Capability building and risk management in commercialisation: lessons from Radiata. Innovation: Management, Policy & Practice. Vol 9 no. 2

Article *in* Innovation: Management, Policy & Practice · January 2007

 Innovation: management, policy & practice (2007) **9**: 170–180.

Capability building and risk management: Lessons from Radiata

SUMMARY

This paper examines the wider lessons to be obtained from the story of the CSIRO-related start-up company, Radiata Inc. It shows how CSIRO's sustained trans-disciplinary capability-building efforts in radio-astronomy helped to produce a generation of electronic engineers well-versed in cutting-edge integrated circuit design and development who were also able to work effectively in commercial environments. Collaboration between radio-astronomers and engineers continued to develop via joint CSIRO-Macquarie University work examining wireless Local Area Network solutions based on mathematical techniques used in radio-astronomy and utilising state-of-the-art chip design methods. This work culminated in the formation of Radiata Inc. and its subsequent acquisition by Cisco Systems in 2001, to be followed by Cisco's withdrawal from wireless chip development in 2004. The paper considers the wider implications of this story, highlighting the importance of trans-disciplinary capability-building to increasing the odds of success in the risky process of innovating. It concludes that CSIRO should continue to develop its options-based approach to valuing R&D outcomes in order to better demonstrate the ways in which capability-building can generate improved odds of success in innovation for a wide range of businesses – provided that they have access to the skilled staff generated by this type of 'rounded' training related to basic research.

KEY WORDS

Radiata; capability-building; innovation; networks; risk; astronomy; semiconductors

Mark Matthews
Executive Director
Forum for European–Australian Science and Technology Cooperation (FEAST)
Australian National University
Canberra ACT, Australia
and
Adjunct Associate Professor
Department of Engineering
Australian National University
Canberra ACT, Australia

This paper considers the role played by CSIRO in the story of the well-known spin-off firm, Radiata. The paper tells a fairly technical story in order to communicate an important message to policy-makers. This message is that *long-term capability-building involving close links between blue-sky research and engineering design skills can be extremely valuable.* The paper explains how strategic decisions about post-graduate research training and research investments made by radio-astronomers in CSIRO in the 1960s helped to generate some major commercial outcomes some thirty-years later – notably the formation and sale of the company Radiata Inc. to Cisco Systems Inc. for a substantial amount of money.

The story told here covers technical issues because these are critical to understanding what capability building means *in practice* – beneath the rhetoric that can characterise policy debates over research commercialisation. The paper draws heavily upon a more detailed paper prepared for the Australian Government Department of Education, Science and Training (Matthews and Frater 2003). The names of individuals are intentionally omitted because specific recollections differ between members of the 'community of practice' involved and it may be unfair to name particular individuals in the context of this group-based activity that extended beyond CSIRO per se. The fact that patent infringement litigation is currently taking place reinforces the need for anonymity.

The lesson for policy-making in general, and for CSIRO's future mission in particular, is twofold; first, that this type of long-term capability building generates important option-values as a by-product of blue-sky research and, second, that these options can only be exploited if the necessary engineering and investment risk management skills linked to international networks of 'communities of practice' are also available. The inter-dependence between option values and commercial acumen complicates policy-making designed to encourage 'research commercialisation'. Whilst it is necessary to protect the intellectual property (IP) that arises from publicly-funded research, not least because businesses may appropriate and suppress potentially useful technologies if they threaten the value of corporate balance sheets, there is a significant difference between formal IP protection and extracting significant value from this IP. Consequently, policy-making would benefit from a more nuanced and less prescriptive association between formal IP protection and extracting value from IP.

Innovation capabilities and collaboration between radio-astronomers and electronic engineers

Pushing the scientific research frontier in radio-astronomy involves advancing the technological frontier in radio signal capture and in signal processing. This means stretching the range of frequencies over which signals can be captured and developing methods for distinguishing between signals and background noise. The application of these methods outside radio-astronomy encompasses industrial applications, satellite-based communications, mobile phones and short-distance applications such as wireless Local Area Networks (LANs). These applications require further advances in antenna technology, microchip technology, mathematical applications and other areas.

