventuate, it confirmed the existence of an opportunity to license ARM's RISC technology in rapidly expanding markets for embedded systems.

The transition from Acorn to ARM can be conceptualised as two partly overlapping phases (figure 1): (1) The birth of Acorn Computers in 1979 and the subsequent development of Acorn's RISC chip meeting current requirements from the early 1980s. (2) The spin-off of the RISC technology into ARM Holdings in 1990 and its transformation as a new techno-organizational species. In what follows, evidence on the unfolding process through which this transition occurred is presented and the evidence is then analysed as a speciation process.

Figure 1 about here

5 Speciation through spin-off: the Acorn-ARM story

5.1 1978-1990: Acorn and the RISC technology

In 1978, after a PhD in physics at the University of Cambridge, the Austrian born Hermann Hauser joined Chris Curry, who had been working with Clive Sinclair, to launch Cambridge Processor

Unit (CPU). Initially the aim was to provide computer consultancy services and so fund the development of microcomputer kits to be sold by mail order. Acorn Computer Ltd (a trading name used by CPU) was able to call on skills at Cambridge University in microcomputer design and was soon pioneering in computer architecture, silicon chip design, operating system design and local area networking (Fleck and Garnsey 1987).

In 1981, Acorn was placed on the list of companies invited to tender for a BBC contract which would allow the selected computer to carry the BBC emblem in return for royalties. Hauser succeeded in persuading a group that included Roger Wilson and Steve Furber to build a working prototype in four days, in time for the BBC contract. He managed to convince them by "by telling each of the team that the others thought this was possible" (Hermann Hauser, personal interview). Together they achieved what they individually thought to be impossible: they came up with an innovative microcomputer system in a very short span of time. The favourable report of the BBC's technical advisors and the energy of the young team with its strong university connections led the BBC group to select Acorn's prototype. The BBC endorsement drove forward sales and allowed the R&D members of the group to develop new, more powerful models.

The group of people in and around Acorn Computers was dedicated to technical excellence and believed in a holistic approach to computer design. Hardware, software, and architecture had to be mastered. As a consequence the group developed knowledge in every aspect of computer design. "The DNA at Acorn at the time, and it was a wonderful time, was dedication to technical excellence […] it probably was one of the last times in our history of computing that a group knew everything about the entire architecture of the computing environment" (Hauser, personal interview). Acorn was able to attract talented software professionals to develop a range of software on an outsourced basis and its computer architecture enabled 'add-on" peripherals from third parties. In April 1984, Acorn won the Queen's Award for Technology for the BBC Micro.

Acorn's reputation was based on their innovative R&D and high quality standards. New product design and development were a priority. Creativity was viewed as a strategic need, the view being that a leading company had to be ahead of its rivals on as many fronts as possible. This was a period of excitement for the young team. "We were congratulating ourselves. We had got it right: quality, delivery – one success after another. We were flying high. You really think you can do anything after that. It was: 'Just give us a problem, we'll solve it' " (Hermann Hauser, personal interview 1987). In 1983 Acorn was floated on the stock market, though the founders retained 90% of shares.

In the early 1980s the company had been developing very new products that were later to become familiar ideas. These included modems, telecommunications products for satellite and cable broadcasting, interactive video and an alternative operating system to UNIX. But by 1983 many of these R&D projects were not relevant to Acorn's core business of microcomputers nor to identified market needs. Few developed into marketable products, and few of those produced sold well. Over the years, however, the propensity to experiment and innovate became a defining feature of the company, creating competences that Acorn employees used in creating spin-off companies.

Although microprocessors could be bought in, Acorn had experienced continual difficulties with obtaining chips of the standard they required. As scale-up took place, Acorn's supplier Ferranti delivered plastic casing which failed to dissipate heat as the earlier prototypes in a ceramic version had done. This resulted in a serious fault: the disappearance of the computer's screen display.[4] In order to prevent any further delays in the launch of new products, a group was set up in 1983 to look into chip design.

Acorn started to search for 16 or 32 bit microprocessors to replace the existing 8 bit MOS 6502 based system. According to Acorn's chief hardware designer Chris Turner "16-bit and 32-bit microprocessors were beginning to appear and the Lisa had been launched which made us realise that we needed a windows system, so some of my more academically inclined colleagues, like Steve Furber, argued that we needed a new architecture". Yet the existing 16- and 32-bit architectures did not fit Acorn's vision. "We looked at National's 16032 and Motorola 680000", recalled Steve Furber, " but

[4] Interview with Professor Andy Hopper 11-04-05. "In their early experiments to introduce simplicity into instructions, Acorn developers cut the safety margin too thin, but over the next few years were able to get the new designs right."

they did not suit our design style. They had very complicated instruction sets giving poor interrupt response. Basically they were too slow." (*Electronic Weekly*, 29/04/1998).

