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The paradox of public science and global business: CSIRO, commercialisation and the national system of innovation in Australia

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ABSTRACT

This article describes three case studies of the commercialisation of early-stage technologies involving Commonwealth Scientific and Industrial Research Organisation (CSIRO); extended-wear contact lenses, biostable biocompatible polymers for medical implant devices, and biodegradable biocompatible polymers for medical implant devices. The case studies extend the portfolio of detailed, highly contextualised studies of innovation in the Australian context. They also provide a window into CSIRO, commercialisation pathways and the national system of innovation in Australia. In particular, they highlight the paradox of public science and global business in the Australian context. The paradox is that global business depends upon public science for innovation more than ever, but makes it increasingly difficult for countries to capture the benefits of public science. It adds major complexity to the successful realisation of a more commercial approach by Australia's public research organisations such as CSIRO, and the capture of benefits from the national system of innovation.

Keywords: innovation; commercialisation; national system of innovation; research; CSIRO

In 2009 the Australian Government's Department of Innovation, Industry, Science and Research (DIISR) launched its 'innovation agenda for the 21st century'. The report highlights the centrality of innovation to 'making a better Australia – a fairer, richer, healthier and greener Australia that can meet the challenges and grasp the opportunities of the twenty-first century' (Australian Government 2009, p. 1). This demands an 'innovation system that offers an unbroken path from vision to realisation':

> The market alone can't deliver this, and governments have a responsibility to step in where markets fail. It is their job to plug gaps in the system through which ideas might be lost. Too many Australian inventions and discoveries end up being commercialised overseas, where the value they create is captured by others. This

> costs Australia jobs and wealth, and denies us the chance to build new industries. (Australian Government 2009, p. 3)

It is difficult to argue with the prospect of new industries, jobs and wealth. Yet it is also difficult to identify the precise 'gaps in the system' whereby ideas are lost and 'governments have a responsibility to step in'. This is partly because the 'path from vision to realisation' is often more than a decade for high value-creating radical innovations (Leifer et al. 2000; Allen Consulting Group 2005). It is much longer than the electoral cycle. It is also because not much is known about innovation pathways in Australia. On this account, Peter Cebon urges 'detailed, highly contextualised analyses' of innovation in the Australian context (Cebon 2008b, p. 3). This article contributes towards this end. It describes three case studies of innovation since the 1980s: extended-wear contact lenses, biostable biocompatible polymers for medical implant devices, and biodegradable biocompatible polymers for medical implant devices. In doing so, it sets out to better understand commercialisation and the national system of innovation in Australia, in particular the process whereby 'Australian inventions and discoveries end up being commercialised overseas'.

The article argues that the paradox of public science and global business adds major complexity to the successful realisation of a more commercial approach by Australia's public research organisations such as Commonwealth Scientific and Industrial Research Organisation (CSIRO). On the one hand, public science is still largely funded by national governments and is expected to provide national benefit. On the other, business systems – including finance, production and distribution – have become increasingly global; linked not just through investment and trade, but a more detailed integration of activities across countries. The paradox is that global business makes it increasingly difficult for countries to capture the benefits of public science, but depends upon public science for innovation more than ever (Narin et al. 1997, 2000). The paradox is acute for high value-added products, which are commonly 'born global' (McKinsey & Company 1993; Knight et al. 2004; Kudina et al. 2008). These products are precisely the concern of DIISR's 'innovation agenda', and form the case studies of this article.

Public science, the national system of innovation and commercialisation

From the late nineteenth century the prestige of organised, professional R&D steadily rose, reaching its high water mark in the wake of the Second World War. In turn, governments ramped up their investment in organised science. The Australian Government, for example, launched the Council for Scientific and Industrial Research (CSIR) in 1926, and relaunched it as the CSIRO in 1949. During this era the R&D system – in both public and corporate sectors – was commonly seen as '*the* source of innovations', and a 'simplistic linear model of science and technology 'push' prevailed (Freeman 1995, p. 9). For example: 'it seemed so obvious that the Atom Bomb (and it was hoped nuclear power for electricity) was the outcome of a chain reaction: basic physics → large-scale development in big labs → applications and innovations (whether military or civil)' (Freeman 1995, p. 9). It also seemed obvious that public investment would produce national benefit; hence, a routinely casual attitude towards commercialisation on the part of public research organisations.

An official history of CSIRO, for example, tells the exemplary tale of how its scientists used the 1954 Royal Visit to demonstrate the effectiveness of their new formula insect repellent. The formula made headlines, prompting a phone call from an Australian-owned firm called Samuel Taylor, manufacturer of Mortein fly spray. The following summer Samuel Taylor released Aerogard™, which is still a best-selling product more than 50 years later – albeit the property of Reckitt Benckiser, a British-based multinational corporation. The lead scientist of the project received

a dozen cans of the new product for Christmas. 'Back then,' he recalled, 'CSIRO policy was to make its discoveries freely available because they had been developed with public funding' (Collis 2002, p. 44).

Similarly, Alan Walsh – a CSIRO scientist – invented atomic absorption spectroscopy (AAS) in the early 1950s, and pursued its commercial development despite management indifference (Encel 1970, p. 50). He initially approached large manufacturers in the USA and UK, but obtained little interest. A British corporation licensed the technology during the mid 1950s, but did not exploit its potential. Attempts to interest large domestic manufacturers were also unsuccessful (Willis and Sturman 2005, p. 17). Walsh then (as he recalled) 'toured the backyards' of inner city Melbourne to find three 'machine shops' able to produce component parts, which were assembled by his laboratory into 'do it yourself' instruments (Encel 1970, p. 51). In 1963 one of the machine shops undertook the full manufacture of the spectrometers, encouraged by demand from the resurgent mining sector. In 1960 it had three staff; by 1966 it had 287. In 1967 the factory moved to Mulgrave on the south-eastern outskirts of Melbourne, and was taken over by Varian Associates, a high-technology corporation from the USA. (Willis and Sturman 2005). The Mulgrave factory remains Varian's largest manufacturing and R&D plant, although Varian is now a subsidiary of Agilent, another American corporation.