The close coupling of the technologies used to improve radio-telescope instrumentation capabilities and commercial/defence applications has long been recognised by the radio-astronomy community in Australia and goes beyond simply being receptive to the notion that commercial spin-offs may occur from this R&D work. It extends to a more strategic recognition of the value of building close linkages between the companies that are able to develop and provide critical instrumentation technologies and the R&D, and research training, carried out in order to support radio-astronomy. This results in a system of academic–industry linkages that, from the 1960s, has been far more symbiotic than the simplistic 'linear model' of how basic research translates into industrial applications. The scientists and engineers involved in these capacity-building efforts in blue-sky research recognised that close links with electronics companies could also help to build and sustain a competitive electronics industry in Australia. At that time, radio-astronomy required inter-disciplinary skills in order to design and develop custom microprocessors to handle cutting-edge signal processing challenges and these trans-disciplinary skills had general relevance to industry.

As a result, radio-astronomers have deliberately created an environment for carrying out doctoral research that challenges students to deal with complex projects in which they must deploy leading-edge scientific and engineering skills in order to solve real-world technological problems if they are to carry out blue-sky research. These long-term training strategies did not have particular end-results in mind but sought to create a better *capacity* to carry out research and innovation in this field.

The core of the story told in this paper is the use of the *Fleurs Synthesis Telescope* (FST) as a basis for doctoral research training that focused upon real-world radio-astronomy challenges. Several leading figures in Australian (and subsequently global) electronic engineering carried out their doctoral research on the FST within CSIRO. The FST was subsequently taken over by the School of Engineering at the University of Sydney which continued the work. Use of the FST as a focus for 'rounded' doctoral research training had its precursor in the work carried out on the Mills Cross radio-telescope at Hoskinstown in NSW. Following this experience, CSIRO was persuaded to hand over an old field station at Kemp's Creek to the University of Sydney. This became the FST. The FST doctoral experience has produced cohorts of engineers who subsequently went on to work overseas, particularly in Europe and the United States.

CSIRO's Very Large Scale Integration (VLSI) Program was launched when some FST-trained researchers with US experience returned to Australia. The VLSI Program was critical to the development of a key element of the Australia Telescope, known as the Correlator Chip. The Australia Telescope's requirements set a substantial challenge for the VLSI Program because it required putting 100,000 transistors on a chip, at the time an ambitious goal, and making specialised chips for comparing, synchronising and then multiplying signals from different radio-telescope antennae. These chips performed multiplications at 1GHz. The Australia Telescope provided the essential user-focus and first customer for this R&D work and, as a result, enhanced Australia's capacity to design VLSI chips.

In 1984, the CSIRO VLSI Program was spun off into a company called AUSTEK Microsystems. Austek collaborated with CSIRO Radiophysics researchers in an IR&D Board-funded project to produce a 'Fast Fourier Transform' (FFT) chip, subsequently commercialised by AUSTEK Microsystems. This experience at AUSTEK contributed to Radiata's success. AUSTEK also supplied the FFT chip initially used by the bionic ear company, Cochlear, widely regarded as another Australian technology success story.

One other spin-off from applying the FFT chip technology was the formation of Lake DSP in 1991. Lake developed the technology used to produce surround sound in headphones, a technology subsequently licensed to Dolby Laboratories (Lake's first customer) in 1992 and made available on long-haul aircraft following a commercialisation agreement with Dolby Laboratories signed in 1998. Lake DSP continued to work with Dolby, who eventually acquired Lake over the period 2004–5.

The final aspect of the 'precursor' capability-building activities to note is the establishment and continuation of CSIRO's work on Gallium Arsenide chip technology when this became unfashionable. In the 1980s, CSIRO had accumulated extensive expertise in designing microwave circuits using Gallium Arsenide chips. Leading US R&D operations such as Bell Labs were understood to be pulling out of research on radio chips and the decision by CSIRO to continue with the Gallium Arsenide (GaAs) R&D in relation to microwave/radio applications caused some criticism within the organisation as this appeared to be against the tide of global R&D. The advocates of using GaAs technology successfully argued that there was an established technological trajectory of performance improvement associated with Moore's law.[1] When these expectations were factored into the analysis, the medium-term potential of GaAs technology was still promising because Silicon chips could not at that time attain frequencies as high as those attained by GaAs chips. The decision to continue with the R&D in GaAs and antennas in the late 1980s made this expertise available for the development of the demonstrator microprocessors that would subsequently assist in the wireless LAN work. CSIRO's GaAs group continued to develop research instrument applications for the Australia Telescope.