As Andy Hopper explained, "Starting from scratch to design a 16-bit microprocessor would simply appear insane to most of the people in the microprocessor business" at that time (personal interview). But a former colleague in the US pointed them to the Berkeley RISC design.[5] Using a Reduced Instruction Set of this kind could bypass many of the problems involved in standard chip design. In 1983 Steve Furber and Sophie Wilson went to the Western Design Centre in Phoenix where they were working on a 16-bit version of the 6502. "We found it to be a cottage industry working in a bungalow in a back street. That gave us confidence. Sophie started playing with instruction set designs. Our mentality was: 'let's have a go at building a microprocessor'" (The Guardian, 08/03/2001). Hermann Hauser decided to back the project. As he recalls "We decided to do a microprocessor on our own so I gave my team the only two things we had: no money and no people! The only could do it by keeping it really simple" (personal interview). Furber set to work defining the architecture while Wilson developed the instruction set.

Work started in 1983 and the first silicon was run on April 26th 1985. It had taken 18 months and five man years. The Acorn RISC Machine (ARM) was designed by the same group of people who worked on the first computer kit and the pattern was the same; it worked sufficiently well the first time to be debugged using the system itself: "The ARM chip performed well, given that its power was limited because of a low number of transistors. But this did mean it had extremely low power consumption that could be adjusted up or down, and was of very small size" (Sapsed, 1999, p. 73). The chip had 30,000 transistors, the same number as a Z80 or the 6502 that Acorn used in its BBC Micros, but it was twenty times faster. It was also the world's first RISC processor. According to Hauser, "ARM was part of a policy decision that a computer should be designed on silicon rather than cobbled together out of third party components. This focus made Acorn one of a small, select group of genuine computer companies (Apple being the most obvious) that own their own technology from the ground"

[5] The development of RISC in the US is documented by Khazam & Mowery (1994).

(personal interview). ARM's first sample was delivered in 1985 and was manufactured by VLSI which later was also licensed to sell chips using Acorn's new design.

The ARM microprocessor emerged in a period when Acorn was experiencing financial difficulties. However after a five year period of expansion the founders were not alarmed by mutterings about retailers' sales; they were sure these would pick up as Christmas approached. By January 1985, one third of the Christmas stock remained unsold; sales were about 35% below the April forecast and the pressures on Acorn made it necessary to cut staff numbers from 450 to 250 by early in 1985. Acorn's share values slumped. Suppliers' demands for payment became pressing and by March 1985 a winding up petition was issued. Acorn had to cease trading.

No British company appeared willing to enter into an arrangement acceptable to Acorn. Elserino Piol, a Director at Olivetti, made an approach which was to result in the Italian electronics company taking a 49% share in Acorn. By September 1985, Olivetti took ownership of 79% of Acorn after sales' targets were missed. Olivetti paid under £15m for Acorn which had been valued at £100m in the previous year. "In accordance with Olivetti's partnering policies, Acorn had originally been acquired to gain market share in the UK and a strong foothold in the education market. However, it came as a surprise to Olivetti that Acorn's labs contained a wealth of people, skills and on-going projects that turned out to be of strategic relevance" (Ciborra, 1994).

The challenge was to make the transition from Acorn as an independent company to Acorn as a subsidiary which could benefit from Olivetti's international access and resources. But like most large organizations, Olivetti was not a unified entity. In the UK branch of Olivetti there was support for Acorn's new developments. In contrast, the more cautious operational groups at Olivetti favoured standard, well proven technology. There were no effective processes for integrating Acorn's many innovative projects into Olivetti's operating branches. This caused friction and conflict.

In the late 1980s, the possibility of spinning out the microprocessor unit from ARM was under discussion, since the prospects for a RISC chip unit inside Acorn Computers were poor. There was reluctance among manufacturers to source from a competitor company or one that might terminate the license to protect their own markets. Hermann Hauser and Elserino Piol, of Olivetti, were of the same mind as engineers engaged in advanced R&D at Acorn; they viewed a spin out of the microprocessor unit as desirable. This did not prove practicable until Apple Computers needed a microprocessor for the handheld device, known as the Newton Notepad, that it was developing. Apple Computers had identified Acorn as a potential partner because they were impressed by the ARM chip. But they did not want to depend on a competitor for the microprocessor for the Newton. Morever, Acorn, as a PC company, had little incentive to provide wider support for their RISC technology. A joint venture was proposed between Apple Computers and Acorn to develop a microprocessor for the Newton notepad. VLSI took part in the joint venture, with Acorn, Olivetti and Apple Computers.[6] Pressures at Acorn had left the market potential of the RISC microprocessor unrealised. But the new venture now had the freedom to leverage the extensive expertise it had inherited from Acorn. As managing director Sam Wauchope explained "It is a bit of a wrench to separate what has been an integral part of Acorn, but we have decided that ARM and Acorn are best served by the creation of a separate company. The deal opens up many possibilities in terms of product development which we probably would not have been able to afford" (Electronic Engineering Times, 14/02/2000).

