

BIOTECHNOLOGY CLUSTERING

PHASE II: LANDSCAPE ANALYSIS

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Biotechnology Clustering – Landscape Analysis

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BIOTECHNOLOGY CLUSTERING STUDY

Executive Summary

Despite the strong reputation of Australian research in medicine, biology, and agriculture, the biotechnology industry in Australia remains modest by global standards. At the United States Studies Centre in the University of Sydney, through a research program funded by the Merck Foundation, we have studied this issue by comparing the biotechnology industry and its supporting ecosystem in Melbourne, Sydney and Brisbane with that of San Diego, California.

San Diego is a pertinent comparator city. Its metropolitan population is scaled roughly halfway between that of Brisbane and Melbourne, and its biotechnology sector has grown rapidly in recent years, generating significantly higher revenues, materially higher R&D spending, and a conspicuously greater asset base than the biotechnology sector across the whole of Australia.

The view that predominates in Australia, as confirmed by a range of participants in Australia's biotechnology sector whom we surveyed, is that we have failed to leverage our research base in biotechnology because of problems in Australia's industrial system. These include the lack of a "flagship" company that can act as a repository of talent when start-ups fail, a lack of access to patient venture capital funding, and a lack of sustained government policy support for biotechnology industry development at both the state and federal levels.

Our analysis, however, suggests a more worrying problem: that Australia's research base is not as outstanding as is popularly imagined. Contrasting the public research base in medical and biological sciences in Brisbane, Melbourne, and Sydney with that in San Diego reveals four fundamental points of difference.

First, Australian cities suffer from a lack of investment intensity. The absolute scale of investment in university research in Australian cities is lower than the equivalent investment in San Diego. More significant, however, is the difference in intensity of investment, as measured by university research investment per capita. Investment on university R&D per capita in San Diego (~US\$400 per person) is significantly higher than in Brisbane (~US\$300 per person), Melbourne (~US\$250 per person), or Sydney (~US\$200 per person).

Second, Australian cities support a relatively shallow, clinically oriented research portfolio in the life sciences. The scale of investment specifically in medical research (predominantly clinical research) in Australia's largest cities is not far behind the equivalent investment being made in San Diego. In San Diego however, for every research dollar invested in medical sciences, \$1.10 is also invested in the biological sciences. This contrasts starkly with the situation in Australia where, for every research dollar invested in medical sciences, less than 40 cents is invested in the

biological sciences. The implication is that the research portfolios of Australian cities are more clinically focused, more applied in orientation, and less likely to generate fundamental breakthroughs than is true in San Diego.

Third, Australian institutions generate research outputs of low average quality compared with San Diego. Over recent years, life scientists in Sydney, Melbourne, and Brisbane have steadily increased the number of articles they publish in scientific journals. Indeed, researchers from each of Melbourne and Sydney now author more papers in life science journals than researchers from San Diego. There is evidence, however, that Australian life scientists are generating volume by publishing in low impact journals and in parochial Australasian journals. As a consequence, while Australia's best research institutes do perform on a par with similar organizations in San Diego, aggregated citations per paper for Australia's leading universities look more like those of San Diego State University than the University of California, San Diego. This raises questions about the quality and global significance of much of Australia's research in the life sciences.

Fourth, Australian institutions appear to generate research outputs of lesser commercial significance. The life science research community in San Diego is much more active in patenting its intellectual property than is true in Australia. Public sector institutions in San Diego make significantly more patent applications based upon their research than do equivalent institutions in any of the Australian cities. Across both the public and private sectors, researchers in San Diego generate more than six times the number of international organic chemistry patents and more than four times as many international medical patents as researchers in any of the Australian cities. These figures imply not just a stronger research base in San Diego, but also a more abundant pool of new ideas available for exploitation by local businesses.

We believe that these fundamental differences should temper near-term expectations about the extent to which Australian public-sector research will generate commercial activity in biotechnology. We also suggest that without first increasing the scale, quality, and the focus of the research base in Australia, it is impossible to establish the extent to which any other purported deficiencies really do represent genuine problems that will impede the development of a biotechnology industry in Australia.

Our assessment suggests that a nascent appetite among some Australian policymakers to try to build higher scale and higher quality research institutes with a molecular rather than a clinical focus (as exemplified by the Institute for Molecular Bioscience at the University of Queensland) has been appropriate. Our analysis also implies, however, that such initiatives can be seen only as a starting point if Australia is to position itself as a serious participant in a future global biotechnology industry.

1. Background

Australia has an impressive history in medical, biological, and agricultural research. By way of illustration, of the nine Nobel Prizes awarded to Australian researchers since the Second World War, seven were in physiology or medicine and one other (John Cornforth's Nobel Prize for Chemistry) was awarded for biologically-relevant work. Indeed, since 1915, Australian researchers have won no Nobel prizes in any area of science without some biological or medical relevance.

At the same time, some of the most stirring and high profile success stories of Australian science in recent times have stemmed from biomedical research. One need only consider: the development of the bionic ear; the rational discovery of zanamivir, the world's first effective anti-influenza drug (now marketed as Relenza); and the more recent invention, development, and rollout of effective vaccines for the human papillomavirus and cervical cancer (Gardasil and Cervarix).

Inevitably, even discounting the Nobel prizes, it has been in the areas of medicine and biology that Australia has customarily identified its most inspiring researchers. Of the 54 Australians of the Year named since 1960, the recipients' most common fields of activity have been sport (15 Australians of the Year), the arts (10 Australians of the year), and medicine or medical science (11 Australians of the year). In comparison, with the exception only of Manning Clark (a historian), there have been no Australians of the Year outside the medical sciences who have predominantly earned recognition for their research activities.

Likewise, of the six chief scientists appointed to advise Australian Commonwealth Governments since 1989, four have held their specialty in the biological or medical sciences. Of the seventeen presidents of the Australian Academy of Science since 1954, nine have had a focus in biological or medical sciences – more than half.

These patterns of individual attainment are strongly reflected in the nation's public sector R&D investment. Around 40% of Australian public sector R&D activity is in the medical, biological or health sciences, while over 50% of Australian public sector investment in R&D is in the medical, biological, health, environmental, or agricultural sciences. (See ABS 8112.0.) This compares with just 8% of business investment, although even in this sector investment in the 'bio' fields has been growing dramatically. Over the decade from 1996/97 to 2006/07, total business investment in R&D across all fields expanded threefold, in nominal terms. By contrast, in the medical, biological, health, environmental and agricultural sciences, business R&D investment grew more than fourfold. (See ABS 8112.0.)

The existence of an impressive underlying capability in biological, medical and agricultural sciences in Australia has often been remarked upon in the Australian context. Arguably it has constituted part of the justification for significant recent investments in public research infrastructure. Two examples that stand out in this respect are the Institute for Molecular

Bioscience at the University of Queensland and the Bio21 Institute at the University of Melbourne. A question does remain though about the capacity within the Australian economy to leverage its knowledge base in the biosciences in order to grow a vibrant, internationally significant biotechnology industry.

It is a question, moreover, with ramifications that extend beyond this particular area of technological focus. A recent scoping report commissioned by the US Studies Centre has highlighted the very different capacities that seem to exist in the Australian and US economies for fostering innovative industrial clusters more generally. (See Barlow 2008.) Given the importance of clustering in US industrial development, common perceptions about the quality and scale of the Australian research base in the biosciences, and the policy focus that has been given specifically to biotechnology industrial development in Australia over the past decade, the US Studies Centre has commissioned an extensive comparative analysis of biotechnology clustering in San Diego, Sydney, Melbourne, and Brisbane.

The first phase of this study was to conduct a small survey of around 40 senior participants in Australia's biotechnology sector. These individuals were interviewed one-on-one on a confidential basis and were asked to provide responses to a consistent set of questions as well as to speak more broadly about their perceptions of biotech clustering in Australia. The results from this survey and the methodology are detailed elsewhere (see Barlow 2009a) but the key findings are summarised as follows.

- First, there was a majority view among those surveyed that Melbourne provides the closest thing in Australia to a biotechnology cluster and there was a weaker perception that Sydney provides the closest thing Australia has to a geographically concentrated medical-devices cluster. But San Diego was widely perceived as providing a richer cluster for biotechnology (using a broad definition) than Sydney, Melbourne, or Brisbane. *In other words, there was an acceptance that Australian entrepreneurs, scientists, and policy-makers might be able to learn something useful from a study of the biotechnology sector in San Diego.*
- Second, insofar as industrial development in biotechnology had occurred in the three Australian cities, there was a very strong perception that this has been driven predominantly by public research capability. *Over two-thirds of those surveyed cited the existence of a strong regional research capability as one of the main historical drivers supporting biotechnology cluster development in Australian cities.*
- Third, there was a widespread perception that biotechnology cluster development requires supportive state government policies. Other factors important for cluster development were raised, including: entrepreneurship; the existence of a pool of skilled scientists; federal government policies; the availability of capital; good industrial and academic networks; and the existence of global markets for biotechnology products. *But after the importance of local research capability, state*

government interest stood out for being the next most commonly cited driver of biotechnology cluster development in Australia. Interestingly, the lack of state government action was also the most commonly cited impediment to biotechnology cluster formation in NSW.