This complex chain of precursor activities was focussed around the dual objectives of improving radio-telescope performance whilst also developing the industrial capacity to provide the technologies necessary to achieve the scientific objective. The strategy was long-term and less explicitly aimed at specific commercial outcomes than at pursuing a process of 'learning-by-doing' in chip design that would generate a wide range of options for future exploitation. What stands out is the strong priority placed upon capability-building linked to the trans-disciplinary skills required to do cutting-edge radio-astronomy – a classic blue sky basic research activity.

Radiata story

There are two dimensions to the innovation process that resulted in the development of effective wireless Local Area Network (LAN) technologies. Firstly, growing generalised awareness of the market potential for wireless LANs. Secondly, specific ideas on how to solve the technical challenges – the notion that the 'Fast Fourier Transform' (FFT) techniques used in radio astronomy could provide a solution to the challenges of developing wireless LAN solutions.

The underlying assumption amongst electrical engineers keeping abreast of wireless LAN thinking in the late 1980s was that short distance wireless communication could be a major market area in the future as various users of electronic equipment sought to maximise the flexibility and interconnectivity of different types of device. These were pervasive technological expectations in the ICT industry – in the mid-1980s both Apple Computer and Hewlett Packard produced corporate videos depicting future computing environments as wireless environments (Skellern 2001). The technical challenge was that signals used for wireless communication in the available frequency ranges bounce off the walls, floor, ceiling and furniture, creating a highly complex three-dimensional system of interfering pathways between the transmitter and the receiver. Each packet of information travels a different distance between the transmission source and the receiver and consequently arrives at the receiver at a slightly different time. This has the same sort of message corrupting effect as the 'ghosting' (duplicated weaker images) in television pictures caused by integration of signals bounced from nearby buildings.

The idea that 'Fast Fourier Transform' (FFT) techniques could provide a means of overcoming some of the many technical challenges faced in LANs originated from radio astronomy R&D. FFT is a mathematical technique used in radio astronomy that allows signals to be divided up, transmitted, and re-combined in such a way that the complex interactions and interference effects can be handled. Orthogonal Frequency Division Multiplexing (ODFM) is the term used to describe this application of FFT. It is understood that in the early stages of the CSIRO–Macquarie University project the CSIRO Radiophysics team put forward the idea of creating wireless broadband networks by using FFT techniques to divide up the spectrum in a way that handled the complex reflections found inside buildings. At a time when CSIRO was re-structuring to provide an increased focus on applicable research in telecommunications (signal processing, wireless communication and imaging work) in collaboration with the team of electronic engineers at Macquarie University, this use of FFT was a pragmatic approach.

CSIRO decided to fund some exploratory work on the use of FFT in wireless LANs, initially providing around $200,000, subsequently increasing to nearly $1m in a follow-up project. A relatively high carrier frequency of 60 GHz was initially selected because CSIRO's existing expertise lay in radio astronomy, and microwave landing systems, that operates in this high frequency range. A joint CSIRO Division of Radiophysics and Macquarie University Department of Electrical Engineering 'Program for Local Area Networks' (PLANS) started in 1990 with a target of developing 100 Mbit/s indoor wireless networks (Skellern 2001). The team at Macquarie University worked on the design of chip design, network and decoder. A joint research centre linking these two organisations was formed in 1993.

The mid-1990s were a difficult period for the joint research centre. IBM pulled out as a partner (for reasons that are not documented) and the Europeans selected a wireless LAN technology different from the one Australians were developing (initially not based on ODFM). As the head of CSIRO's Division of Radiophysics at the time observed, '*There was mounting opposition within the CSIRO division to even continue with the project.*' The joint research team's response to this uncertainty was to proceed with a CSIRO-funded demonstrator project within Macquarie University to counteract the growing scepticism over the attractiveness and the feasibility of this technological solution. The research was also supported by Australian Research Council (ARC) grant funding to Macquarie University for infrastructure provision.

By 1995, an ODFM system able to overcome the problems faced in an indoor environment emerged. The researchers in the joint research centre published their work (see for example Skellern et al. 1995). The fairly high level of disclosure of information suggests that consideration of any commercial applications would rest upon more tacit and proprietary capability to engineer the solution within the demanding cost, power and heat generation parameters.