5.2 Post 1990: Inheritance and spin-off driven speciation

The recruitment of Robin Saxby as managing director of the new company, was favoured by Hermann Hauser, a member of Acorn's Board who had known him at Motorola. The goal of the new CEO was to "address and attack the growing market for low-cost, low-power, high performance 32-bit RISC chips" according to internal documents. On the basis of his experience in the industry, Saxby immediately sought to make the most of the company's limited resources. Saxby had a degree in

[6] Acorn's original expertise and development team was valued at £1.5 million, Apple invested the same amount in cash and each company took 30% of the company's total shares. VLSI invested £250,000 cash for a 5% holding, with the remainder of the shares set aside for future investors, including ARM's employees. The majority of shares were initially held by the partners' shareholdings (Acorn and Apple with 46% and VLSI with 8%). Shares were set aside for further strategic alliances.

electronic engineering and had spent 11 years as marketing and engineering manager at Motorola. He a few years at a smaller company, European Silicon Structure (ES2) before taking over as CEO at ARM. He chose to promote three of the twelve Acorn engineers who had left to form ARM to positions of management in sales, marketing and engineering; they later became directors. Saxby believed it was quicker and easier to teach engineers to sell than to teach salesmen to understand ARM's complex technology. ARM also shared the services of Acorn's company secretary and ES2's financial controller to perform its initial licensing and financial work on a part time basis. In November 1991, ARM released ARM6, the first family of products after the spin-out. VLSI manufactured the processor, which was customized to users' requirements. As recalled by Hauser: "By the time we spun out ARM there was a very well established relationship with VLSI Technology, who manufactured the ARM. At that time we also convinced Apple to use the ARM for the Newton, so there were two built in customers for ARM when we spun it out (the other was Acorn). They made the chips and they sold them to Apple and to us" (personal interview).

The expertise accumulated by the ARM team at Acorn, together with Saxby's vision of defining the global standard for micro-processors for mobile devices, set ARM on a winning course at an early stage. "Saxby's approach of focusing on maximising the available resources to deliver the technology and win business, rather than spending time raising finance, proved to be effective as the small and fast moving ARM became self sustaining by only its second year of operation, without the need for further financing" (ARM, Strategic Report, 1999). Increasing numbers of customers needed low-power consumption microprocessors which offered small size, lower cost and lower power consumption, performance factors which were less relevant in the PC sector.

At this early stage, Saxby was confronted with a variety of possibilities. One option was to merge the business with a semiconductor company and lead a new division that would have financial resources. Another option was to create a semiconductor company that would design and market chips but subcontract manufacturing. Alternatively ARM could have partnered with Apple to drive all future product development. The option that was adopted was to design a base technology and then license the intellectual property (ARM Annual Report, 2005). From Acorn, ARM had inherited a model based not on fabrication but on the contracting out of chips' manufacture. Saxby took the 'fabless model' a step further and decided that ARM would be a "chipless, chip company," their technology enabling microprocessor design by customers.

Saxby decided to avoid the costs incurred in sales and marketing. He reasoned that partnering with semiconductor companies was a better option, since they would bear those costs and deliver chips based on ARM cores. In 1992 GPS became the first independent licensee to manufacture ARM chips, followed by Apple when the Newton was equipped with an ARM6 processor. In 1993 Sharp became the third licensee to manufacture and market ARM processors. As experience increased, ARM offered further services to its clients such us consultancy, feasibility studies, training and prototypes supply.

The learning and experience that ARM was able to gain through these partnerships proved to be significant. When Texas Instruments (TI) took out a license in 1993, its aim was to win the mobile phone business of a relatively unknown Finnish company, Nokia. Though TI had considerable expertise in Digital Signal Processing (DSP), it was relatively weak in the complementary technology for central processing units (CPUs). What they needed was a CPU design that would work reliably in the background, use minimum power, and be well supported with design tools, models and applications. ARM's CPU technology promised to provide that platform, so TI decided to package the ARM design into its overall offer to Nokia.

TI, ARM and Nokia formed a consortium to seek a new solution. This provided an opportunity for ARM to gain a detailed understanding of Nokia's priorities and needs. They found that memory size and the volume of code were viewed by end users as the critical impediments. This gave the company a clear signal: the key to the business of end users was memory reduction. ARM worked with TI to set and meet ambitious targets for power consumption and code size. The outcome was an innovation that became known as the "Thumb" architectural extension which made it possible to use ARM's processor as a programmable tool for developing Complex System on Chips (SoCs). Though the processor was not itself a differentiating feature of their product, customers could use the ARM chip to differentiate their product by developing complex SoCs. This experience taught ARM the value of working with partners and listening to their feedback on its products. The company also realised that end-customers could provide information crucial to product development. The Thumb experience reinforced ARM's approach of working closely with market-leading OEMs as well as their direct licensees - the semi-conductor companies like Texas Instruments - leading to rapid introduction of new product families and parallel entry into new markets (O'Keeffe and Williamson, 2002).