- Fourth, when asked about what they believed would be the main drivers for biotechnology cluster formation over the next 5 years, nearly half of those interviewed suggested the importance of achieving some successes or of attracting a major flagship company to their city. Other elements were also held to be important for the future development of a biotechnology cluster in Australian cities, including: the delivery of supportive state government policies; the extent to which Australian firms are able to attract capital; and the development of cooperative social networks across the industry. *But the desire for successful growth stories or for attracting a major flagship company to the region was the most commonly cited requirement for biotechnology clustering in Australia over the next five years.*

Given the high importance that seems to be attributed to the role of government (especially state government) in Australian biotechnology cluster development and given the significance that was attributed to flagship companies in cluster development, it was decided that these should form the basis of the United States Studies Centre's research into the San Diego biotechnology cluster. However, the issue of attracting (or retaining) a flagship company to a city also fits within a broader theme about Australia's distance from global markets and global investors. Recognising this, and seeing that this theme is relevant also to other issues (such as access to capital) that were raised in the survey, it was recommended that research on the San Diego biotechnology cluster be categorised as follows:

(a) The Role of Government

- How important have government policies been for the development of a biotechnology industry in San Diego? What should be the role of government in cluster development, vis-à-vis public policy, public investment and actual management of programs? What are the potential tradeoffs of more or less involvement?
- How important too are government actions today in helping the San Diego region to establish new technology directions (such as in stem cell research and algae biofuels) and to build momentum from basic research in these areas through to viable industries and jobs growth? In this, researchers will very explicitly document the developmental process.

(b) The Challenge of Remoteness

- San Diego, like Brisbane, Melbourne and Sydney, continues to be shaped: (i) by public policies that are often established in other places; (ii) by resources, in particular

capital, coming from other places; and (iii) by the need for strategic partners in the actual manufacturing and distribution of products. How does the biotech community in San Diego deal with the challenge of remoteness in these three dimensions?

- In relation to this challenge, moreover, what has been the role of major successes (i.e. companies that have a major impact) as well as “flagship” companies in enabling the growth of clusters in the San Diego region? What role do companies like these play in generating serial entrepreneurs, or attracting people to the region, or retaining people and companies in the region?

San Diego clearly has the potential to provide a very interesting model for comparison in trying to establish what might be effective and what might be counter-productive in the ongoing development of innovative biotechnology businesses in Brisbane, Melbourne and Sydney. Ongoing research sponsored by the United States Studies Centre, and being conducted by researchers at the University of California San Diego and at Global Connect in San Diego, is now looking into the issues outlined above.

However to understand the applicability of the San Diego model it is also important: (a) to test out some of the Australian perceptions identified in our survey; and (b) to establish a quantitative baseline for drawing comparisons. This was the original purpose of this document, which provides a landscape analysis of biotechnology activity in San Diego, Brisbane, Melbourne, and Sydney. The following, in other words, was intended primarily as a complement to the comprehensive research specifically on the biotechnology cluster in San Diego that has been commissioned by the United States Studies Centre.

In performing this analysis, however, some rather novel and exciting results have emerged. Principal among these is that there appears to be considerable evidence that the scale, quality and focus of the research base in Australia is not as conducive to industrial development in biotechnology as is currently imagined, even by people working within or associated with the biotechnology sector.

There is a widespread belief in Australia that the national culture promotes scientific creativity but not commercial innovation. According to this view, Australians make great scientists but poor entrepreneurs, Australians are unusually gifted in making discoveries but they lack an ability to commercialise their ideas, and Australians are highly inventive but their most valuable ideas nearly always end up being developed overseas.

The myth of Australian originality in discovery and the countervailing perception of national ineptitude in the commercial exploitation have been dealt with in broad terms in a recent book about the historical character of innovation in Australia. (See Barlow 2006.) Assessing this theme has not been the goal of the current study. It has emerged very strongly however, and in some ways quite surprisingly, from the comparative analysis of biotechnology clusters in Melbourne, Sydney, Brisbane and San Diego, described in this report.

Biotechnology Clustering – Landscape Analysis

This is not to denigrate the standard of 'bio' research in Australia as performed by its greatest researchers. Nor should it be interpreted as a sign that all of the major biotechnology policy initiatives of the past decade have failed in Australia. As we shall see, it does suggest however that the future vibrancy of any Australian biotechnology industry is not assured and will depend at least in part upon not just upon the activities of Australian entrepreneurs but also upon the extent to which public institutions can expand upon the efforts begun during the last decade to concentrate significant investments to build internationally leading research institutes.

2. Sector overview

Consistent with the views of Australian opinion leaders interviewed in late 2009, the evidence for industrial clustering in biotechnology is much stronger in San Diego than it is in Melbourne, Sydney or Brisbane.

This is neatly illustrated in table 1, which summarises information about public biotechnology companies, collated by Ernst and Young and published in 2009. The data here suggest that the San Diego biotechnology sector – as measured by assets, revenues, and R&D expenditures – is actually larger than that across the whole of Australia combined.

Especially striking is (a) the level of R&D spending per firm in San Diego, which is an order of magnitude higher than that in Australia, and (b) the total revenues of the sector in San Diego, which are nearly ten times as large as those in Australia once one excludes CSL from the analysis.

Table 1 – Public company comparison in biotech, 2007-08

(US dollars)	San Diego	Australia	Australia (excl. CSL)
Number of public companies	40	84	83
Market capitalisation	17.5 billion	21.5 billion	5.6 billion
Total assets	15.6 billion	6.5 billion	2.4 billion
Revenue	3.97 billion	3.6 billion	430 million
Net income (or loss)	(945 million)	134 million	(492 million)
R&D expenditures	1.72 billion	499 million	298 million
R&D / revenue	43%	14%	69%
R&D / company	43 million	5.9 million	3.6 million

Note: Data obtained from E&Y 2009 and CSL 2008. Takes a narrow definition of biotechnology – i.e. does not include medical technology companies like Cochlear and ResMed.

In contrasting the San Diego sector with the sector in Australia, it is quite instructive to exclude the data on CSL as the scale of this organisation arguably distorts any conclusions that might be drawn about the rest of the sector. There is no single firm in San Diego with the same dominating scale as CSL exerts in Australia. In addition, as a multinational blood plasma company, CSL is arguably quite distinctive both in technological orientation and in geographic footprint compared with the other biotechnology companies underpinning this dataset.

Taking such an approach then, a further observation to be made is how much less profitable the Australian sector is compared with the San Diego cluster.

- Excluding CSL from the analysis, the Australian public biotechnology companies reported a combined loss of US\$490 million on assets of US\$2.4 billion and revenues of US\$430 million in 2008 – i.e. the loss in 2008 was equivalent to around 20% of assets and >100% of revenues.

- The public biotechnology companies in San Diego, by contrast, reported a loss of US\$950 million on assets of US\$15.6 billion and revenue of US\$3.97 billion – i.e. the loss in 2008 was equivalent to around 6% of assets and around 24% of revenues.

It can be observed that the above analysis is based only upon publically listed companies and excludes firms working in the medical devices sector. These limitations however should not seriously undermine the broad conclusions that might be drawn.

Given the well documented tendency for Australian firms to go public early (see Vitale 2004), a focus on publically listed firms likely captures a higher proportion of Australian biotechnology businesses than it does of San Diego firms. This may partly explain the low profitability of Australian firms compared with those in San Diego, but it also reinforces the observation that the sector in Australia operates at low scale. Whichever way one interprets the data (as low in scale or low in profitability) the Australian biotechnology industry appears significantly under-developed in comparison to the industry in San Diego.

Gathering equivalent data on the medical devices sector is, in addition, unlikely to modify drastically the conclusions that can be drawn. Australia's two leading medical devices companies (Cochlear and ResMed) had combined net income of around US\$220 million and spent a total of around US\$130 million on R&D in 2008. Including their data on the Australian side of the ledger in table 1 would not materially modify the conclusions one draws from this table – and of course ResMed is now headquartered in San Diego, so arguably its figures should be spread across both locations.

In short, the strong indications from this data are that the biotechnology sectors in Melbourne, Sydney, and Brisbane are significantly smaller and are at a significantly earlier stage of development than is true in San Diego. This conclusion obviously reinforces the perceptions of individuals working in or associated with the biotechnology industry in Australia and confirms the benefits that may be derived from an assessment of the industrial ecosystem in San Diego. But it raises questions too about Australian perceptions of industrial development in biotechnology. For example:

- First, if one accepts as true the widespread view that Australia has a strong public research capability relevant to biotechnology, the observed disparity in industrial outcomes between Australian cities and San Diego must necessarily be attributed to other factors. But this perception needs to be tested by contrasting empirical data on public research capability.
- Second, if one believes that the disparity in industrial outcomes in biotechnology across Australian cities is attributable to differences in government enthusiasm and government support, one might also expect to see higher levels of government support

- Third, if the concerns expressed in our survey about the impact of distance from global markets (especially on the ability to attract flagship companies, the ability to attract investment, and the ability to identify and work with strategic partners and customers) are justified, one might likewise expect to see a significant disparity between San Diego and Australian centres in these respects also.

Some observations about each of these themes will be addressed in the following sections. The dominant focus for our analysis however is to contrast the underlying research capability across the four regions and to test the assumption that Australian cities should expect a biotechnology industry to evolve given the perceived strength and vitality of its research base.

3. Testing assumptions about research capability

It is relatively straightforward to draw comparisons of research capability in biotechnology in San Diego, Brisbane, Melbourne and Sydney. In the section that follows we analyse R&D expenditures, publication outputs, and international patents by region.

Our key findings are:

- (a) that research is conducted at a significantly greater intensity in San Diego than it is in Sydney, Melbourne, or Brisbane; and
- (b) that research in San Diego is more carefully focused in fundamental biology and is more likely to lead to patenting activity than is true in the three Australian centres.

3.1 R&D expenditures

There are several ways to compare regions' R&D activity, but one useful place to start is by contrasting scale of R&D expenditure.

The assessment in the previous section suggested that the scale of industrial R&D spending in the San Diego biotechnology cluster is over three times that in Australia as a whole. On this basis, the amount of industrial R&D spending in the biotechnology industry in San Diego is at least three times greater than the scale of spending in Melbourne, Sydney or Brisbane individually – and probably closer to six times greater than the scale of spending in even the most vibrant of these Australian cities.