These thumbnail sketches provide a glimpse of the national system of innovation in Australia during the post-war decades. A national system of innovation refers to 'the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies' (Freeman 1995). The network of institutions in Australia during the post-war decades included public research organisations such as CSIRO, and local manufacturers such as Samuel Taylor. The case studies of Aerogard and AAS indicate that there was some foundation for CSIRO's casual attitude towards commercialisation, insofar as proximity gave local manufacturers an advantage in the commercialisation of its inventions.

The 1970s were a watershed in national systems of innovation world-wide, in a variety of ways. Public research organisations progressively adopted a more commercial approach (Mowery and Sampat 2005, p. 237); governments deregulated their economies and harmonised their policy settings; businesses fragmented and decentralised their production processes, creating 'vast global chains of production and distribution' (Robinson 2010, p. 5); and the pace of innovation accelerated, most spectacularly in information technologies and biotechnology. By the turn of the millennium, it was commonly understood that 'no one company acting alone could hope to out-innovate every competitor, potential competitor, supplier or external knowledge source in the world' (Quinn 2000, p. 13). Some analysts highlighted the 'strategic management of outsourcing', in particular the 'outsourcing of innovation' (Quinn 2000, p. 13). Others emphasised the networked structure of innovation, involving 'the establishment of long-term relationships in which exchange occurs within a learned and shared code' (Powell et al. 1996, p. 118). Either way, it was agreed that innovation was more distributed than before, and more global. The biosciences exemplified these patterns, both in the extent of their partnerships and their global reach (Powell et al. 2005; Gilding 2008).

In the Australian context, governments progressively reduced tariff protection for local manufacturing, and promoted a more commercial approach for public research organisations – notably CSIRO. The 1977 Birch Report (Independent Inquiry into the CSIRO) recommended 'a shift in the balance of CSIRO's research from longer-term, fundamental research toward strategic-mission orientated research and the greater involvement of end users in the allocation of research funding' (Upstill and Spurling 2008, p. 144). The *Science and Industry Research Amendment Act 1986* extended CSIRO's commercialisation capacity and allowed it to retain earnings from outside sources without a reduction of its appropriation.

Barry Jones, then Federal Minister of Science, explained that CSIRO was expected to 'play a major role in contributing to the Government's program of restructuring and revitalising high-technology manufacturing, and in supporting the emerging information and space technology industries' (Upstill and Spurling 2008, p. 145). By 2000 CSIRO had substantial commercialisation infrastructure, including 136 specialist staff (full-time equivalent; DEST 2004, p. 6). In close connection, income from IP, including royalties, rose steadily from less than AUD$1 million per annum in the mid-1980s to AUD$20 to 30 million per annum by the mid 2000s (CSIRO 1980–2005).

Commonwealth Scientific and Industrial Research Organisation is now better adapted to industry collaboration and commercialisation than in earlier times, but there is enduring disquiet about its position in the national system of innovation. Upstill and Spurling, for example, claim 'a serious loss of clarity on CSIRO's role' (Upstill and Spurling 2007, p. 123). Similarly, Thorburn describes CSIRO as 'caught between the proverbial rock and a hard place, being required to generate significant levels of external earnings, address major national research needs, build Australian industry (and prove that it is doing so) while continuing to undertake basic research' (Thorburn 2007, p. 167). More generally, Marceau argues that policymakers – in CSIRO and further afield – 'have struggled to comprehend the nature of innovation itself and the processes by which major innovations are developed, adopted and managed' (Marceau 2007, p. 98). She argues that the 'underlying model still in science policymakers' heads' is mostly 'some form of the linear model – that science provides information and that if industry knows about a good idea it will take it up' (Marceau 2007, p. 100). The long overdue question now is 'how to rebuild the major roots and branches of Australia's knowledge tree, its research and science systems and its knowledge generation processes, *including the CSIRO* as a central player, to make it a coherent whole, to make it more of an innovation *system*' (Marceau 2007, p. 108).

This article builds on this line of inquiry. Specifically, it closely examines the position of CSIRO in the national system of innovation, and its role in relation to commercialisation. It does so through three case studies, spanning the 1980s to the present – a period of profound change in the national system of innovation, and the commercialisation regime in particular.

A CASE STUDY APPROACH

Innovation is complex: the pathway from discovery to commercialisation routinely takes a decade or longer, and involves multiple organisations in different capacities along the way. An appreciation of the temporal sequence of activities in developing and implementing discoveries is fundamental to the management of innovation and will contribute to understanding which paths are likely to lead to success or failure (Van de Ven and Poole 1990). A case study methodology facilitates detailed observations of complex relationships over a long period of time – it is especially appropriate in addressing 'how' and 'why' (Eisenhardt & Graebner 2007) – and thereby provides scope for forming hypotheses about the broader dynamics (Cebon 2008b, pp. 11–12). A general understanding of the commercialisation of early-stage technologies – in CSIRO or Australia generally – requires multiple case studies and multiple methodologies. The three case studies in this article will contribute to this general understanding.