As a result of this new approach, ARM's emerging capabilities enabled it to tap into extensive information and competencies through numerous partnerships with clients. As one of ARM founders explained to us: "ARM, when it's operating properly, should be able to assimilate information about what's happening in the market much more quickly than most companies because bizarrely, it will work with hundreds of competitors […] not competitors to ARM, but competitors to each other and with their customers so (ARM) has an incredible intelligence machine." This intelligence gave ARM crucial indications on the unfolding technological roadmap, helping ARM to foresee new product generations, decide when and whether to shift to new areas, and solve different user problems.

Thus ARM was able to develop products incorporating additional features and instruction set enhancements appropriate to application needs. At the same time ARM maintained a common, general purpose RISC instruction set, which provided code compatibility (Annual Report, 2006). Architectural extensions were introduced in subsequent versions of the ARM architecture, building on the previous architectures, thus adding backwards code compatibility of new processor cores with older generations[7]. As a result of this process, RISC chips that were designed after ARM was spun-out (ARM6, onwards) came to differ substantially from those that had been designed at Acorn, though there was underlying continuity. (The core remained largely the same size throughout these changes. ARM2 had 30,000 transistors, while the more powerful ARM6 increased transistors marginally, to

[7] ARM first development was the next step from the ARM3 processor, which was named ARM6 and included full 32-bit addressing embeddedness support, one of many changes originally requested by Apple in order to use the ARM in planned products. An improved video controller, VIDC20, was also developed and a floating point processor was also introduced. This was followed by a tight sequence of product families matching new segments and applications including the ARM7 family, ARM9 family, ARM9E-S family, SecurCore family, StrongARM family, ARM10 family, ARM11 family, ARM Cortex family, Intel-based products, Marvell Feroceon and Qualcomm Scorpion processor cores.

35,000.) ARM co-founder, Jamie Urquhart, who was VSLI Design Manager when ARM was formed, explained that the main changes in the RISC chip involved altering the processor from a 26-bit address bus to a 32-bit address bus and converting from a dynamic design to a static design. The former change made it easier to program for large applications, particularly when an operating system was used (Apple and Nokia both needed this change). The second change made the design a little more complex and slightly larger but easier to use. The dynamic version required that the clock running the processor never stopped to prevent the processor 'forgetting' its state. Making the processor static meant this restriction was removed and so made it easier to design the processor into complex 'System on Chips' (SoCs). Acorn's chip was designed as a component for their PC product. ARM in contrast offered a set of highly customized processors and supporting macrocells suitable for the use in a wide range of applications. Table 2 provides a summary of differences in the RISC technology.

Table 2 about here

The technology inherited by ARM from Acorn's component chip had the great benefit of requiring very low power consumption. The differences introduced at ARM reflected new technical and product requirements and the recognition of the need for IP protection. The changes required to suit the new application domain facilitated programming and designing systems on chips. A simultaneous change in ARM's business model had a major impact on the industry. ARM was no longer producing a chip for personal computers, but offering customers the capability to design customised, low-power consumption chips for highly integrated applications such as cell phones, personal digital assistants, information appliances and other embedded systems.

In 1993 ARM had 50 employees and £10 million in revenues; 3.5 million chips had been produced with ARM technology. At the end of the same year ARM launched ARM7 in California. At one 16th the size of the Intel 486, the reduced size enabled a price cut to under $50. More significantly, the reduced power consumption meant it could be run off a much smaller battery, strengthening its position as the leading microprocessor for embedded applications. ARM's growth continued to soar during the second half of the 1990s, along with the increase in licensing deals. At the end of 2001, with ARM chips in an estimated 77% of the embedded RISC processor market, they had become the de facto global standard. By December 31, 2006, ARM had £263.3 million in revenues, 1,659 employees and ARM's technology has been licensed to 188 semiconductor companies, including many of the leading semiconductor companies worldwide.

The intellectual property inherited by ARM from Acorn, the 32-bit Acorn RISC Machine, had languished in VLSI Technology's data book as a functional block for ASIC design for several years without evoking interest in the industry. The RISC chip, developed as process innovation at Acorn for their PC product, mutated into a new platform technology, providing a software core on the basis of which customers could customize chip design and apply it to a variety of high volume applications in the wireless, consumer electronics and networking markets. This process was supported by the development of a highly distinctive IP centred business model. "The spin-off ejected ARM into a whole new world of opportunities" (Saxby, personal interview).