The level of business R&D activity though is perhaps as much a consequence of success in the San Diego biotechnology cluster as it is a cause of it and for this reason an equally useful comparison can be made by analysing public-sector investment in biotechnology R&D.

Public investment in R&D has been linked to industrial clustering in biotechnology since the genesis of biotechnology as an industry sector, but it is especially useful to contrast public R&D investment in biotechnology as this is an area of perceived special strength in Australia. As noted in the introduction to this report, over two-thirds of those interviewed in our preliminary survey of biotechnology leaders in Australia cited the existence of a strong regional publically funded research capability as one of the main historical drivers of local biotechnology cluster development.

The simplest way to evaluate public investment in R&D is to contrast levels of university investment. Of course a comparison of organisations classified as higher education institutions overlooks the role of CSIRO, of the medical research institutes and of some state hospitals and state departments of primary industries in Australia. But it also overlooks the

investment in San Diego within the Salk Institute, the Burnham Institute, and other non-university, non-commercial research organisations operating in San Diego.

It should be noted too that the three Australian cities and the San Diego region all invest significantly more in university R&D (if one follows the convention of the National Science Foundation and includes the Scripps Research Institute as a higher education institution) compared with their regional investment in government agencies and private non-profit research institutes. This means that a comparison made of university R&D activity should be expected to provide a useful, if imperfect, representation of the relative scale of public research activity being carried out in the Australian centres compared with that in San Diego.

To this end then, table 2 summarises total R&D expenditure in higher education institutions in the four cities. It suggests the following two points.

- First, the total scale of university R&D activity across all fields is clearly higher in San Diego than it is in Melbourne, Sydney, or Brisbane. However the absolute difference is not drastic in every case. San Diego’s investment is roughly double that in Brisbane but only 30% higher than the scale of activity in Melbourne.
- Second though, given the scale by population of the cities in the question, it is striking how marked are the differences in intensity of activity – i.e. expenditures normalised for population. Spending per person on higher education R&D in the wider San Diego area is double that which is spent in metropolitan Sydney.

Table 2 – Higher Education R&D, 2006

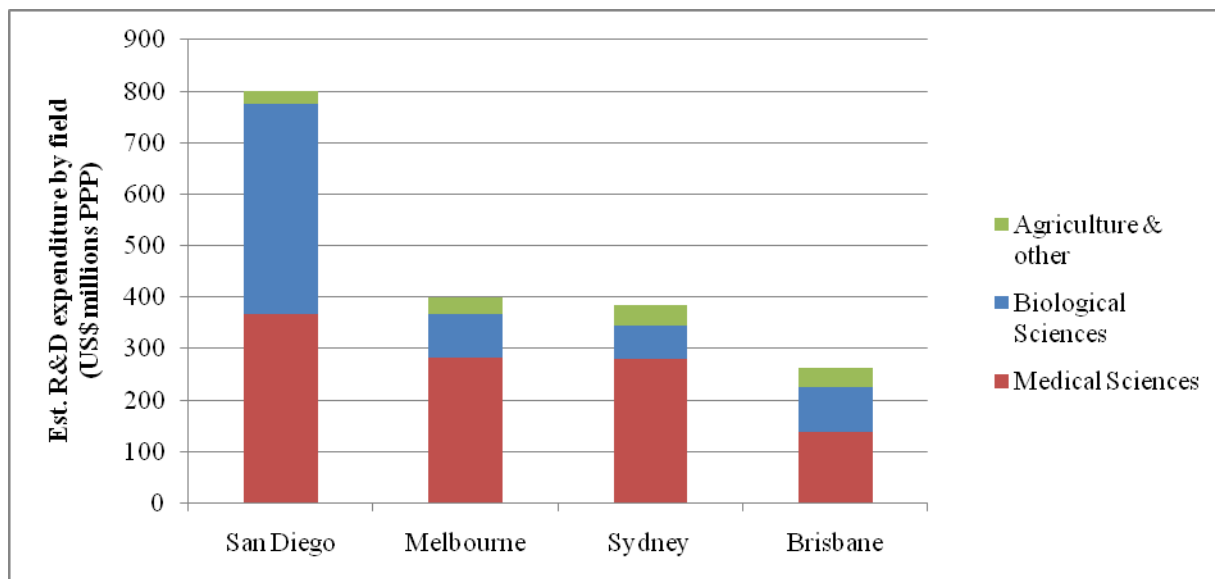
City	Population	Est. higher education R&D spending (US\$ PPP)	Est. higher education R&D spending per capita (US\$ PPP)
San Diego	2.8 m	\$1.2 bn	\$406
Melbourne	3.7 m	\$930 m	\$247
Sydney	4.3 m	\$870 m	\$203
Brisbane	1.8 m	\$560 m	\$309

Note: Metropolitan areas are broadly defined; R&D spending is rounded to the nearest \$10m; in the case of San Diego the Scripps Research Institute is counted as a higher education institution while the Salk Institute is not; in the case of Australian cities medical research institutes are not counted as higher education organisations. Data sourced from Barlow 2009.

One might conclude from this data that institutions in San Diego have been highly successful at attracting resources from other parts of the US. Certainly organisations in the San Diego region can only have benefited in building scale in their research by operating with access to continental-scale funding programmes such as those provided through the NSF and the NIH.

There is more to the story than this though as illustrated by figure 3, which looks more specifically at university R&D expenditures in the life sciences – i.e. in fields of research that might be expected to be relevant for a local biotechnology industry.

Figure 3 – Higher Education R&D in agricultural, biological, and medical sciences, 2006



Note: Data sourced from NSF 2009, ABS 8111.0, and Barlow 2009. NSF data is available only for the three major institutions in San Diego: UCSD, the Scripps Research Institute, and San Diego State University.

The R&D expenditures used in this figure are collected in different ways in both countries (though using a shared definition as proscribed by the OECD) and, as a caution, the more one disaggregates this data the more circumspect one should be about how one uses it, especially in making international comparisons. Nonetheless, it is interesting to note the significantly higher expenditures in life sciences fields in San Diego institutions and especially the massively higher focus on fundamental biology *relative to* investment in medical science.

The comparison here is especially well made between San Diego and Melbourne. In 2006, university investment in biological sciences in Melbourne was only 30% of the level of investment in medical sciences. This compares with the situation in San Diego's universities, where investment in biological sciences was 110% of the investment in medical sciences. To put it another way, in 2006 it would seem that:

- a) across all fields, higher education R&D spending was only 30% higher in San Diego than was true in Melbourne;
- b) in medical sciences, higher education R&D spending was only 30% higher than was true in Melbourne; but
- c) in biological sciences, higher education R&D spending was nearly five times higher than was true in Melbourne.

This interesting distinction may, in part, be an artefact of how researchers in the US and Australia define their disciplines. People doing identical work in Australia and San Diego may be choosing to report under medical codes in Australia and under biological codes in the US. It is unlikely however that this definitional effect could account for the entire difference in the observed funding profile, such is its magnitude.

This raises an alternative hypothesis: that the perceptions of a strong research base in Australia are predicated upon investment in Australian medical research rather than upon investment in fundamental biology. This is a hypothesis that is strongly reinforced through an assessment of the scientific literature.

3.2 Scientific publications – research focus

There are several ways to analyse scientific outputs at a regional level but the method we have chosen for this report is simply to count publications using key address fields in the ISI Web of Science.

For our four regions, ISI Web of Science publication counts were first identified between 2001 and 2008 using the address fields specified below:

- address=(San Diego or La Jolla)
- address=(Sydney or NSW or New South Wales) SAME Australia
- address=(Melbourne or Victoria or VIC) SAME Australia
- address=(Brisbane or QLD or Queensland) SAME Australia

It should be noted that the Australian regions in this instance have had to be expanded to the state level rather than the city level due to the high number of Australian metropolitan authors who specify their addresses using their state and suburb rather than their city.

Having derived a dataset of outputs for each region, publications were next classified into groups using the ISI's subject categories. Categories of relevance to medical and biological sciences are listed in table 4, where they are grouped into three sets: medical subject categories, molecular and cell biology subject categories, and other biology subject categories.

The groupings in this table are subsequently used in figures 5 to 9 to compare the scientific focus of the research community in the medical and biological sciences in the four regions. Figure 6, for example, shows publication counts in the ISI Web of Science by region in journals listed in subject categories from the first column in table 4; figure 7 shows publication counts by region but only in journals listed in subject categories from the second column of table 4; while figure 8 shows publication counts by region for journals listed in subject categories from the third column of table 4.

In interpreting these figures it should be remembered that, while most journals are linked to one subject category, some journals are linked to more than one subject area. The journal *Vaccine* for example is linked within the ISI Web of Science to three subject areas, each of which sits in a different column in table 4: 'medicine, research and experimental', 'immunology', and 'veterinary sciences'.