A patent application had been filed in 1993 and in 1995 US patent for a wireless Local Area Network (LAN) was granted and assigned to CSIRO by the inventors. Given the importance of tacit knowledge and speed to market in the electronics sector, obtaining a patent was not, reportedly, viewed by the researchers as a major priority at the time (Cooper 2001). Indeed, only one of the inventors named in the patent subsequently became involved in forming Radiata. The CSIRO patent describes in some detail the rationale and circuit design details required to transmit data in a wireless LAN and makes 72 specific technical claims. CSIRO decided to license the technology on a non-exclusive basis. The CSIRO patent is fairly broad in scope and covers 802.11a, 802.11g and 802.11j wireless LAN standards, making it potentially valuable in this growing market.

During the initial period of wireless LAN technology development, one of Radiata's founders was working in the United States. In 1998, CSIRO and Macquarie University created an attractive half-time position at the University in order to lure this well-regarded microprocessor designer back to Australia. At that time, there was a vague notion to form a company at some point to exploit opportunities in the wireless LAN field but this was not a major motivation for attracting him back to Australia. The funds to bring him back as a professor were provided by CSIRO via the joint research centre.

Once established at the University, the new recruit put in place some of the people and equipment required to make a commercial excursion into chip design. This involved a move into commercial Computer Aided Design (CAD) tools and CAD tools worth US$6m were supplied by a US CAD company at zero cost, a deal made possible through personal contacts. A deliberate effort was made to target circuits of potential interest in developing wireless LANs. A team was trained in how to use this CAD equipment (Weste 2002).

Radiata Inc. was formed in 1997 in response to the market potential created when the 5GHz-based spectrum for wireless LANs became available as part of the *US National Information Infrastructure* (NII) policy initiative which made the 5GHz part of the spectrum available for schools to connect to the Internet. This was important because the 5GHz range is relatively un-congested whilst Bluetooth, which operates at 2.4GHz, shares spectrum with cordless telephones, microwave ovens and devices such as baby monitors.

The parent company was incorporated in the US State of Delaware but then established as an Australia-based R&D operation, Radiata Communications Pty Ltd, and a California-based sales and marketing operation known as Radiata Communications Inc. Radiata's intellectual property (IP) was generally related to IP developed at the joint CSIRO–Macquarie University research centre but the company's informal IP (know-how) included substantial accumulated expertise in designing different types of integrated circuits. Arrangements for handling IP in the joint research centre specified that developments would be shared jointly by the two parties. However, some specific elements of the technology licensed to Radiata involved a deal solely with CSIRO. This was because Macquarie University had no specific rights to the wireless LAN patent. It is plausible that the licence arrangement with CSIRO, rather than a more direct involvement, was beneficial to all concerned because time to concluding subsequent deals would have been longer if CSIRO's stringent time consuming legal processes had been on the critical path.

Shortly after Radiata had been formed, the new IEEE 802.11a standard for 5GHz wireless LAN networks was defined and seemed to represent a potentially lucrative market. Despite it being unclear how to address this standard in detailed technological terms (particularly in relation to a small, low power consumption solution), the existence of a new international standard for wireless LAN communication at 5GHz had a significant impact in reducing the investment risks faced in the commercialisation process. IEEE 802.11a defined the key performance parameters for the engineering decision-making process and this tight focus reduced the range of potential technological options to be considered and the scope and complexity of the engineering trade-offs faced.

The collaborative work between CSIRO and Macquarie had been directed towards 60GHz mm wave length radio-frequency solutions using Gallium Arsenide (GaAs) technology. The new 5GHz opportunity lowered the bar for the R&D effort, although the initial response was still that a GaAs solution should still be sought.

The Radiata team had the credibility required to interest external investors, whether these were ICT companies or venture capitalists. It is important to note here that membership of the US-based electronic engineering 'community of practice' was one of the critical elements in the success of Radiata as this network provided the connections between influential people and the trust critical to investors' capacity to judge the degree of risk they face. Risk reduction is particularly important for innovators outside the core of the world ICT market and the hub of corporate venture capital finance – the US. One of Radiata's founders had spent most of his career in the US and had taken up US Citizenship (a significant factor to US-based investors).