The case studies are all grounded in the same platform technology, forged through CSIRO's investment in basic polymer science that began with the development of polymer bank notes (Prime and Solomon 2010). Further, they are all biomedical applications, which require high-level technical knowledge and sophisticated manufacturing capacity. In turn, they carry the promise of building high-technology, export-oriented industry, as envisaged by the authors of the DIISR report cited at the beginning of this article. Some of the most successful high-technology firms in Australia during the past 30 years have operated in this sector; notably, CSL, Cochlear and

ResMed. Although the case studies are confined to a single sector, it is an important one within the national system of innovation.

There is a sense in which the common threads between cases make them a unified case study of the national system of innovation. CSIRO and some of its scientists were involved in all of the cases. Moreover, the cases had their origins during the 1980s when CSIRO's commercialisation policies changed profoundly, and reached the market in one form or another in the late 1990s and 2000s by which time the new policies were well established. At the same time, the differences between cases highlight diverse pathways to market within the national system of innovation, notwithstanding shared origins and personnel.

The first case study – which has been described elsewhere on the basis of formal documents (Cebon, 2008a) – concerns the development of extended-wear contact lenses. Ciba-Geigy, a Swiss-based multinational pharmaceutical corporation, and its American subsidiary CIBA VISION were key players in the project, providing focus and funds. In 1999 Novartis – the outcome of a merger between Ciba-Geigy and Sandoz – launched the Focus Night and Day™ extended-wear lens, manufactured at its American headquarters in Atlanta. The royalties from the lenses make it one of the most successful commercialisation deals for CSIRO in its history.

The second case study concerns the invention of a biostable, biocompatible polymer for medical implant devices. The polymer, eventually marketed under the trade name of Elast-Eon™, was initially developed as a coating for pacemaker leads at the instigation of Telectronics, a pioneer of the Australian medical device industry. In 2001 Elast-Eon's™ ownership moved offshore to a small British medical device firm called AorTech International. In 2003 AorTech opened a factory in the outer suburbs of Melbourne, but in 2011 announced plans to move its manufacturing operations to the Minneapolis/St Paul area in the USA.

The third case study concerns the invention of a biodegradable, biocompatible polymer for medical implant devices, branded NovoSorb™. Unlike the other case studies, this technology was initiated and directed by scientists from CSIRO, not industry. The technology is now fully owned by a small Australian biotechnology investment firm called Calzada, which has several licensing agreements with US corporations. At this stage there is no product on the market.

The case studies were undertaken as part of a project about CSIRO and innovation, with the support of the CSIRO Future Manufacturing Flagship. It involved interviews with key participants, and consideration of internal documents as required. Two of the authors (Spurling and Simpson) identified initial informants through their personal involvement in the technologies; thereafter informants were selected through non-probability snowball sampling (Goodman 1961). There were 30 informants altogether: 16 from CSIRO, 6 from industry, and 8 from elsewhere. The interview schedule addressed the trajectory of the technologies, and key institutions, organisations, networks and individuals. Interviews occurred at locations of the respondents' choosing, in Melbourne, Sydney, Canberra and Adelaide; two were conducted by phone. All interviews were digitally recorded, transcribed, and coded using Nvivo (QSR International 2008). Most took between 60 and 90 minutes.

This article uses interviews and documents to identify key institutional players, their articulation with the national system of innovation, and their role in commercialisation. Quotations from interviews in the case studies are identified by 'I' (for interview) followed by a random number allocated to the informant; no other information is provided in order to protect confidentiality. In those instances where quotes include identifying information, informants have provided permission for its use. Sensitive quotes have an 'x' instead of the interview number to decouple them from other quotes.

The fact that events occurred up to 25 years ago means that they are compromised by memory and retrospective 'sense-making' (Weick 1995). They are also compromised by political and interpersonal considerations. Informants routinely

emphasised the importance of trust and camaraderie in doing good science: for example, 'we became good friends and we were constantly on the phone' (I4). Conversely, informants described profound conflict at various points in all of the projects: for example: 'we drove the concept from here all the way through here, and then it just gets completely screwed up by a bunch of no-hopers' (Ix). In turn, informants were careful in what they said and mindful that it was recorded. Notwithstanding sensitivities, informants took great care in the course of interviews, often providing supporting documentation afterwards. More generally, the interviews provide a check against each other, and documentary evidence provides further triangulation.

The case studies have a rough chronological logic: Focus Night and Day™ was launched in 1999, Elast-Eon™ in 2004, and NovoSorb™ is still in prototype. As it happens, the case studies also proceed from the most parsimonious commercialisation pathway to the most labyrinthine. Each of the case studies directs particular attention to organisations and institutions which inform the pathway from invention to product. There are profound similarities across the case studies, but also substantial differences.

Extended-wear contact lenses (Focus Night and Day™)

The development of extended-wear contact lenses involved what one informant described as 'market pull, big time' (I21). Market research during the 1980s reported that 'people don't like putting their fingers in their eyes, and all of the paraphernalia with cleaning and disinfecting solution' (I4). As a result, the extended-wear contact lens was the 'holy grail' of the industry (I4). The market leader Johnson & Johnson had already launched an extended-wear lens with Food and Drug Administration (FDA) approval, but it had failed and approval was withdrawn. In the late 1980s the Swiss pharmaceutical corporation Ciba-Geigy, a distant third to Johnson & Johnson and Bausch & Lomb, decided to direct its efforts towards breakthrough technologies, especially extended-wear lenses. From the outset its objective was to manufacture the product and 'be first to market' (I4).

The architect of the breakthrough strategy was Adrian Hunter, the Vice President of R&D in CIBA VISION, Ciba-Geigy's US subsidiary. Hunter's R&D network included Brien Holden, an academic from the School of Optometry and Vision Science at the University of New South Wales (UNSW) and a pioneer of corneal and contact lens research in Australia. Holden was an uncharacteristically entrepreneurial academic, drawing together interdisciplinary and inter-organisational research teams with large industry funding. In 1989 Holden recruited a polymer scientist at CSIRO, who 'did a few experiments on the cheap', without external funding (I1). The results were encouraging, resulting in talks with a 'relatively small' Australian firm about a possible commercial alliance to 'create a new generation of contact lens' (I20). The firm could not decide how to proceed, whereupon Holden 'got in touch with Ciba and they took about five milliseconds to buy into the whole thing with some money' (I1).