Acorn Computers was disbanded in 1997 and part of the company moved into Element 14 (soon acquired by Broadcom), partly in order to realize the value of the shares in the ARM joint venture. This had an impact further afield. Apple Computers, whose share price was at a low point in 1997, was able to mobilize resources to renew its capabilities from the sale of Apple's shares in the ARM joint venture, as Hermann Hauser pointed out (personal interview).

In what follows we present our interpretation of the case and propose the concept of techno-organizational speciation to depict this instance of technological branching enabled by the emergence of a new business model.

6. Interpretation of the case evidence

The Acorn-ARM transition is made up of a variety of strands that include a major change in application domain, a new platform technology, the demise of the parent company and a new business model. The dimensions of speciation identified in evolutionary theory can encompass this diverse evidence in a coherent manner. It is always a challenge to assign actual instances to conceptual categories. It is to deal with this issue that different criteria for distinguishing between species have been proposed, including (1) inter-species incompatibilities, (2) the selection environment of niches or eco-systems, and (3) historical lineage. Dosi wrote that "The .. idea of a technological paradigm should be taken as an approximation, adequate in some cases but less so in others…" (Dosi, 1984, p.8). The same could be said of efforts to categorize 'families' of technological products and to deal with subsystems of technology if there are 'paradigm changes' at some levels but not at others in innovative architectures. Dosi points out that these challenges do not invalidate the use of conceptual distinctions that clarify previously overlooked connections between phenomena. Dosi's rationale applies to identifying a new species of technology.

Unlike the blind determinism of natural selection, processes of technology selection involve learning and deliberate efforts by purposive actors to shape their opportunity space. Nevertheless, concepts developed to address the categorization problems of assigning instances to species in the natural world also provide conceptual grounding for the idea of technological speciation. As we go on to show, a new business design can contribute to this process by providing distinctive technical and organizational features. We refer to this process as techno-organizational speciation.

6.1. Technological incompatibilities and standards

Both biological and technological systems are based on interaction, and consequently incompatibilities can operate to eliminate an idiosyncratic competitor. As a new technology is altered to the point of incompatibility with the originator technology, this brings to an end the design replication process that keeps a technology species extant (Rohlfs, 2001). Acorn's technology had been incompatible with what had become the dominant standard in Acorn's product market, the IBM PC and Microsoft's operating system. Bill Gates had offered to license MS-DOS to Acorn on favourable terms in the 1980s but had Acorn adopted the Intel chip that supported MS-DOS, this would have deprived Acorn of critical experience from the use of their own RISC chip in their products, experience which was to prove so valuable to ARM.[8] The incompatibility of Acorn's products with the IBM's PC and Microsoft's DOS operating system led to unfavourable network effects as these took over as the industry standard, eroding Acorn's market share**.** By the time Acorn was disbanded, ARM's inherited RISC technology had branched away and no longer supported personal computer products.

Hauser later acknowledged that youth and inexperience had limited understanding of the business environment faced by Acorn and recognition of the benefits of open innovation for hardware as well as software: "We thought our wonderful proprietary technology gave us an advantage over competitors, so we bagged it." That is, they refused to license out Acorn's technology. "We should have really analysed how we compared to competing computers around the world. This would have shown us we had a real lead in terms of speed, price, operating system and expansion slots compared to our nearest rivals Apple II and Sinclair Spectrum … We should have gone around the world persuading people to adopt Acorn's products as the industry standard. Then we should have licensed our hardware and software to anyone that wanted them" (*The Guardian*, 2001). Whether or not such an open strategy would have succeeded for Acorn, it became the business model adopted by ARM. The RISC chip design technology licensed by ARM was not for PCs. Instead it offered compatibility with a range of embedded systems as a new technology standard with prospects for much wider diffusion into multiple markets than could be achieved by Acorn's proprietary technology.

6.2. Speciation in new selection environments through niche construction

[8] According to Hermann Hauser (personal communication): "The Bill Gates story is always misquoted. Acorn would have declined much faster had we adopted MS-DOS because this would have meant us to use an Intel microprocessor. It was our use of the ARM that allowed Acorn to survive for 10 years against Intel and Microsoft, because we had better price/performance."

The second perspective on speciation focuses on new species that arise in new niches and ecosystems. ARM succeeded in no small part through niche construction involving interaction with users (Schot and Geels, 2007). How ARM positioned itself within new business niches was revealed by the account of collaboration with Texas Instruments and Nokia. Close interaction with co-producers became as a central feature of ARM's business model. So extensive were the niches created in different sectors through ARM's various partnership arrangements (mobile devices, multi-media, automotive, etc.) that ARM gave rise to what has been described as a business ecosystem of users and suppliers (Moore, 1993; 1996), based on interactive and compatible technologies. This was a result of intended effort as well as exogenous constraints. ARM's latest processor had been destined for the Newton Notepad developed by Apple, but this product was not adopted by consumers. "We have to find a way to turn our enemies into friends" Robin Saxby had declared. In achieving this conversion, managers at ARM positioned the venture to grow in expanding markets for embedded devices, a much more munificent environment than the intensely competitive market for PCs and hand held computers.