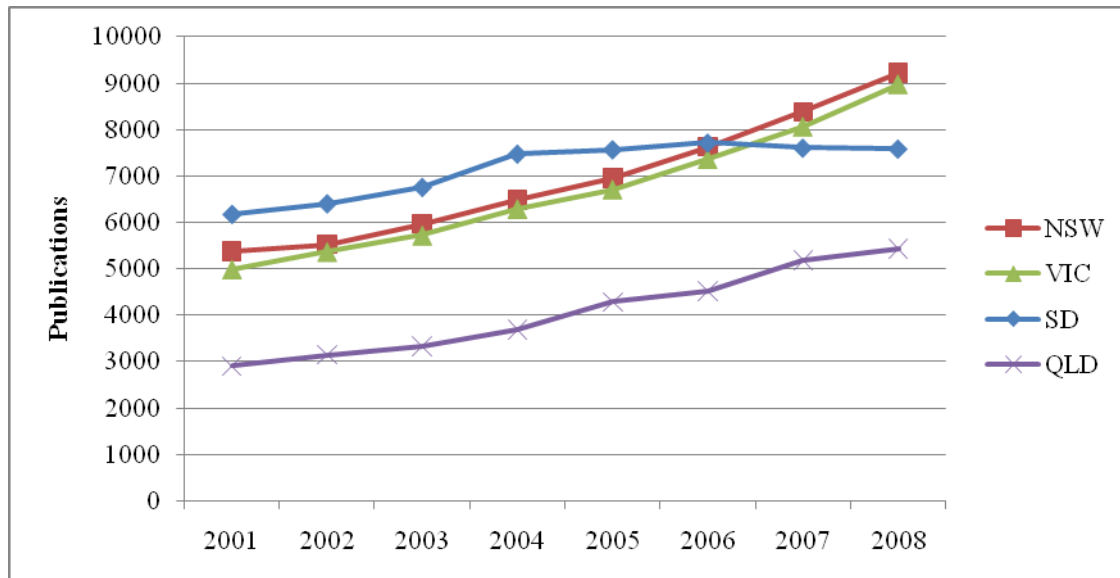
This effect means that you cannot sum outputs across the three broad areas designated in table 4 in order to reach regional totals, but it does not prevent useful comparative conclusions from being drawn from the analysis.

Table 4 – Classifying Subject Categories in the ISI Web of Science

Medical sciences	Molecular and cell biology	Other biological sciences
Allergy; Anatomy & morphology; Andrology; Anesthesiology; Cardiac & cardiovascular systems; Clinical neurology; Critical care medicine; Dentistry, oral surgery & medicine; Dermatology; Emerging medicine; Endocrinology & metabolism; Ergonomics; Gastroenterology & hepatology; Geriatrics & gerontology; Gerontology; Health care sciences & services; Health policy & services; Hematology; Infectious diseases; Integrative & complementary medicine; Medical ethics; Medical informatics; Medical laboratory technology; Medicine, general & internal; Medicine, legal; Medicine, research & experimental; Nursing; Nutrition & Dietetics; Obstetrics & Gynecology; Oncology; Ophthalmology; Orthopedics; Otorhinolaryngology; Parasitology; Pathology; Pediatrics; Peripheral vascular disease; Physiology; Psychiatry; Psychology, clinical; Radiology, nuclear medicine & medical imaging; Rehabilitation; Reproductive biology; Respiratory system; Rheumatology; Social sciences, biomedical; Substance abuse; Surgery; Toxicology; Transplantation; Tropical Medicine; Urology & Nephrology	Biochemical research methods; Biochemistry & molecular biology; Biophysics; Biotechnology & applied microbiology; Cell biology; Chemistry, medicinal; Crystallography; Developmental biology; Genetics & heredity; Immunology; Microbiology; Neuroimaging; Neurosciences; Pharmacology & pharmacy; Virology	Agriculture, dairy & animal science; Agriculture, multidisciplinary; Agronomy; Biodiversity conservation; Biology; Ecology; Engineering, biomedical; Entomology; Environmental sciences; Evolutionary biology; Fisheries; Food science & technology; Forestry; Marine & freshwater biology; Materials science, biomaterials; Mathematical & computational biology; Mycology; Plant sciences; Psychology, biological; Soil sciences; Veterinary sciences; Zoology

Note: Medical and biological subject categories used by the ISI Web of Science are re-classified into three groups for this report.

Figure 5 – Publications in medical and biological journals, 2001 to 2008



Note: Derived from ISI Web of Science. Counts publications listed in the Web of Science published in journals listed in the subject categories shown in table 4. Whole rather than fractional counts are used.

We begin then with figure 5, which shows whole publication counts in the ISI Web of Science in journals listed in all subject categories in table 4.

This figure is interesting in the first instance since it seems to imply that, despite the gap between San Diego and Australian cities in university R&D investment across medical and biology fields, there is no corresponding gap in publication outputs. To put this in a different way, compared with the R&D expenditures shown in figure 3, the publication counts from Australian states relative to those from San Diego in figure 5 seem to be very high.

There are several possible explanations for this, most of them methodological and these explanations are worth summarising briefly so that this data is not over-interpreted.

- First, it must be remembered that the results in both cases are influenced by the different catchment areas used for both analyses. One should remember that figure 5 shifts the focus from Australian cities to states. It is also possible that the method employed in searching the ISI Web of Science under-counts outputs from the San Diego region, depending upon the address fields used by researchers in the region.
- Second, the analysis in the previous section did not establish the level of public sector R&D investment occurring outside universities – for instance in hospitals and medical research institutes – in the various locations being studied, which obviously will have a bearing on any cost-efficiency analysis.
- Third, the figure is based on whole publication counts rather than counts that are fractionated for co-authorships. This will tend to exaggerate the productivity of

researchers who have high levels of collaboration with researchers outside their own region.

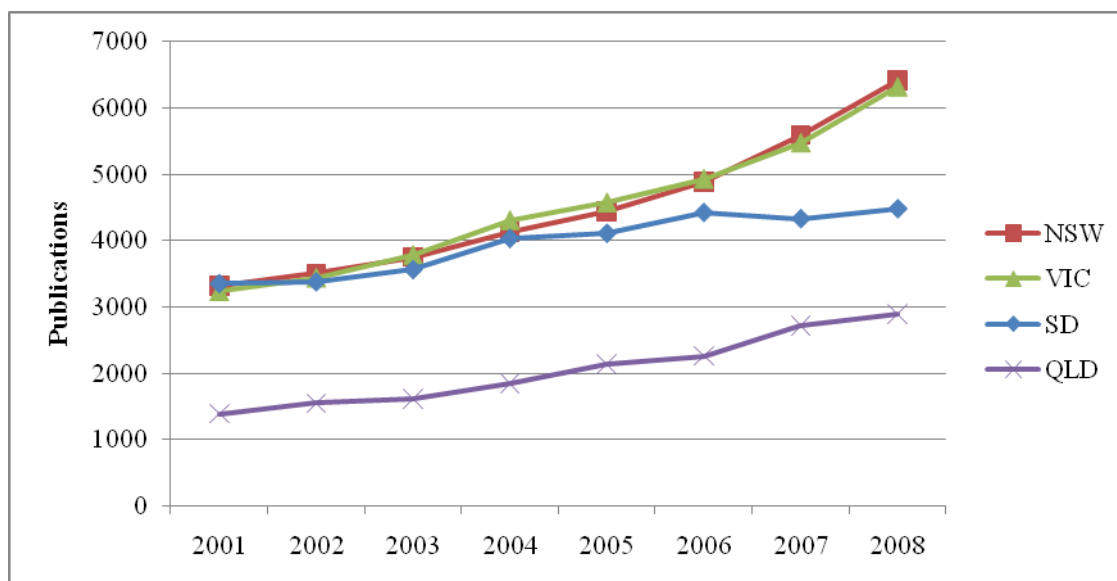
- Fourth, the similarity in scale of outputs compared with the apparent dissimilarity in scale of inputs could be influenced by the cost structures of different fields, and by the different disciplinary focus in San Diego compared with the Australian centres. Thinking back to the R&D expenditure data presented in figure 3, it would seem credible to suggest that research performed in San Diego in biological sciences is far more capital-intensive than the medical research currently taking place in Australia.
- Fifth, and most significantly, the apparent contradiction between outputs and inputs may reflect differences in publishing behaviours. Australian researchers in general appear to be cost-effective at producing papers in terms of dollars spent per publication (see Barlow 2009). There is evidence though that this efficiency is being achieved at the expense of publication quality. One factor here may be the role of government policy in Australia, which funds research, in part, based upon crude publication counts (see Butler 2003a and Bulter 2003b). Whatever the cause, as we will see, Australian researchers are much less likely than researchers in San Diego to publish in the highest impact journals.

This last point is extremely significant in interpreting the role that public-sector research may play in biotechnology cluster development, and we will return to this below (see section 3.3). In the first instance though, we present these five caveats simply to discourage readers from drawing elaborate conclusions by comparing the input and output data. What is more important for our analysis is not the number of total outputs per se, but rather the number of outputs in different areas of scientific focus – i.e. the extent to which each region balances its activity between medical science, molecular and cell biology, and other areas of biology. Here we turn to figures 6, 7 and 8, where the evidence is strongly consistent with the R&D input data, pointing to a relative weakness in fundamental biology research in all three Australian cities.

Looking first at figure 6, one observes two features: (i) a very similar production of scientific articles in medical science journals across San Diego, Victoria and NSW through to 2004; then (ii) a burst of productivity in the Australian states relative to San Diego from 2004 onwards.

The latter of these points – the substantial growth in total publication outputs from Australian states within journals in medical subject areas – arguably reflects the dramatic expansion in Australian university research investment over the period. The timeframe in figure 6 corresponds to a period where ARC and NHMRC funding in Australia more than doubled and there is evidence that Australian funding over this period was preferentially allocated to medical research (Barlow 2009). It is the former point though – the similar production of scientific articles in medical science categories across San Diego, Victoria and NSW – that is most interesting about the figure.

Figure 6 – Publications in medical journals, 2001 to 2008



Note: Derived from ISI Web of Science. Counts publications listed in the Web of Science published in journals listed in the subject categories shown in column 1 of table 4. Whole rather than fractional counts are used.