Bringing investment banking experience into the Radiata team also proved critical to reducing the perception of investor risk, as was the tactic of making clear statements over the milestones and other targets that the engineering team intended to hit and then making every effort to meet these targets. This pragmatic strategy enabled Radiata to feed project management information back to potential investors in a timely manner. Again, this deliberate effort to drive-down perceptions of investor risk was critical to the eventual success of the venture. Weak engineering capabilities risk setting unfeasible targets in order to 'look good' and subsequent failure to meet these targets may backfire on the project, so the strategy followed in the Radiata case only worked because the team actually had the engineering capability to perform as stated.

Blind alleys were nevertheless followed in the engineering design process and the risk of failure at an engineering level was present for a considerable time during the innovation process. Radiata obtained an IR&D Board R&D Start grant of $750,000 in September 1998 on the basis of a contract with the US company M/A-COM to develop a radio-based wireless LAN 'radio' chip for the firm. The R&D Start grant was critical in two respects. Firstly, it allowed the company to take on its first employees and gain some critical mass. Secondly, it prevented the firm being forced into a deal with a venture capital company, which would have almost certainly led to a loss of effective control in terms of tactics and strategy and would also have diluted the equity held by the founders and other employees.

A whole year was spent working on the M/A-COM radio contract. The radio was completed by M/A-COM in 1998 but it never worked effectively and left Radiata with a major problem. As an interim solution, Radiata asked CSIRO Radiophysics to produce the radio part of a demonstrator chip-based design to operate at 5GHz in order to have something to use in Radiata's marketing efforts. The CSIRO radio chip was never used directly by Radiata but it did contribute to forming useful ideas about the ways to proceed in the design effort.

What emerged was a less than ideal solution but the story illustrates the technical difficulties often encountered. CSIRO produced the radio element of the demonstrator for Radiata by drawing in part upon the Gallium Arsenide (GaAs) technology then being used as part of radio-astronomy work. Until this point, Radiata's preferred design solution included two chips: a radio chip (via the M/A-COM contract) and a modem chip to be developed by Radiata, reflecting known territory for the Radiata design team. Growing awareness that competing 2.4GHz Bluetooth solutions were moving towards low-cost single chip designs and the failure to develop a separate effective radio chip forced a change in strategy to meet 802.11a: a single chip solution at low unit cost. The team had no idea how to achieve this objective but the single chip target helped to focus the next phase of their engineering effort.

Work started on designing two complementary chips in 1999 (a modem and a radio-frequency chip) with the new aim of a fully integrated design. The low-cost design parameter led to a shift in focus away from a GaAs chip and toward a Complementary Metal Oxide Semiconductor (CMOS) solution that would be relatively cheap to produce. The other chips that operated in this frequency range used Gallium Arsenide (as used in CSIRO's demonstator chip), Silicon Germanium (SiGe) or Silicon-on-Insulator (SOI) technologies but all of these are more expensive to produce. The design objective for Radiata evolved to finding a way of solving the complex set of small scale high frequency problems that arise when a CMOS chip is used at the smallest possible fabrication geometries and also incorporates a microprocessor operating at 5GHz. This combination creates operating constraints that must be addressed by developing algorithms and filters able to adjust for the problems encountered. The major design trade-off was that the more complex the engineering solution used to counter-act the problem of small-scale high-frequency operation, the higher the power consumption, the larger the size of the device and the greater the heat generated. The design therefore had to find elegant ways of filtering signals that did not involve numerous filters. The eventual solution used on-chip devices then rarely integrated into radio-frequency chips because of difficulties in making them perform in a stable manner in such a small-scale high-frequency environment.

The value of the capability possessed by the Radiata team lay in the ability to design complex chips without incurring prohibitive design and development costs. Few companies in the world were able to cope with such severe challenges – which have been compared to the equivalent of 'writing a million line computer program, running it for the first time and never having a single bug' (Weste 2002). If a chip does have design faults, the chip test fabrication runs required to test whether these design problems have been eliminated can quickly bankrupt a company or delay time to market. The source of competitive advantage in the Radiata case therefore lay in possessing the tacit knowledge required to design error-free chips with a minimum number of re-design loops. At that time, a test run of CMOS chips cost $0.5m (closer to $1m today) and a full re-work of the design would cost as much again and take from three to six months. If the re-work of the design only required smaller modifications to the mask used to produce the chip in order to eliminate a few specific bugs the costs stood in the region of $100k to $200k and would take around one month to complete. Design modifications aimed at enhancing performance in a bug-free chip have a similar cost to minor re-designs. To the limited extent that there are industry benchmarks for the number of design iterations required to get the design right for this type of chip (companies are reluctant to reveal such data) the norm at the time was around seven iterations. The unusually advanced design capability of the Radiata team was therefore a major intangible asset.