To increase the chances of favourable selection, ARM garnered insights and knowledge through partnerships and licensing agreements worldwide. Unlike the usual bilateral relationships with lead clients, ARM developed close relationships not only with the big chip manufacturers, but also with their partners' customers. Learning of this kind engendered a structure of coordination practices (Kogut, 2000) that translated into effective knowledge-sharing (Dyer and Singh, 1998). The role of teacher and student shaped ARM's partnering relationships and thereby created barriers to potential competitors (Arino et al., 2001). This was how ARM moved from constructing favourable niches to creating a business ecosystem for the users of their micro-processing design tools, aided by the massive growth in demand for embedded devices, especially mobile phones. Companies like Nokia were able to use ARM's processor to develop complex systems on chips run on the client company's chosen software. "ARM created an ecosystem for companies that needed chips for embedded devices" Urquhart explained (personal interview). In contrast with Acorn, whose increasingly marginal technological design lost ground in the PC business ecosystem, the global standard created by ARM in microprocessor design for embedded devices grew to be a dominant standard and compatibility with a wide range of applications promoted its further expansion.

6.3. Historical lineage and techno-organizational speciation

Historical lineages and their continuities have been the focus for a third approach to speciation. Central to evolutionary processes are interactors that replicate the design they embody, or alter it by chance or intention (Beinhocker, 2006). Through the reproduction of designs, lineages of replicable knowledge develop among technologies and among organizations and are discontinued if a knowledge base falls into disuse.[9] In the case history examined here, there was critical continuity in the inherited technological design but a complete break in business model design between parent and progeny. Technological differences were at first relatively minor as between the ARM chip used by Acorn and that launched by ARM, initially involving the processors' bus address design and clock. But these and the further changes undertaken were crucial for adoption in new markets.

ARM's new business model was of particular importance because prior to ARM's success it was doubted whether licensing a technology could bring in sufficient revenues to support a new company. ARM's business model involved the company in co-production activities with customers and the ability to maintain relational continuity by building and sharing a development road map: "It's not just a licensing business, it's a road map. It's investing in a future. And that comes back to the shared destiny point. Again, it is partnership….as long as ARM can keep evolving and in a way bring value to its customers, it earns its roadmap and so it has value". (Urquhart, personal interview). A business model favouring a distinctive pattern of alliances with lead clients (von Hippel, 1986) has significant strategic advantages for resource-constrained new ventures in networked industries which must rapidly reach a threshold in scale and market share to avoid unfavourable network effects (Lorenzoni and Baden-Fuller, 1995).

[9] Organizations can be viewed as interactors that carry and activate knowledge embodied in specific technologies while organisms are interactors (phenotypes) that carry and express genetic information.

Certainly there was lineage continuity between the two companies. Indeed ARM was favoured with a uniquely valuable set of endowments from Acorn: (1) a core technology that was proven and protectable, removing the need for speculative, time consuming R&D; (2) a generic technology in the form of platform microprocessor; (3) team continuity in the 12 engineers from Acorn who founded ARM;[10] (4) immediate custom and revenues from Acorn Computers. Nevertheless, in support of the idea that practices in the company of origin can exert an unfavourable influence on the spin-off, ARM deliberately broke with the way many things had been done at Acorn. Here ARM benefited from the input of managers recruited for experience and skills achieved elsewhere.

These outsiders abandoned Acorn's practice of avoiding the expense of patenting. Part of the strategy as the company moved forward was to develop a roadmap that included patentable IP and programs were put in place to reward engineers for the creation of relevant, patentable ideas. Acorn's aim to turn a proprietary standard into an industry standard without licensing or partnerships was abandoned. ARM's new managers fostered a much more commercial culture while building on Acorn's commitment to technological excellence. Thus a component technology from an unsuccessful product was inherited from the parent company and transformed into a new technological species, enabled by distinctive organizational arrangements and new forms of business partnering. This change was not the result of a revolutionary upheaval in technology but emerged gradually from its antecedents and as a result of different selection pressures operating in new niche domains (Basalla, 1988).