Holden thereupon coordinated a bid for the first round of the CRC Program in 1991. Partners for the proposed CRC for Eye Research and Technology (CRCERT) included UNSW (and two other universities) and CSIRO. Ciba-Geigy committed to fund the project through CIBA VISION, but were not partners. Ciba hoped to leverage its high-risk project through Australian Government funds, but there was little chance that the eventual product would be made in Australia. One informant recalled a top-level meeting which struggled to identify 'Australian national benefit':

> The conversation was yes, it will be the case that Ciba will consider manufacturing in Australia, but by the way the probability of that occurring is close to negligible for extended-wear contact lenses. This is a world-wide market, you've got to be close to your main marketplace, etcetera … The flip side [is that for] … a new market product … like artificial cornea, we will definitely look to see if we can make that in Australia. At least initially. (Ix)

The CRC bid was successful – in 1991, and again for renewal in 1997. As a result the Australian team joined two corporate research teams working towards the same end; one in Atlanta where Ciba's American headquarters were located, and another in Switzerland, the location of its international headquarters. Ciba actively promoted 'competitive collaboration' across teams (I7), where information and benefits were shared and breakthroughs earned immense prestige. There was a 'dedicated communications network' through Lotus Notes; scientists in specific fields were in 'frequent contact' by phone, 'to share learnings' and 'to make sure we were complementary' (I4); there were three monthly management meetings 'of a very high scientific standard' (I21); and there were six monthly meetings in 'prestigious locations', including not only scientists but 'marketing, manufacturing, and … intellectual property and patenting … from each country' (I4). Informants described the experience as outstanding; not only in terms of the science, but also in terms of knowledge exchange between science and industry. In specific terms, for example, one scientist recalled how working with patent attorneys 'was a very big learning to me and it was a very big learning to pretty much everyone in the project' (I4). In more general terms, another described the project as 'by a country mile the most challenging scientific environment in which I've worked in my career' (I21).

The polymer scientists at CSIRO and their corporate partners 'eventually came up with some good materials' (I4). Novartis – the outcome of a 1996 merger between Ciba-Geigy and Sandoz Laboratories, another Swiss pharmaceutical corporation – took the material to 'pilot-scale manufacturing as soon as possible' in its Atlanta plant. Scientists nonetheless kept 'working on back-up materials just in case there was failure', which there was – but 'the lessons we'd learned in scale-up and manufacturing were in many cases directly applicable to the new material' (I4). In 1999 Novartis launched an affordable daily wear contact lens under the brand name Focus Night and Day™.

The CRCERT morphed into the Vision CRC in 2003. CSIRO is a supporter of the CRC (www.visioncrc.org), while CIBA VISION continues to fund projects. The UNSW remains involved through the Brien Holden Vision Institute, which is located alongside and affiliated with the university (www.brienholdenvision.org). The research focus has shifted away from contact lenses and toward the development of a bionic eye. The CRCERT and Vision CRC have so far received royalties of AUD$42.6 million for Focus Night and Day™ and a follow-on product (O2OPTIX™).

Biostable polymers for medical implant devices (elast-eon™)

In 1986 Telectronics Pacing Systems (Telectronics) approached CSIRO for help in enhancing the substance used to coat cardiac pacemaker leads. At the time Telectronics was a subsidiary of Nucleus, a pioneer in the Australian medical device industry. Paul Trainor, the CEO of Nucleus, was a classic entrepreneur – one respondent described him as 'the godfather of the medical device industry here' (I6). Starting out in the low-risk business of medical equipment supplies, he shifted into the high-risk business of commercialising medical device technology that originated in Australian public research organisations. Different subsidiaries commercialised different technologies, including the cochlear ear implant (Cochlear is now the largest medical device corporation in Australia) and ultra-sound imaging. Telectronics specialised in pacemakers, achieving leadership in the market through hermetic sealing technology (I11). By 1986 it was a global enterprise, with more than 300 engineers in Australia, the US and Europe, and an annual R&D budget of AUD$60 million. It contacted CSIRO because the materials used in the pacemaker leads deteriorated over time (I11). A Telectronics' informant recalled: 'organic chemistry was not our expertise, and that's where we'd go – to someone like the CSIRO or a university – to get expertise' (I11).

Mike Skalsky – a research leader at Telectronics – was the key player in forging the collaborations which facilitated the technology. Skalsky contacted CSIRO, and then forged a broader coalition (the UNSW, the Medical Industry Association of Australia, the American multinational Johnson & Johnson, another American corporation Cyanamid, and a Japanese corporation Terumo) to bid for a Commonwealth Government Generic Industry Research and Development grant (GIRD). Telectronics' rationale was that the 'high risk, potentially high reward' nature of the project meant that it should 'try and leverage' its investment as far as possible through government grants (I11). The GIRD grant led to a polyurethane material protected by patents, but with enduring technical problems. In the course of this grant it also became apparent that Telectronics 'didn't have an interest in manufacturing it, but they were a consumer' (I4). In this respect, one scientist explained his growing appreciation of the 'value chain':

> You know, you might manufacture a kilo of polymer for $5, that's a bit of an underestimate, but … the next stage is to fabricate that into componentry which might be worth $100, and then make it into a finished medical device which went for $2000 … In the medical device industry there's a few examples of integration, but typically there are independent polymer manufacturers, componentry manufacturers, different companies … So the question was … what are we going to do about this polymer manufacturing? (I4)