Radiata's experience included the formulation of a set of good practice guidelines for the chip design process based upon precursor chip design work at AUSTEK Microsystems. Radiata started its design work with the benefit of this substantial accumulated experience of how best to organise the flow of work required to design a CMOS chip. Although radio-frequency (RF) chip design was new to the team's members, they applied the same basic design flow methodology that worked in CMOS design. It should also be noted that Radiata hired a top flight RF systems engineer with GaAs experience from his PhD. This expertise in radio architecture in association with his coming up to speed in CMOS design made the radio possible.

As work continued on the two chip design solutions throughout 1999, it became clear that a one-chip solution was theoretically possible and the task shifted to making it work in practice with a favourable cost profile. During much of this period Radiata was renting space from CSIRO. The ability to 'trouble-shoot' technical problems in RF design by discussing them with nearby CSIRO researchers and using CSIRO's diagnostic equipment when the company only consisted of some six staff and possessed limited equipment of its own was very useful.

As the work aimed at producing a single radio-frequency chip and modem chip solution proceeded, the importance of technological expectations as a basis of competitive advantage started to become apparent. The dominant radio-frequency chip paradigm at the time was associated with GSM chips for mobile phones. These required far higher resolutions in signal processing than the shorter-range LAN 'radio' single-chip solution being pursued by Radiata. The engineering trade-offs are significantly different for GSM and wireless LAN chips. Competitors with considerable GSM chip design capability found it difficult to grasp that it might be possible for Radiata to meet LAN objectives because GSM engineers approached the problem with far higher tolerances. Radiata had set out to develop crude short-range radios on a chip, not sophisticated ones, and was able to gain competitive advantage in the face of very powerful competition simply because it realised that it was operating with different technological expectations.

A business relationship had started to develop with Cisco Systems, essentially based upon the Radiata engineering team being goaded by Cisco executives to prove that they had a potentially viable technological solution to the IEEE 802.11a challenge. It later became apparent that Cisco had in fact been keeping a close watch on the Australian research since 1992 (Cooper 2001). The dialogue with Cisco eventually involved an invitation to meet Cisco's key expert in this area to try to convince him of the viability of Radiata's approach. When this gatekeeper had been satisfied that the solution was viable, Cisco moved quickly to take an 11 percent stake in Radiata, with an identical stake being taken by the chip fabrication company, Broadcom, with whom Radiata had been negotiating in parallel with Cisco. From Radiata's perspective, the negotiations with both Cisco and Broadcom were useful because both possessed non-overlapping complementary capabilities.

The 802.11a compliant chip was completed and demonstrated at a major international exhibition in September 2000. The R-RF5, as it was called, could handle transmission rates sufficient to send full motion video via the wireless LAN. At that point six large US companies are reported to have made direct bids for Radiata. At the same time, Radiata realised that alone it did not have the financial resources required to proceed through the next stage of the innovation process – inventory costs were escalating and establishing a new distribution network was becoming a costly challenge.

When searching for substantial 'Stage Two' funding, Radiata initiated discussions with venture capital companies in both Australia and the US, together with established industry players. The existence of the Cisco and Broadcom stakes is reported to have discouraged Australian VCs. Radiata had approached Cisco as they already had an 11% stake holder and Cisco's bid of AUS$567m (US$296m) was accepted on 13 November 2000 with the deal finalised in January 2001. When the Cisco bid was accepted Radiata had 53 employees and all held stock in the company.

Three years later, in January 2004, Cisco announced that it was winding down the development of its 802.11a wireless chipsets based on the Radiata technology. The reasons given were that newer Wi-Fi standards had become more important and that, as the market for wireless chipsets had matured to the point of becoming 'commoditised', it was no longer necessary to possess internal design capability in that area (Reardon 2004). It is also worth noting that the Stanford University start-up Atheros had beaten Cisco to market with their 802.11a chips, apparently because the need to comply with Cisco's stringent design quality assurance processes had slowed the Radiata team's progress (Skellern 2001).