7. Conclusions

The concept of speciation has helped us to interpret the case evidence on innovation and to identify strong and recurrent causal currents amid the eddies of detail. Three perspectives on speciation derived from evolutionary theory were found to illuminate case evidence. The study focussed (1) on boundary constraints on technological replication; (2) on new variants arising in new niches and ecosystems, and (3) on common lineages of design and replication. Empirical evidence thereby interpreted provides

[10] Virata, a successful spin-off from another spin-off from Acorn, Olivetti Research, also met the conditions of having a proven, protected and generic technology applied in a high growth market (for Internet connection), a different domain from that originally envisaged. Licensing models without such positive attributes are less likely to succeed.

theoretical grounding for the concept of techno-organizational speciation. This requires analysis at the level of the organization's business model. The importance of business model innovations is increasingly recognised (Chesborough and Rosenbloom, 2002, Beinhocker 2006). Bit the concept of business model has not yet been assimilated as a construct in evolutionary theory which still depends on the notion of routines (Nelson and Winter 1982). A business model amounts to more than a collection of routines. A business model can be thought of as a design that specifies how a firm is connected to others in its ecosystem in order to create and capture value. A business model is a design which can be operationalized in practice and which may be wrought as a response to experience, as occurred at ARM, or be developed ex-ante. The links between business model and co-evolutionary processes are apparent when the firm's business model is conceptualised as a design for creating value for customers and capturing value from its economic activities (Lim et al., 2006). The business model, endorsed by the firm's Board and operationalised by its management, guides the allocation of resources and specifies the ensemble of routines needed for value creation for customers and value capture for the firm and its investors. Sustained value creation and capture (Bowman and Ambrosini, 2000) are the goals of business organizations. ARM's business model secured value for customers through co-production and other forms of collaboration with suppliers and resource providers. The firm's strategic positioning in the fragmented semiconductor value chain gave it a system integration role, as an IP and system support provider, that enhanced value capture for the firm and its investors. Techno-organizational speciation occurs when a firm reorders the way in which it creates and captures value, that is, alters its business model, in launching a new type of technology.

The key reason for the branching and diversifying of the technology revealed here was the branching and diversity of the firms that were the agents of change. This idea is intuitive when firms are seen as incubators and carriers of technologies (Rosenberg, 1994) as they move technologies into new domains of application through entrepreneurial spin-off. But the idea is not obvious when speciation studies focus on incumbent firms. Spin-off studies, on the other hand, have not addressed the issue directly. These two strands of research, on speciation in incumbent firms and on spin-off, when brought together, illuminate the speciation process and show how it involves continuity alongside discontinuity.

Discontinuity is seen when a new company finds its own direction, informed by knowledge and experience from elsewhere, free to adapt to the new environment and explore market prospects (Chesbrough, 2003). This involves abandoning inappropriate practices in the company of origin (de Holan and Phillips, 2004; Nystrom and Starbuck, 1984). On the other hand, continuity helps to overcome the liabilities of newness, as identified by Stinchcombe (1965). This has implications for technology strategy. While advice on corporate venturing recommends launching emerging and unproven technologies in a separate venture (Christensen, 1997), our evidence demonstrates a different set of benefits from spinning out a proven technology, nurtured within a parent company, so that the venture can launch its variant of the technology in new domains without the risks and costs of speculative, pre-competitive R&D. The liabilities of newness can be greatly reduced when a proven technology is applied in a new domain (Garud and Nayyar, 1994). This is a promising theme for further inquiry.

The Acorn-ARM story sheds light on the more general problem of how to preserve and safeguard knowledge with high technological and wealth creation potential, the value of which cannot be fully anticipated ex-ante (Garud and Nayyar, 1994). By the time the ARM spin-off took place, Acorn had already taken a downward path which would eventually lead it to its dissolution. Without the successful spin-off of ARM, a valuable legacy of know-how that generated wealth and technological progress might have been lost. The role of progeny in preserving important knowledge threatened by the closure of parent firms is an area for further inquiry that has important policy implications. As noted by Hoetker and Agarwal (2007: 462) "To the degree that knowledge languishes after the demise of the innovating firm, other industry participants and society at large lose the benefit of a potential source of technological progress". By the same token, an apparently unsuccessful company may make an important contribution to the economy through its progeny. What is noteworthy in this case was the way competencies developed at Acorn were preserved and enhanced even after its demise. This raises a new research agenda around firm reproduction and the preservation and transfer of knowledge after firm closure.

We have found that consequences and mechanisms of speciation include the following. (1) Techno-organizational speciation has lasting consequences when it launches a technology that becomes a dominant standard compatible with multiple applications. (2) This can be achieved through multiple niche creation, from which develops a new business eco-system. (3) There is a complex interplay between inherited knowledge and new learning, manifest in a firm's technological and organizational lineage. By such routes, inter-generational transmission among firms is a crucial source of the branching and diversifying of technologies that shape industrial structure and economic change.