At this stage the project's future was uncertain. Johnson & Johnson, Terumo, Cyanamid and the Medical Industry Association had lost interest. More significantly Telectronics was now a different sort of corporation to what it had been. In 1988 a personal tragedy caused Trainor to sell Nucleus to Pacific Dunlop, a manufacturing conglomerate which owed its position to the protected domestic market. Pacific Dunlop had little experience in either the medical devices sector or the US market, but it had grand ambitions – and pursued an aggressive merger and acquisition program to this end. Skalsky (at Telectronics) still promoted the polymer project, and CSIRO and UNSW researchers continued to carry out unfunded R&D without company support. The lead scientist described the work at the time as 'back-breaking' and 'not particularly innovative', but 'we were motivated by the goal of getting this right, and Mike [Skalsky] was instrumental in saying, "Look, you don't have a project unless you can make it or process it"' (I4).

In 1992 the recently introduced CRC Program provided another opportunity for government leverage. Nucleus was instrumental in three successful bids in the new program, including a CRC for Cardiac Technology (CRCCT) in its second round. The CRCCT involved eleven partners (Telectronics, CSIRO, UNSW, four other universities, three hospitals, and one Australian biotechnology firm), and four projects. By all accounts, the CRC enjoyed neither cross-fertilisation nor good will across projects, but the collaboration around biomaterials was fruitful. In the words of one participant, 'we put together a much stronger and bigger team, and did some more focused and more directed research into improving what we had before' (I6). The upshot was a polymer that was both soft and biostable, suitable for use in medical implant devices.

Meantime, Telectronics was imploding. There were two reasons: long-running patents litigation, and damages litigation around pacemakers, both in the USA. The patents litigation had its origins in the takeover of General Electrics' pacemaker business in the USA during the mid 1970s. It was unconnected with the Australian technology and eventually resolved, but bled Telectronics dry in legal expenses. The damages litigation originated in modifications to pacemaker leads in the USA, again unconnected with the Australian technology. There were four deaths associated with use of pacemaker leads before the problem could be identified and more when cardiologists rushed to remove pacemakers (I11). In 1996 Pacific Dunlop 'panicked and they sold the company' (I11) to St Jude Medical, an

American-owned multinational device corporation. St Jude was not interested in Australian operations, whereupon Pacific Dunlop folded them. In turn, the CRCCT lost its only substantial commercial partner and Mike Skalsky lost his corporate base.

Telectronics' implosion created a commercial void in the CRC, into which two new players entered. The first of these players was a start-up company called KMR formed by Skalsky and two colleagues from Telectronics; the second was a small Edinburgh-based biomedical firm called AorTech International, introduced by David Williams, a British academic who was Chair of the CRCCT's Scientific Advisory Committee. AorTech was developing a heart valve which required a biostable, biocompatible coating, and proposed a joint venture with Skalsky's start-up if it was able to obtain the license for the technology. At this point the technology's trajectory became fractious. The CRCCT board opposed the sale of the license due to concerns that the start-up secured private benefit from public funds. From Skalsky's point of view, the CRCCT board did not understand the entrepreneurial role in turning an invention into a commercial product. After protracted negotiation, Skalsky and his colleagues hired Macquarie Bank to negotiate on their behalf in exchange for Macquarie Bank receiving 1% equity in the new firm. Macquarie promptly closed the deal. The upshot was the formation in 1998 of a spin-out company called Elastomedic, owned by AorTech (40%), Skalsky and his partners (29%), and the CRC stakeholders, including CSIRO (31%; Carroll 2000). Skalsky had plans to outsource the manufacturing in Sydney (where he lived), through a joint venture with a polymer manufacturer. When the deal fell through, CSIRO facilitated incubator facilities in Melbourne, minimising capital costs and facilitating access to scientists as required. The facilities laid the foundation for Melbourne-based manufacturing of the product.

Meantime the dotcom boom created soaring share prices for high-technology firms, including the UK-listed AorTech. In 2000 AorTech – flush with capital – made an offer for Elastomedic that was 'too good to refuse' (I6), whereupon Elastomedic became its fully owned subsidiary. The CRCCT shareholders – including CSIRO – cashed out at a premium price. In contrast, under the terms of sale, Skalsky and his partners were unable to cash out in less than two years due to their management involvement, and found themselves hostage to circumstances beyond their control. The dotcom boom crashed, AorTech's heart valve failed to find its way to market, and the share price tumbled. In turn, there was growing 'management tension' between the new owners and the one-time Telectronics team (I6). In 2002 senior management closed the Sydney office where the former Telectronics team was based. Skalsky and his partners departed the project with 'some money' from their investment but 'not very much' (I11).

AorTech then reinvented itself as a biomaterials company. Its CEO was located in the USA, where he negotiated with medical device corporations for business, including St Jude Medical. In 2004 AorTech opened its manufacturing facility in Melbourne, grounded in its embedded fabrication expertise. Orders, licenses and applications for the polymer – which was called Elast-Eon™ – thereafter improved steadily, but operating expenses still exceeded expenses, not least because of the rising Australian dollar (AorTech International PLC 2010). In 2011 the company announced the relocation of its manufacturing operations to the Minneapolis/St Paul area in the USA; partly in order to be closer to the medical device corporations which it supplied, and partly to remove foreign exchange risk (AorTech International PLC 2011).