Patent infringement litigation initiated by CSIRO has been developing in parallel to these events. If CSIRO is successful, over 100 companies could be forced to pay CSIRO royalties relating to the use of chips that comply with the 802.11a and 802.11g IEEE standards covered by the CSIRO patent (and indeed possibly the new 802.11n standard because this also uses the ODFM technology covered by the CSIRO patent).

It is inappropriate to comment on this ongoing litigation, except to highlight two issues. Firstly, substantial financial resources are required to defend IP (supporting the argument for the critical mass in R&D provided by CSIRO). Secondly, there are complex, and potentially problematic, relationships between IP rights and the design of IEEE (and other) technical standards. If a new technical standard is designed around pre-existing IP, the risk created by vested interests is handled by a letter of assurance from all participants in the standard-setting process. This letter guarantees that the owner of any IP influencing the standard will license the IP for use in further research and will apply non-discriminatory pricing to licences for commercial use of the IP. This complex issue is discussed in some detail in Matthews and Frater (2003). The conclusion reached in that paper regarding the CSIRO patent was that there is only an indirect connection between CSIRO's wireless LAN patent and the subsequent 802.11a standard. The patent is based on finding a non-trivial practical solution to wireless LANs based upon parameters set by the laws of physics over radio-wave propagation in this frequency range. Similarly, IEEE 802.11a is also based upon these immutable physical laws. Consequently, the specification of IEEE 802.11a is likely to have converged with that of CSIRO's patent simply because this is a logical solution. In turn, this convergence of design solutions explains why chips complying with the 802.11a and 802.11g IEEE standards are currently subject to litigation but this does not imply that these standards stemmed directly from CSIRO's patent.

Implications for CSIRO's future role

CSIRO provides Australia with critical mass in trans-disciplinary capability-building. Over the last decade or so, this critical mass has tended to be framed by a strong 'direct path to commercialisation' ethos. Indeed, the Radiata story is cited as an exemplar of the sort of commercial outcome that CSIRO, Australian universities and government officials would like to occur more frequently.

The story told in this paper suggests a different interpretation of the facts. Radiata was a particular, and transitory, manifestation of commercial yield in a 'halo' of more general, but less noticeable and well documented, wealth-creation outcomes that stemmed from trans-disciplinary capability-building linked to basic research. This basic research was executed with a well thought-out and long-term strategic intent in order to increase the odds of generating (unspecified) commercial benefits in the future.

From this perspective, commercialisation activity has a strong stochastic dimension. It is a game in which a portfolio of options is generated and in which unpredictable external events tend to determine which options will succeed and which will fail. Commercialisation can involve taking abnormally high investment risks in order to generate the (usually remote) possibility of making abnormally high returns. When this process is successful the result is, in statistical terms, an 'outlier' – a rare event that deviates from the norm. Comparatively little attention is paid to these outliers in economics and econometrics because the events are viewed as transient phenomena that reflect a temporary disturbance to normal competitive circumstances. Business schools also devote comparatively little attention to steps in the leap from invention to innovation because these are, by definition, 'pre-competitive' activities. Researchers and research commercialisers therefore face not only a major gap in progressing from invention to innovation in terms of the capacity to manage the abnormal risks involved but we also face sparsely populated regions in the academic literature that analyse these processes (Hartmann and Myers 2001).

From a policy and strategy perspective, although we cannot develop policies and commercialisation strategies based upon what are, in statistical terms, unpredictable 'lightning strikes', we can seek to create more favourable conditions and incentives to encourage appropriately skilled people to take these abnormal risks. If the risks are not taken, the probability of creating beneficial outliers in the distribution of returns against investments all but disappears. The policy objective is to create more favourable odds for generating abnormally high rates of company growth but with no strong expectation that such rates can be forecast or predicted on a case-by-case basis.

If this argument is accepted, CSIRO should be encouraged to continue to develop and refine its use of real options-based valuation methods to assess research outcomes (see CSIRO 2006). However, this approach should be taken one step further and extended into explicit portfolio-based measures designed to highlight how trans-disciplinary capability-building impacts upon the odds of success of the investment portfolio as a whole.