Given that biotechnology industry was growing more rapidly in San Diego over these years than was true in Sydney or Melbourne one might conclude from this either:

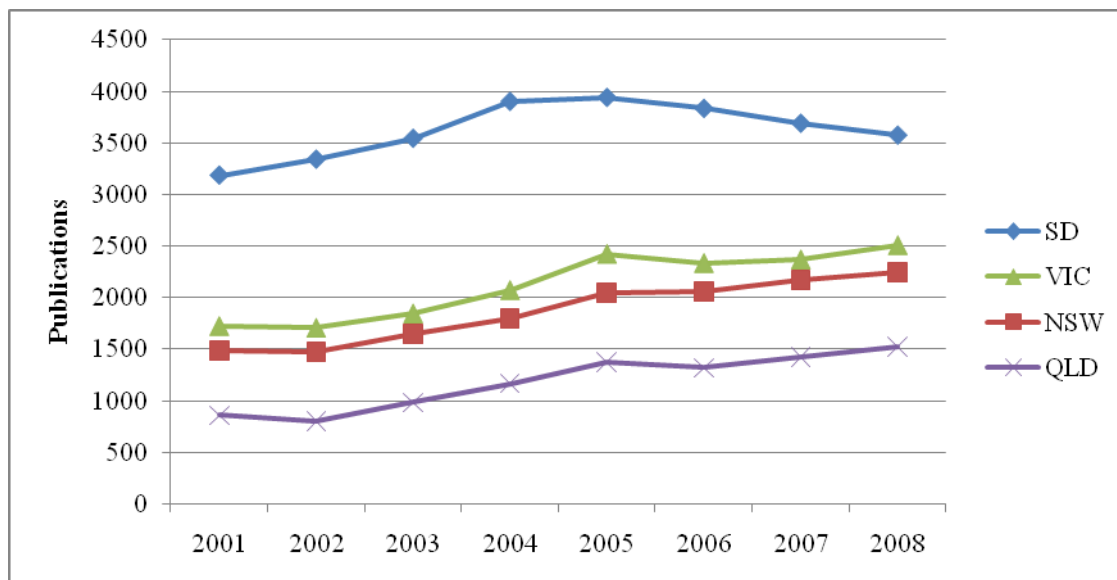
- a) that Melbourne and Sydney both have adequate medical research capacity and that the slower growth of their biotechnology industry is largely due to other impediments unrelated to public research capability – this arguably is emerging as the fashionable view in Australia; or
- b) that medical research is a less critical determinant of biotechnology industry growth than research in other areas, and that Australian regions interested in building biotechnology clusters may actually need to refocus their public research effort.

Figure 7 is instructive in choosing between these interpretations. This figure shows that the level of publication outputs in molecular biology and cell biology subject areas is dramatically different in San Diego and in the Australian states – with San Diego’s level of output significantly higher than in any of the Australian states. These are apparently fields where public institutions in San Diego have focused and they are fields in comparison where researchers in Australia have not.

These are also the fields that intuitively seem most aligned with recent breakthroughs in medical biotechnology and they are the fields that are potentially more relevant for industry development than much of the research that is carried out, by contrast, in clinical medicine. The picture that emerges, in other words, from the publications data does reflect the qualitative patterns of R&D investment estimated previously in figure 3: Australian regions do seem to be producing medical articles on a similar scale to San Diego but are lagging in

their production of outputs in fundamental biology. This, in turn, may suggest that the research base in Australia does not provide so strong a foundation for biotechnology industry development as is widely perceived in Australia.

Figure 7 – Publications in molecular and cell biology journals, 2001 to 2008



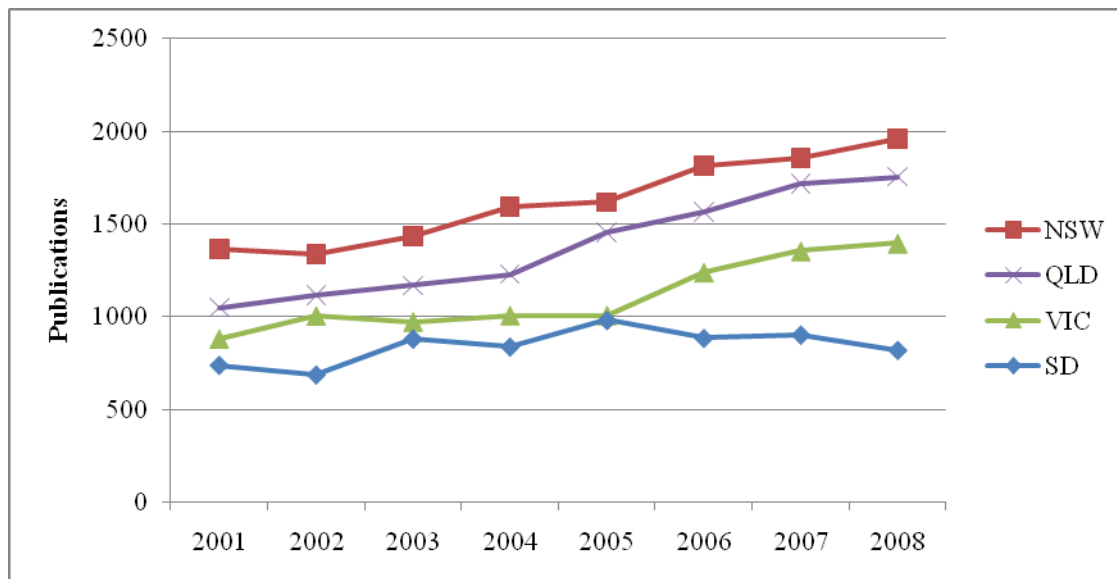
Note: Derived from ISI Web of Science. Counts publications listed in the Web of Science published in journals listed in the subject categories shown in column 2 of table 4. Whole rather than fractional counts are used.

By contrast, all Australian regions seem to have considerable strength relative to San Diego in agriculture, whole-organism, and environmental biology. Figure 8 plots publications in the ISI Web of Science by region corresponding to the subject categories listed in the third column of table 4. It shows that San Diego’s outputs in these areas lag behind those of NSW, Queensland and Victoria. The distinction is even more strongly made in figure 9, which plots the same data but with journals corresponding to the ISI subject categories of ‘biology’ and ‘mathematical and computational biology’ excluded.

The justification for these exclusions is that these are areas where there is considerable overlap with other ISI subject categories. Some of the research published in these two categories is relevant to the grouping in the third column of table 4, but not all. For example, a number of outputs in the subject category of ‘biology’ are due to publication in the journal FASEB, a journal which has been already counted in two other subject areas listed in the second column of table 4: ‘biochemistry & molecular biology’ and ‘cell biology’. Arguably including FASEB and similar outputs in an assessment of ‘other areas of biology’ inflates performance for regions like San Diego that we already know have a strong focus on molecular and cell biology. By discounting for this effect, in other words, figure 9 provides a more accurate representation of relative performance – and indicates that the discrepancy between San Diego and the Australian states in agricultural, whole-organism and environmental biology is actually quite substantial. Compared with Sydney, Melbourne and Brisbane, it would appear that San Diego and La Jolla have only a modest output in most

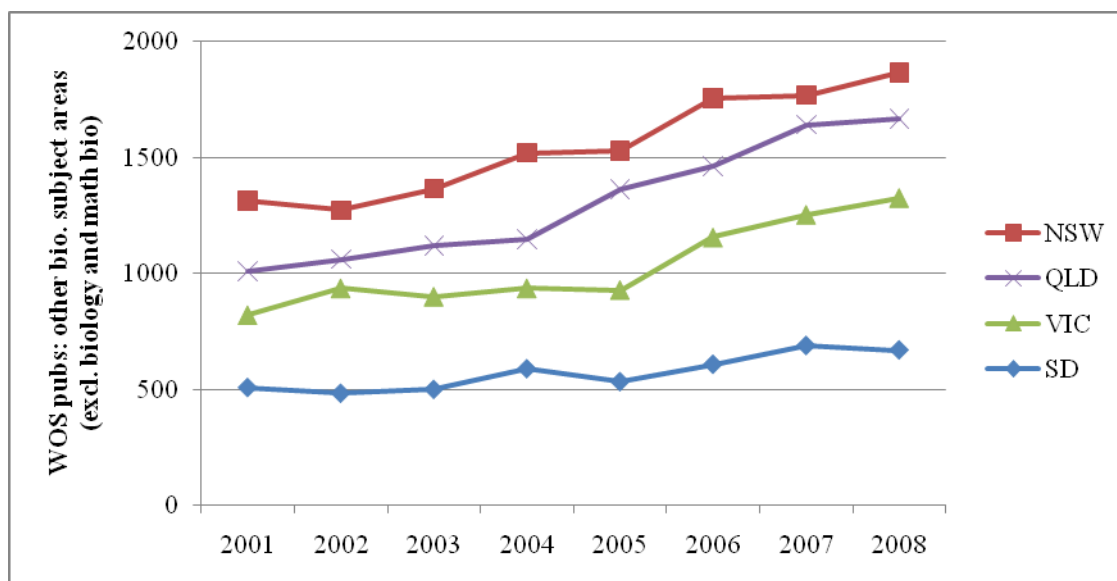
areas relating to agriculture, whole-organism, and environmental biology. This may suggest that Australia’s public research base (especially in NSW and Queensland) remains in some ways better attuned to the development of new industry in agricultural biotechnology and environmental biotechnology than it is to the development of a globally competitive industry in medical biotechnology.

Figure 8 – Publications in journals relevant to other areas of biology, 2001 to 2008



Note: Derived from ISI Web of Science. Counts publications listed in the Web of Science published in journals listed in the subject categories shown in column 3 of table 4. Whole rather than fractional counts are used.

Figure 9 – Publications in journals relevant to agricultural, whole-organism, and environmental biology, 2001 to 2008



Note: Derived from ISI Web of Science. Counts publications listed in the Web of Science published in journals listed in the subject categories in column 3 of table 4, but excluding journals listed in the subject categories of ‘biology’ and ‘mathematical & computational biology’. Whole rather than fractional counts are used.