Biodegradable polymers for medical implant devices (NOVOSORB™)

Following the Elast-Eon spin-out, CSIRO's polymer scientists asked 'what do we do next?' (I7). They knew a lot about biocompatible polymers through the development of Elast-Eon™. The shift towards a 'more regenerative' medical model – 'trying to encourage the body to heal itself' – directed their

attention towards development of a biodegradable polymer which assisted the body's regenerative facility. One scientist explained: 'There will always be a place for biostable polymers and hip implants, at least in the foreseeable future, but the ability to use biodegradable polymers was perceived to be an opportunity and to result in another platform technology' (I26). In 2000 CSIRO scientists obtained an internal grant to design a polymer for tissue engineering application. A member of the Elast-Eon™ project recalled: 'Until yesterday we were working on completely non-degradable [polymers]; now we are working on polymers which have to be degraded'. Less than 3 years later 'we had developed a concept', which was filed as a patent: 'an injectible polyurethane, which was cell friendly and biocompatible' (I26). The novel material was called NovoSorb™.

By the early 2000s CSIRO had dedicated business development professionals, responsible for taking new technologies to market. Their initial business model was 'a licensing strategy', where technology was licensed to different firms for different applications; for example, 'Company A would come along interested in knee replacements and we'd give them a license to go away and generate that; Company B would come along and want spinal disks and they'd go off and do that' (I2); and so on. The dotcom boom, soaring valuations for early-stage technology firms (including AorTech), and the burgeoning venture capital industry fuelled growing misgivings about this strategy. As one commercialisation manager explained, licensing 'doesn't work … because we don't know the market', either in terms of 'who to talk to' or how the technology will actually be applied (I2). Business development specialists initially adopted a licensing strategy with NovoSorb™, negotiating a possible license with ITRI, a Taiwanese state-owned science and technology organisation. When this failed, they 'decided that it would be best to spin the whole technology out into a company and let the company work out where the market was, and then we would move on to the next generation' (I2).

During this period a local venture capital industry specialising in the life sciences was also gathering traction. CSIRO opened talks first with the Melbourne-based Starfish Ventures, and then a Perth-based consortium, which went on to become Southpointe – a listed, one-time mining company turned biotechnology investment firm. Southpointe proposed a jointly owned spin-off company called PolymerCo, directed towards the commercialisation of NovoSorb™. CSIRO's Board Commercialisation Committee initially opposed the proposal for fear that it was 'an excuse to load up CSIRO's brand and use that to get mum and dad investors', but ultimately approved with 'a significant number of specific restrictions' (I26). Southpointe then did a capital raising to finance its 51% share of PolymerCo, which was incorporated in 2004 (PolyNovo Biomaterials Pty Ltd 2010). It also changed its name to Xceed, which debuted on the Stock Exchange under the new name at a 50% premium for its investors.

PolymerCo – or PolyNovo Biomaterials as it was soon renamed – was now in the mould of an archetypal bioscience firm; grounded in public research, with a handful of staff and without a revenue stream. It was still located in CSIRO premises. Its staff consisted of a CEO (recruited from AorTech), three CSIRO scientists on secondment, and a PhD student. PolyNovo's business model involved bringing the technology closer to market, negotiating licensing deals with large biomedical corporations, and then on-selling the technology at a premium. It also required 'a news flow' to satisfy investors, build legitimacy, and position the technology for sale (I14). In 2008 its CEO negotiated licenses with three multinational medical device corporations: Medtronic and Biomet (both based in the US), and Smith and Nephew (based in the UK). To spread the risk, he also initiated development work for basic applications in collaboration with local medicos. The CSIRO scientists on secondment who did the development work acknowledged 'exposure to companies in the US' and industry contacts, but described the scientific work itself as unstimulating and unrewarding. In particular, the

business demand for secrecy meant no scope for patents or publications. PolyNovo tried to even the ledger through share options, but the conditions of CSIRO employment meant that these would be lost if they returned to CSIRO. 'At the end of the day,' one scientist reflected, the benefits did not outweigh 'the loss in the scientific life' (I17).

Meantime, PolyNovo was burning cash. Xceed injected more funds on three occasions, diluting CSIRO's equity to 30%. In early 2007 it decided that the moment was ripe to 'unlock the value' (I14). Management took heart from an independent expert who estimated that PolyNovo's value was 'conservatively $120 million and probably more', but was disappointed when it tried to enlist 'brokers around town':

> We absolutely failed. And the reason why was because Xceed was a listed company that … was a controlling entity. So the brokers said if … this was the first time we'd ever heard the story, we could agree with that, but if we take Xceed's price today and multiply it up, this is your real value. And … because Xceed wasn't doing particularly well … it was something like $17 million. (I14)

Soon afterwards there appeared the 'first crack in the markets', which became the Global Financial Crisis. The scope for 'floating a pre-revenue technology company was now gone, absolutely' (I14). By this stage Xceed desperately needed more capital. There were talks with private equity. Then Xceed's CEO facilitated talks with Metabolic Pharmaceuticals, a listed biotechnology firm of which he was a director and major shareholder. Metabolic was cashed up from the high-tech boom but its technology had failed spectacularly, the opposite problem to that of PolyNovo. PolyNovo aspired to a merger. In the meantime, it borrowed from Metabolic and fitted out a AUD$2 million factory in Melbourne. For its part, Metabolic's owners became increasingly sceptical of PolyNovo management (I14). The upshot was a hostile takeover, whereby Metabolic became 'the controlling shareholder, and Xceed and CSIRO were completely diluted' (I14). It was a graphic demonstration of how 'the last dollar in' reaps the greatest rewards in the commercialisation of new technologies.

PolyNovo's new owners – who were 'not of this industry' (I3) – tried to extract more funds from licensees without success. Medtronic withdrew from its license agreement on a technicality, and the Biomet deal stalled. Meantime, PolyNovo's scientists on secondment returned to CSIRO, and its CEO returned to AorTech. In late 2009 Metabolic changed its name to Calzada, and persuaded CSIRO to exchange its equity in PolyNovo for shares in Calzada (Scottrade.com.au, 2010). There is still no product on the market.