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Table 1
Interviews

Interviewee	Role	Interviews	Interview year
Hermann Hauser	Co-founder, Acorn	5	1986, 1987 1988, 2004, 2005
Andy Hopper	Co-founder, Acorn	2	1988, 2005
Chris Curry	Co-founder, Acorn	1	1986
Peter Wynn	Acorn, Financial Director	1	1986
Jeff Tansley	Technology Manager, Acorn	2	1988
Jim Merriman	Chief Operating Officer, Acorn	1	1988
Brian Long	Managing Director, Acorn	3	1988
Sam Wauchope	Managing Director, Acorn	1	1990
David Lee	Managing Director, Acorn	2	1999
Sam Boland	CEO, Acorn	1	2001
Malcolm Bird	Technology Director, Acorn	3	2004
Alex von Someren	Acorn engineer, wrote 1993 ARM RISC Chip Programmer's Guide	1	2004
James Urquhart	VLSI Design Manager, Acorn; Co-founder and Chief Operating Officer, ARM	2	2006, 2007
Robin Saxby	Co-founder and CEO, ARM	3	1995, 2005, 2006
Ian Phillips	Principal Staff Engineer, ARM	2	2006, 2007
Elserino Piol	Deputy Chairman, Olivetti	2	2005, 2006

Table 2
Key technical changes between ARM 1/ARM3 at Acorn and ARM 6 onwards at ARM Ltd.

	Acorn	ARM Ltd.
Address bus	26 bit	32 bit
Design	Static	Dynamic
Instruction execution	32-bit	16-bit (Thumb)*

* Thumb takes 32-bit instructions and compresses them to 16-bits. This innovation enables programs to be coded much more densely than standard RISC instruction sets (the code size is reduced by 30% at no cost to performance) and to cut some portions of the hardware considerably in size. Processors making it possible to take advantage of Thumb also allow 32-bit instructions to run on the same processor. 16-bit and 32-bit instructions can be mixed together and the hardware will be able to decode and decompress at the same time without a performance hit, thus maintaining powerful computing capabilities. Cost is minimized by having a simple, small structure with many configurations available.

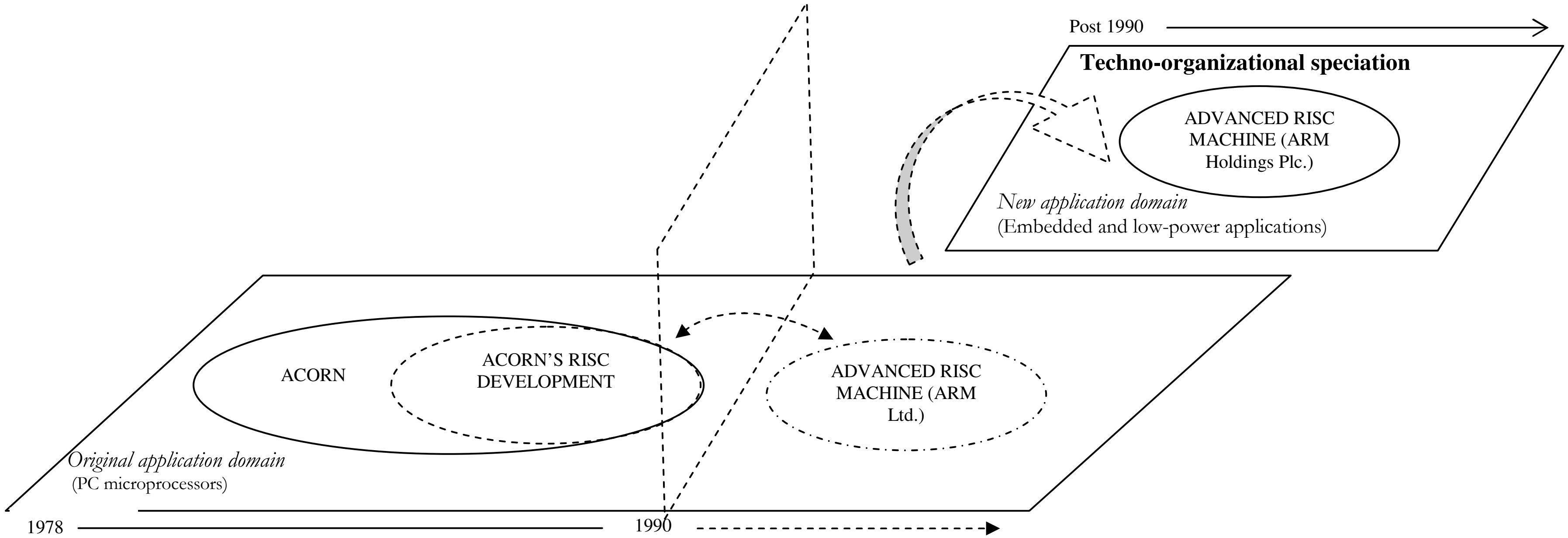

Fig. 1. From Acorn to ARM: the speciation process