In summary, Australian states seem to be on a par with San Diego in medical research and very strong in agricultural, whole-organism, and environmental biology, but weak relative to San Diego in fundamental molecular and cell biology. Confirming the broad evidence above, this conclusion is also supported by an analysis of research quality and of international patent activity, as described in the following two sections.

3.3 Scientific publications – research quality

If the participants in the biotechnology sector in Australia suffer from a conceit about the standard and relevance of the public research base in their regions, it can only be sobering to contrast the journals where Australian biomedical researchers are choosing to report their results with those used for dissemination by researchers in San Diego. Tables 10a and 10b list the leading life-sciences journals for each of San Diego, Victoria, NSW, and Queensland, ranked by number of articles published with at least one author from the relevant region. The difference between San Diego and the Australian centres in these rankings is striking, pointing to significant differences both in the quality of research being performed and in the extent to which researchers in the different regions aspire to participate in *global* as opposed to *regional* science.

On the one hand, the journal list for San Diego is noteworthy for including a number of very high impact journals: PNAS (206 articles), the Journal of the American Chemical Society (87 articles), the Journal of Immunology (59 articles), Science (40 articles), Nature (35 articles), Cell (24 articles), and so on. Indeed the list of top-25 journals for San Diego arguably stands out for including no journals at all of relatively low impact.

On the other hand, the journal list for Victoria, NSW, and Queensland is heavily dominated by lower impact publications (many with impact factors of 1 or lower) and particularly by regional journals. Tellingly in this respect, the three leading life sciences journals in both Victoria and NSW by publication counts are: the Medical Journal of Australia (81 articles published with a Victorian author), the Australian Family Physician (66 articles published with a Victorian author), and the Australian Journal of Experimental Agriculture (41 articles published with a Victorian author). None of the Australian states can include Nature, Science or Cell among its top 25 journals by publication count.

The dominance of regional medical journals in Australia's output should be especially troubling for individuals or organisations that aspire to create around them a globally relevant biotechnology sector. For instance, more than half the top 25 journals in which Victorian life scientists are authoring articles are actually named as "Australian" or "Australasian" journals. The vast majority of these moreover are medical journals. The implication is not only that Australian life-science research is more parochial than that taking place in San Diego, but that the preferential investment by Australian funding bodies in medical research compared with investment in fundamental biology may actually be stimulating this parochialism.

Table 10a – Top life-sciences journals from San Diego, Victoria and NSW, by articles published per journal per region in 2007

San Diego		Victoria		NSW	
Journal	Articles	Journal	Articles	Journal	Articles
PNAS (9)	206	Medical Journal of Australia (3)	81	Medical Journal of Australia (3)	93
Journal of Biological Chemistry (5)	129	Australian Family Physician (<1)	66	Australian Family Physician (<1)	68
J. American Chemical Society (9)	87	Aust. J. Exp. Agriculture (<1)	41	Aust. J. Exp. Agriculture (<1)	52
Bioorganic & Med. Chem. Letters (3)	73	Journal of Immunology (6)	40	Australasian Psychiatry (2)	36
Journal of Immunology (6)	59	Journal of Biological Chemistry (5)	39	Internal Medicine Journal (2)	36
Journal of Virology (5)	53	PNAS (9)	38	Invest. Ophthalmol. & Visual Sci. (3)	34
Journal of Neuroscience (7)	51	Australasian Radiology (<1)	35	J. of Paediatrics & Child Health (1)	34
Journal of Molecular Biology (4)	46	J. of Paediatrics & Child Health (1)	33	ANZ Journal of Surgery (1)	32
Biochemistry (3)	44	Internal Medicine Journal (2)	29	ANZ Journal of Psychiatry (2)	32
PLOS One (4)	40	Anaesthesia and Intensive Care (1)	28	Australian Veterinary Journal (1)	30
Science (30)	40	ANZ Journal of Surgery (1)	28	ANZ Journal of Public Health (1)	29
Biochem. & Biophys. Res. Comms. (3)	37	ANZ Journal of Public Health (1)	28	Contemporary Nurse (<1)	27
Journal of Medicinal Chemistry (5)	37	Australian Journal of Chemistry (2)	27	Journal of Biological Chemistry (5)	26
Cancer Research (8)	35	Blood (11)	27	PNAS (9)	26
Nature (34)	35	Australian Health Review (<1)	26	Australasian Radiology (<1)	24
Blood (11)	31	Endocrinology (5)	26	Marine Ecology – Progress Series (3)	23
Journal of Cell Biology (10)	30	Australasian Psychiatry (<1)	25	Nutrition & Dietetics (<1)	23
J. American Coll. Cardiology (13)	28	Emergency Med. Australasia (<1)	25	Acta Crystallographica Section E (<1)	21
Cell (31)	24	Invest. Ophthalmol. & Visual Sci. (3)	24	Austral Ecology (2)	20
Molecular and Cellular Biology (6)	23	Nephrology (1)	24	Australian J. Agricultural Res. (1)	20
Neuroimage (6)	22	ANZ Journal of Psychiatry (2)	22	Clinical & Exp. Ophthalmology (2)	19
Am. J. Physiol. - Heart & Circ. (4)	21	Australian J. Agricultural Res. (1)	21	J. American Chemical Society (9)	20
Antimicrobial Agents & Chemother. (5)	21	Australian Veterinary Journal (1)	20	American J. of Ophthalmology (4)	19
Oncogene (7)	21	Infection and Immunity (4)	19	Emergency Med. Australasia (<1)	19
Invest. Ophthalmol. & Visual Sci. (3)	20	Journal of clinical Neuroscience (1)	19	Journal of clinical Neuroscience (1)	19
J. of Bacteriology (4)	20	Journal of Virology (5)	19	Lancet (31)	19
J. of Clinical Investigation (15)	20	Vaccine (4)	19	ANZ J. of Obstetrics & Gyn. (1)	18
J. of Natural Products (3)	20	Sexual Health (1)	18	J. of Physiology – London (5)	18

Note: (i) Derived from ISI Web of Science. The top medical, biomedical or biology journals in the Science Citation Index are shown by number of articles published with a least one author from a given region. (ii) Impact Factors for the journals are shown in brackets based upon 2009 data as some of the Australasian journals did not have impact factors in 2007 (iii) Shading is used to indicate journals with impact factor > 10, while journals based out of Australia or Australasia are also highlighted in bold.

Table 10b – Top 25 life-sciences journals from San Diego, Victoria and Queensland, by articles published per journal per region in 2007

San Diego		Victoria		Queensland	
Journal	Articles	Journal	Articles	Journal	Articles
PNAS (9)	206	Medical Journal of Australia (3)	81	Medical Journal of Australia (3)	41
Journal of Biological Chemistry (5)	129	Australian Family Physician (<1)	66	Australian Family Physician (<1)	32
J. American Chemical Society (9)	87	Aust. J. Exp. Agriculture (<1)	41	Journal of Biological Chemistry (5)	29
Bioorganic & Med. Chem. Letters (3)	73	Journal of Immunology (6)	40	Marine Ecology – Progress Series (3)	28
Journal of Immunology (6)	59	Journal of Biological Chemistry (5)	39	Australian Veterinary Journal (1)	26
Journal of Virology (5)	53	PNAS (9)	38	Australian J. Exp. Agriculture (<1)	25
Journal of Neuroscience (7)	51	Australasian Radiology (<1)	35	Coral Reefs (3)	25
Journal of Molecular Biology (4)	46	J. of Paediatrics & Child Health (1)	33	Aquaculture (2)	24
Biochemistry (3)	44	Internal Medicine Journal (2)	29	Zootaxa (<1)	24
PLOS One (4)	40	Anaesthesia and Intensive Care (1)	28	Australasian Psychiatry (<1)	20
Science (30)	40	ANZ Journal of Surgery (1)	28	Acta Crystallographica Section E (<1)	18
Biochem. & Biophys. Res. Comms. (3)	37	ANZ Journal of Public Health (1)	28	Marine and Freshwater Res. (2)	18
Journal of Medicinal Chemistry (5)	37	Australian Journal of Chemistry (2)	27	Australasian Radiology (<1)	35
Cancer Research (8)	35	Blood (11)	27	Australian J. of Agricultural Res. (1)	17
Nature (34)	35	Australian Health Review (<1)	26	Australian J. of Soil Res. (1)	17
Blood (11)	31	Endocrinology (5)	26	Journal of Clinical Nursing (1)	17
Journal of Cell Biology (10)	30	Australasian Psychiatry (<1)	25	PNAS (9)	17
J. American Coll. Cardiology (13)	28	Emergency Med. Australasia (<1)	25	Applied & Environ. Microbiology (4)	16
Cell (31)	24	Invest. Ophthalmol. & Visual Sci. (3)	24	Austral Ecology (2)	16
Molecular and Cellular Biology (6)	23	Nephrology (1)	24	Aus. Occupational Ther. J. (<1)	16
Neuroimage (6)	22	ANZ Journal of Psychiatry (2)	22	Marine Biology (2)	16
Am. J. Physiol. - Heart & Circ. (4)	21	Australian J. Agricultural Res. (1)	21	Emergency Med. Australasia (<1)	15
Antimicrobial Agents & Chemother. (5)	21	Australian Veterinary Journal (1)	20	PLOS One (4)	15
Oncogene (7)	21	Infection and Immunity (4)	19	Australian Health Review (<1)	14
Invest. Ophthalmol. & Visual Sci. (3)	20	Journal of clinical Neuroscience (1)	19	Internal Medicine Journal (2)	14
J. of Bacteriology (4)	20	Journal of Virology (5)	19	Molecular Ecology (6)	14
J. of Clinical Investigation (15)	20	Vaccine (4)	19	Wildlife Research (1)	14
J. of Natural Products (3)	20	Sexual Health (1)	18	Journal of Natural Products (3)	13

Note: (i) Derived from ISI Web of Science. The top medical, biomedical or biology journals in the Science Citation Index are shown by number of articles published with a least one author from a given region. (ii) Impact Factors for the journals are shown in brackets based upon 2009 data as some of the Australasian journals did not have impact factors in 2007 (iii) Shading is used to indicate journals with impact factor > 10, while journals based out of Australia or Australasia are also highlighted in bold.