The paradox of public science and global business

The fledgling literature on CSIRO and its position in the national system of innovation observes tension between its scientific and commercial objectives, and the enduring influence of the linear model in the policy frameworks within which it operates (Marceau 2007; Thorburn 2007; Upstill and Spurling 2007). These themes are not salient in the case studies of this article. CSIRO's polymer scientists operated in 'Pasteur's Quadrant', combining the 'quest for fundamental understanding' with 'considerations of use' (Stokes 1997, p. 73). Specifically, they operated at the cutting edge of world science in understanding the interface between the human body and polymer implants, and developing technologies for diverse biomedical purposes. There is no suggestion that scientists' progress was compromised by CSIRO's commercialisation objectives. On the contrary, progress seems to have been enhanced through early-stage engagement and feedback loops with end users and manufacturers – contrary to the linear model. In two of the case studies, engagement was facilitated through CRCs. The case studies are testament to the innovative capacity of public science in Australia, and CSIRO and the CRCs in particular.

At the same time, the case studies highlight enduring tensions around public science and national benefit on the one hand, and private

advantage and commercialisation on the other. In the case of the extended-wear lens project, an early top-level meeting struggled to identify national benefit, and raised the hope of long-term manufacturing jobs in Australia. In the case of the biostable polymer project, the CRC board opposed the sale of the license because it regarded the start-up as securing private advantage from public investment. On another tack, CSIRO facilitated incubator facilities in Melbourne as an inducement towards local production. In the case of the biodegradable polymer project, CSIRO's Commercialisation Committee initially opposed the spin-off for fear that its financiers would exploit public trust in CSIRO's reputation. The common thread here is the understanding that public science and the commercialisation of its intellectual property should deliver national benefit – notably, new industries, jobs and wealth – over and above private profit.

The case studies suggest that proximity gave local firms an initial but short-lived advantage in the commercialisation process. In the case of the extended-wear lens project, Australian scientists first approached a local firm, which could not reach a decision. The scientists then approached the Swiss multinational Ciba-Geigy. In the case of the biostable polymer project, Nucleus and its subsidiary Telectronics were pioneers of biomedical manufacturing in Australia. Both passed into the hands of the local manufacturing conglomerate Pacific Dunlop, which did not understand the biomedical sector. Pacific Dunlop relinquished the technology, whereupon it fell into the hands of a local intermediary which on-sold its interest to an offshore firm. Even then, proximity to CSIRO facilitated local production in the first instance, but not in the long haul. In the case of the biodegradable polymer project, both Xceed and Calzada were local intermediaries, directed towards raising the value of the technology by taking it closer to production. Xceed failed to do so, and Calzada is still trying. It is striking that not one of the local firms in these case studies has so far profited from its investment.

In the longer run, the case studies indicate that other considerations – notably global business models – trump proximity in the commercialisation process. In the case of the extended-wear lens project, Ciba-Geigy's business model was well understood from the outset; hence its substantial investment in resolving the technical challenges of the project, the parsimonious pathway to market, and the location of production facilities in the USA. In the case of the biostable polymer project, the small British biomedical firm AorTech became involved at a late stage of its development. AorTech's original business model involved using the polymer as a component of its artificial heart valve. When the valve failed, it revised its business model (with the support of windfall funds from the dotcom boom) to become a components manufacturer for biomedical firms in the world industry hubs. AorTech now plans to relocate its manufacturing operations to the USA to be closer to these biomedical firms. In the case of the biodegradable polymer project, both Xceed and Calzada have directed their efforts towards deals with biomedical firms in the world hubs, with a view to a commercial sale. The common thread here is the global organisation of the biomedical industry, involving integration of research, development and production on a global scale.

Notwithstanding their global trajectory, the case studies demonstrate national benefit in a variety of ways. The extended-wear lens project facilitated a rich international research experience for Australian scientists, generated on-going royalties for public science, and created a product worn by more than half a million people in 40 countries, including Australia. The biostable polymer project created local employment in high-technology, export-oriented manufacturing for almost a decade, and there are now more than two million Elast-Eon™ implants in service world-wide, including Australia. NovoSorb™, the next generation of vision technologies (notably the bionic eye), and the next generation of polymer technologies for biomedical devices promise further benefits down the track. Yet the case studies have disappointed the promise of new industries, jobs and wealth. On the contrary, they indicate a logic whereby – in the

words of the Australian report cited at the beginning of this article – 'Australian inventions and discoveries end up being commercialised overseas, where the value they create is captured by others' (Australian Government 2009, p. 3).

More generally, the case studies suggest a paradox whereby global business depends upon public science for innovation more than ever, but makes it increasingly difficult for countries to capture the benefits of public science. The paradox is consistent with the adoption of a more commercial approach on the part of CSIRO and other public research organisations; the deployment of diverse commercialisation strategies on the part of CSIRO; and the failure of a more commercial approach to consistently deliver new industries, jobs and wealth. The mining boom and the rising Australian dollar makes CSIRO's task progressively more difficult in this respect, as demonstrated in the relocation of AorTech's manufacturing operations. The paradox of public science and global business adds major complexity to the accomplishment of an 'innovation system that offers an unbroken path from vision to realisation' (Australian Government 2009, p. 3).

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References

Allen Consulting Group. (2005) *The economic impact of cooperative research centres in Australia: Delivering benefits for Australia,* Cooperative Research Centres Association Inc., Melbourne, Victoria, Australia.