What matters here is not the prevalence of transitory, and essentially unpredictable (yet large), Radiata-style outcomes. Rather, what matters is that a large number of both new and existing businesses benefit from small but pervasive increases in the probabilities of success that they face by virtue of the capability building that CSIRO has achieved. The inter-sectoral mobility of the scientists and engineers with this useful trans-disciplinary know-how is the vector that generates pervasive commercial yield – not IP per se. The Radiata story tells us that if capability-building is executed in a strategic manner and this personnel mobility occurs, indirect long-term outcomes from basic research can generate a substantial commercial yield via a broad-front of outcomes – not just the headline ones. Policy cannot, and should not, be based upon expectations of 'lightning strikes' but it *can* be based upon generalised improvements to the odds of success in commercial ventures. It is therefore encouraging that risk-based programme evaluation methods exist that are able to measure R&D outcomes as improvements in probabilities of success. The potential therefore exists to assess the yield generated by public R&D in this probabilistic manner – as a component of increased 'preparedness' (see Matthews 2006).

Acknowledgements

The author would like to thank Robert Frater, Denis Redfern, David Skellern and Neil Weste for providing extensive information and advice during the preparation of the a more detailed case study upon which this paper draws. Thanks also to Jane Marceau for invaluable advice on turning the longer case study upon which this paper is based into this journal article. Any errors or omissions are the sole responsibility of the author.

Endnote

1 The 1965 observation that the number of transistors that can be placed on an integrated circuit at least cost doubles every two years).

References

Branscomb L and Aursweld P (eds) (2001) *Taking Technical Risks: How Innovators, Executives, and Investors Manage High-Tech Risks*, MIT Press. Cambridge MA.

Chesbrough G and Rosenbloom R (2001) Defining Risks and Rewards: The Dual-Edged Role of the Business Model, in Branscomb L and Aursweld P (eds) *Taking Technical Risks: How Innovators, Executives, and Investors Manage High-Tech Risks*, pp. 57–68, MIT Press. Cambridge MA.

Cooper D (2001) *Radiata Inc. in Commercialising Innovation*. Proceedings of a workshop held on 10 May 2001 in Sydney, pp. 41–46, Australian Academy of Technological Sciences and Engineering (NSW Division).

CSIRO (2001) *Response to the House of Representatives Inquiry on Broadband Wireless. Submission by CSIRO Telecommunications & Industrial Physics*. CSIRO. Canberra.

CSIRO (2006) *Public Support for Science and Innovation*. Submission to the Productivity Commission, Canberra.

Frater R (2002) Rome wasn't built in a day: The Pre-History of a Startup. Presentation slides.

Hartmann G and Myers M (2001) Technical Risk, Product Specifications, and Market Risk, in Branscomb L and Aursweld P (Eds) *Taking Technical Risks: How Innovators, Executives, and Investors Manage High-Tech Risks*, pp. 30–43, MIT Press. Cambridge MA.

Matthews M and Frater R (2003) *Creating and Exploiting Intangible Networks: How Radiata was able to improve its odds of success in the risky process of innovating*. Case study prepared for the Science and Innovation Mapping study of the Department of Education, Science and Training, Canberra.

Matthews M (2006) *Managing uncertainty and risk in science, innovation and preparedness: why public policy should pay more attention to financial and geopolitical considerations*. Discussion Paper commissioned by the Federation of Australian Scientific and Technological Societies, Canberra.

Reardon M (2004) Cisco retires wireless chipsets. CNet online news item. January.

Skellern D, Percival T, Lee C, Ryan P, McDermott T, Weste N, Dalton J , Graham J Wong T, Myles A (1996) A mm-Wave High Speed Wireless LAN for Mobile Computing – Architecture and Prototype Modem/Codec Implementation. Paper presented at the IEEE Hot Interconnects '96 Conference, 15–17 August, Stanford, California.

Skellern D (2001) The Radiata story: Technology or Trees? *Telecommunications Journal of Australia* 51(4): 15.

Weste N, Eshraghian K, Sabastian Smith M (1993) *Principles of Cmos Vlsi Design: A Systems Perspective with Verilog/VHDL Manual*, Second Edition, Addison-Wesley, Reading MA.

Weste N (2002) Radiata's Success – Exiting from the spin-off without diluting equity. Presentation to a conference on Spin-Off/Start-Up Companies, 27–29 May, Avillion Hotel, Sydney. Organised by IIR Conferences.