One can hazard a caution in interpreting the publication habits of Australian researchers. It is easy to imagine that the peculiarities of the Australian environment could create a special role for regional journals in agriculture, veterinary sciences, environmental management, and ecology – indeed there is evidence for this in Queensland’s portfolio of high-output journals, as summarised in table 10b. Furthermore, regional medical journals can and should play a role in disseminating new knowledge to the clinical medical community in Australia. Yet research that finds its way into the latter journals seems very unlikely to constitute a solid intellectual foundation from which to nurture a globally relevant biotechnology industry.

To put it slightly differently, if you had to bet on a region’s capacity to develop a biotechnology industry based on its public research outputs, you would have to put your money every time on a region like San Diego that generates hundreds of articles annually in PNAS and in the Journal of Biological Chemistry, and where the outputs in high profile journals like Science and Nature are also very strong. At the same time, you would surely have to bet against regions like Victoria, NSW and Queensland, each of which generates a comparatively slight number of outputs in similar journals – and where intellectual outputs are focused so clearly towards publications of worthy though less profound content, like the Australian Family Physician and the Australian Health Review.

It is worth noting too that the parochialism of Australian research is not only an artefact that emerges when one studies the top 25 journals by number of articles authored per region. Table 11 shows that the data in table 10 is actually representative of a broader trend whereby Australian researchers are twice as likely to publish in an overtly Australian denominated journal as San Diego researchers are to publish in an overtly American denominated journal.

Table 11 – ISI Web of Science articles in national journals, 2007

Region	“American Journal of ...”		“Australian Journal of ...”	
	Articles	% of regional output	Articles	% of regional output
San Diego	216	3.0%	3	0.0%
Victoria	119	1.5%	506	6.3%
Sydney	100	1.1%	590	6.3%
Brisbane	39	0.7%	385	7.1%

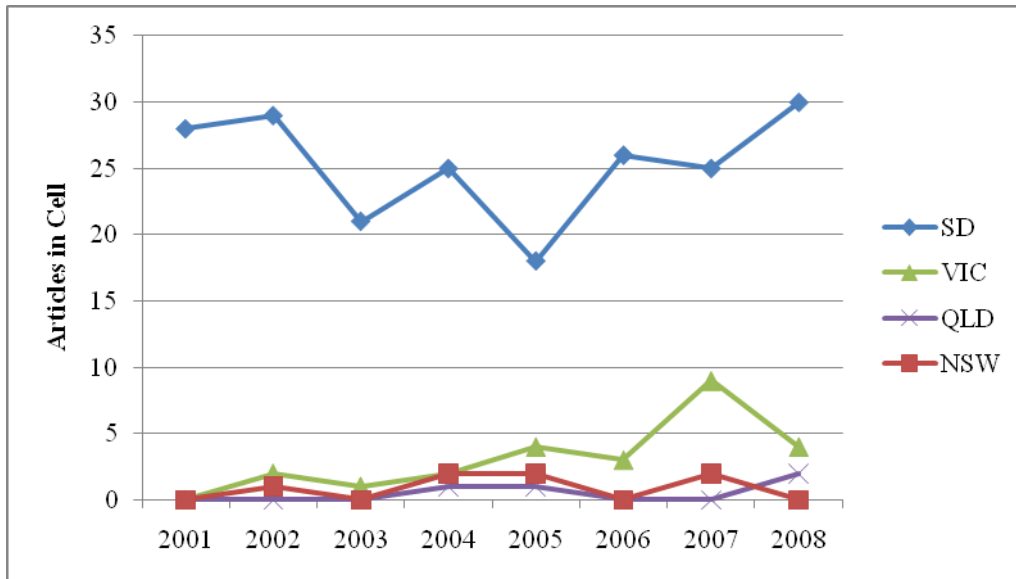
Note: Derived from ISI Web of Science.

Now there may be some exogenous reasons for this – relating for instance to the way in which the global peer review process operates. Institutional and regional reputations do play a role in determining the ease with which researchers globally are able to place work in the highest impact journals. This may impact upon the publishing habits of Australian researchers. Nonetheless, the analysis should still raise questions about the quality, or at least about the global significance, of Australian research.

Such questions are reinforced by a closer analysis of regional outputs in some of the specific leading journals in biotechnology and in molecular and cell biology. Figures 12 to 15 show regional publication outputs in the journals Cell, Nature Biotechnology, Neuron, and the

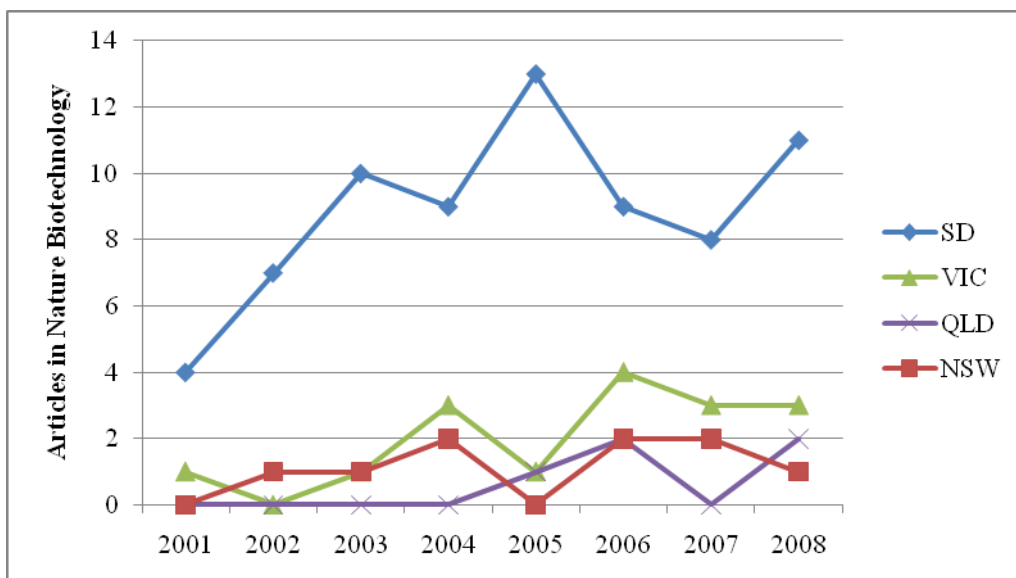
Journal of Molecular Biology. All four figures show the profound strength of the very best fundamental biology research being performed in San Diego relative to that emerging from Melbourne, Sydney and Brisbane. The data in these figures is consistent with the substantial advantage in investment San Diego’s non-profit researchers enjoy in fundamental biology relative to their Australian peers. It may also (as an incidental observation) constitute part of the explanation for the apparent efficiency at which Australian researchers operate: possibly spending less per article published, but publishing far fewer articles in high-impact journals.

Figure 12 – Articles or Review Articles in Cell, 2001 to 2008



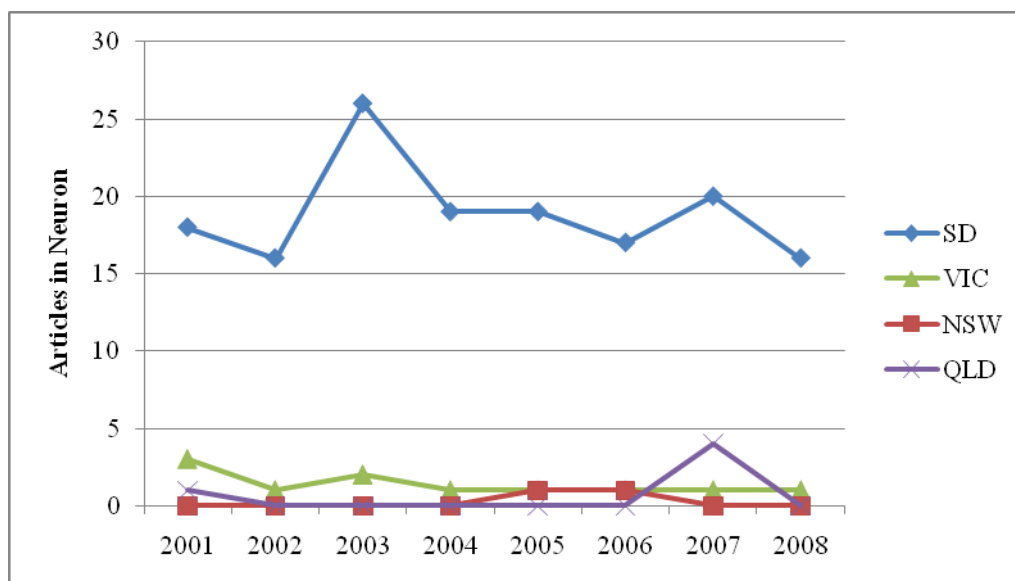
Note: Derived from ISI Web of Science. Counts number of articles or review articles in the journal with an author in the specified region.