AorTech International PLC. (2010) *Annual Report* [Online]. Surbiton, UK. Available at http://aortech.com/CmsContent/Pdf/AorTech%202010%20Annual%20Report.pdf

AorTech International PLC. (2011) *AorTech to open US manufacturing and technology center* [Online]. Retreived August 9, 2011, from http://aortech.com/business/news/article/226/aortech-us-factory

Australian Government. (2009) *Powering ideas: An innovation agenda for the 21st century*, AGPS, Canberra, Australian Capital Territory, Australia.

Carroll, S. (2000) *Acquisition of elastomedic; licence to AorTech*. CSIRO, Canberra, ACT.

Cebon, P. (2008a) The extended wear contact lens project. In P. Cebon (Ed.), *Measured success: Innovation management in Australia,* Melbourne University Press, Melbourne, Victoria, Australia.

Cebon, P. (2008b) *Measured success: Innovation management in Australia,* Melbourne University Press, Melbourne, Victoria, Australia.

Collis, B. (2002) *Fields of discovery: Australia's CSIRO,* Allen & Unwin, Sydney, New South Wales, Australia.

CSIRO. (1980–2005) Annual reports. CSIRO, Canberra, ACT.

DEST (2004) *National Survey of research commercialisation: Years 2001 and 2002*. Canberra, ACT, Department of Education, Science and Training.

Eisenhardt, K. M. and Graebner, M. E. (2007) Theory building from cases: Opportunities and challenges, *Academy of Management Journal 50*: 25–32.

Encel, S. (1970) *Science, discovery and innovation: An Australian case history*, *International Social Science Journal 22*: 42–53.

Freeman, C. (1995) The 'national system of innovation' in historical perspective, *Cambridge Journal of Economics 19*: 5–24.

Gilding, M. (2008) 'The tyranny of distance': Biotechnology networks and clusters in the antipodes, *Research Policy 37*: 1132–1144.

Goodman, L. A. (1961) Snowball sampling, *The Annals of Mathematical Statistics 32*: 148–170.

Knight, G., Madsen, T. K. and Servais, P. (2004) An inquiry into born-global firms in Europe and the USA, *International Marketing Review 21*: 645–665.

Kudina, A., Yip, G. S. and Barkema, H. G. (2008) Born global, *Business Strategy Review 19*: 38–44.

Leifer, R., McDermott, C. M., O'Connor, G. C., Peters, L. S., Rice, M. P., Veryzer, R. W., et al. (2000) *Radical innovation: How mature companies can outsmart upstarts,* Harvard Business School Press, Boston.

Marceau, J. (2007) The knowledge tree: CSIRO in Australia's innovation systems, *Innovation: Managment, Policy & Practice 9*(2): 98–112.

McKinsey & Company. (1993) *Emerging exporters: Australia's high-value added manufacturing exporters*, Australian Manufacturing Council, Melbourne, Victoria, Australia.

Mowery, D. C. and Sampat, B. N. (2005) The Bayh-Dole Act of 1980 and University-Industry Technology Transfer: A model for other OECD Governments? *The Journal of Technology Transfer 30*: 115–127.

Narin, F., Albert, M., Kroll, P. and Hicks, D. (2000) *Inventing our future: The link between Australian patenting and basic science. A report for the Australian Research Council and CSIRO,* Commonwealth of Australia, Canberra, Australian Capital Territory, Australia.

Narin, F., Hamilton, K. S. and Olivastrod, D. (1997) The increasing linkage between U.S. Technology and Public Science, *Research Policy 26*: 317–330.

PolyNovo Biomaterials Pty Ltd. (2010) *History* [Online]. PolyNovo Biomaterials Pty Ltd., Melbourne, Victoria, Australia.

Powell, W. W., Koput, K. W. and Smith-Doerr, L. (1996) Interorganizational collaboration and the locus of innovation: Networks of learning in Biotechnology, *Administrative Science Quarterly 41*: 116–145.

Powell, W. W., White, D. R., Koput, K. W. and Owen-Smith, J. (2005) Network dynamics and field evolution: The growth of Interorganizational Collaboration in the Life Sciences, *American Journal of Sociology 110*: 1132–1205.

Prime, E. L. and Solomon, D. H. (2010) Australia's plastic banknotes: Fighting counterfeit currency, *Angewandte Chemie International Edition 49*: 3726–3736.

QSR International. (2008) *NVivo 8*. QSR, Doncaster, VIC.

Quinn, J. B. (2000) Outsourcing innovation: The new engine of growth, *Sloan Management Review, 41*: 13–28.

Robinson, W. I. (2010) *Global capitalism theory and the emergence of transnational elites*. Working paper 02, World Institute for Development Economic Research, Helsinki, Finland.

Stokes, D. E. (1997) *Pasteur's quadrant: Basic science and technological innovation,* Brookings Institution Press, Washington, DC.

Thorburn, L. (2007) Spinning along: CSIRO's knowledge business, *Innovation: Managment, Policy & Practice 9*(2): 159–169.

Upstill, G. and Spurling, T. H. (2007) Adjusting to changing times: CSIRO since the 1970s. *Innovation: Managment, Policy & Practice 9*(2): 113–124.

Upstill, G. and Spurling, T. H. (2008) New structures, new strategies: CSIRO's changing role in Australian innovation. *Prometheus 26*: 141–152.

Van de Ven, A. H. and Poole, M. S. (1990) Methods for studying innovation development in the minnesota innovation research program, *Organization Science 1*: 313–335.

Weick, K. E. (1995) *Sensemaking in organizations,* Sage, Thousand Oaks, CA.

Willis, J. B. and Sturman, B. T. (2005) A CSIRO invention and the development of the Australian spectropic instrument industry, *Chemistry in Australia 72*(4): 16–18.

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