Figure 13 – Publications in Nature Biotechnology, 2001 to 2008



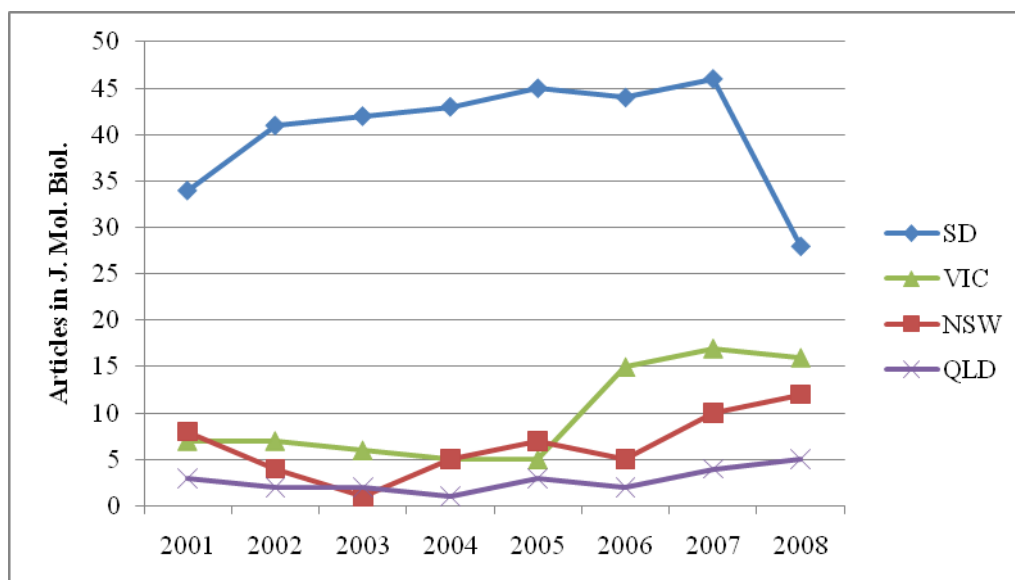
Note: Derived from ISI Web of Science. Counts number of articles or review articles in the journal with an author in the specified region.

Figure 14 – Publications in Neuron, 2001 to 2008



Note: Derived from ISI Web of Science. Counts number of articles or review articles in the journal with an author in the specified region.

Figure 15 – Publications in the Journal of Molecular Biology, 2001 to 2008

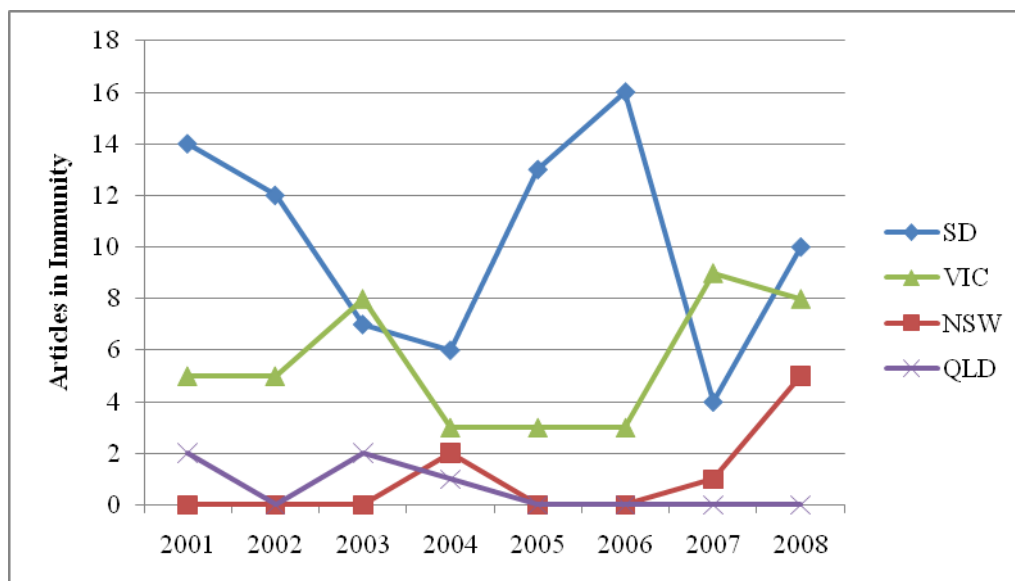


Note: Derived from ISI Web of Science. Counts number of articles or review articles in the journal with an author in the specified region.

A similar pattern of output is observed across a large range of other high-impact journals of relevance to the medical biotechnology sector. The one area of exception in this respect is in immunology. Figures 16 and 17 show the number of articles published per region in two high-profile immunology journals: Immunity and Nature Immunology. Immunology is an area where Australian researchers, especially at the Walter and Eliza Hall Institute and at the University of Melbourne (and also at the ANU, although this institution is not included in this

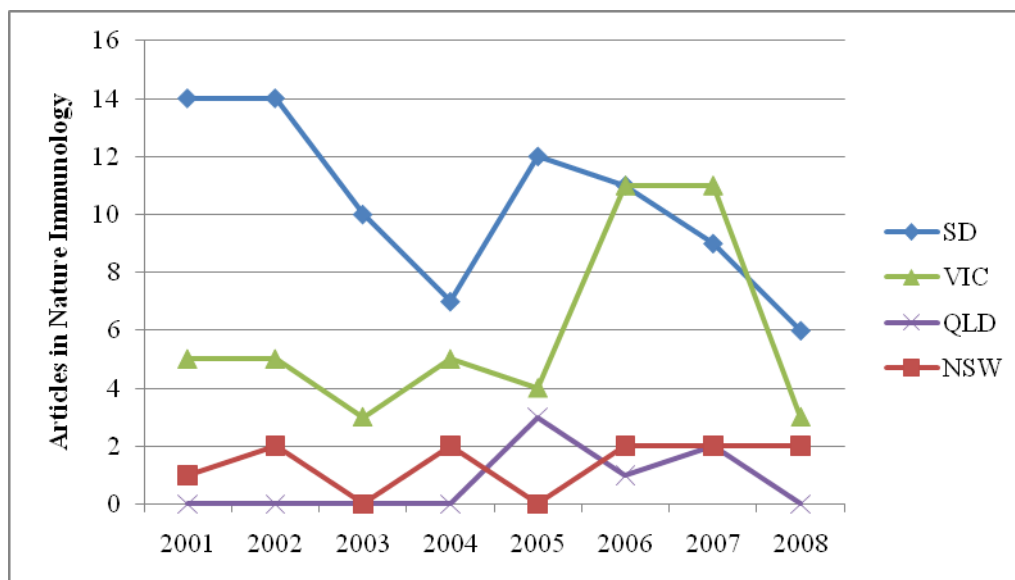
analysis), do have a significant international reputation. The figures show, however, that even in this area of strength no Australian region outperforms San Diego.

Figure 16 – Publications in Immunity, 2001 to 2008



Note: Derived from ISI Web of Science. Counts number of articles or review articles in the journal with an author in the specified region.

Figure 17 – Publications in Nature Immunology, 2001 to 2008



Note: Derived from ISI Web of Science. Counts number of articles or review articles in the journal with an author in the specified region.

The picture we have then appears to be of an Australian public research base in the life sciences that is dominated by a parochial medical research community and that provides only relatively modest support by comparison for fundamental research of global significance. Unfortunately, the consequences of such a scenario, if this really does reflect the reality,

extend beyond the simple profile of Australian research in the global scientific literature. Biotechnology is one of the few areas where there is a strong connection between the quality and scale of research in non-profit institutions and in the patenting activity of such institutions. In addition, patents are critical enablers of industrial development in biotechnology, to a degree that is uncommon across other areas of industry or research.

In the next section we will look at the different levels of patenting activity in San Diego and in our three Australian regions and postulate whether in fact, contrary to popular opinion, the lack of research in fundamental biology has held back the development of biotechnology industry across all three Australian regions.

3.4 Patents

The majority of patents in biotechnology (or in broader categories relating simply to the biological or medical sciences) are taken out by private organisations. Nonetheless, patenting has emerged as a critical mechanism by which non-profit organisations such as universities are able to convey intellectual property into companies for commercial development. Indeed, given the timeframes and costs associated with bringing medical therapies in particular through national regulatory processes in the developed world, patents have become an essential mechanism for applying intellectual property in biotechnology, whatever its source.

This means that an analysis of the patenting behaviours of public and non-profit research organisations can serve as a reasonable indicator of the extent to which the public-good research base in a particular region is operating usefully to the development of local biotechnology industry. Any such assessment will of course be imperfect, not least because counting patents gives no real indication of the value of patents counted. There are also methodological challenges in evaluating patenting activity due to variations in patenting behaviours across different regions. These caveats however do not take away from the essential point: in the biotechnology area, for anyone interested in the relevance and dynamism of the research base, patent analysis is a very useful indicator.

In the following evaluation, we have chosen to count international patent applications in key bio-related patent classes, as assigned to organisations in our four regions and as published by the World Intellectual Property Organisation (WIPO) between 2001 and 2008. The comparison of patent applications made through the PCT system internationally is arguably fairer in evaluating organisational patent activity than an equivalent analysis of patenting activity through national offices (such as the USPTO) would be, not least because application counts to national office tend to favour local inventors. For this reason we use the PCT data. It should be recognised, however, that the PCT process captures only a subset of the patenting activities of many organisations.

It is also worth noting that for the most part we have opted to analyse a broader set of patent classes than those used by the OECD in evaluating biotechnology activity. The OECD

defines patent classes relevant to biotechnology fairly narrowly, excluding for instance several classes that are relevant to medical technology and to food production. For example, the OECD methodology includes patents for new plants or processes for obtaining them but not patents relating to animal husbandry, horticulture, or the processing of harvested produce – all of which would be areas of technological significance for Australia. The OECD methodology likewise includes patents for medical and dental preparations but not for medical and dental apparatuses or devices, nor for prosthetics.

Our desire here is to identify capabilities relevant to biotechnology in a broad sense and our concern is also to be as encompassing as possible so as not to make particular regions look especially weak or strong simply because of a particular technological focus. For this reason we concentrate our initial evaluation on the broad patent classes relevant to biological and medical sciences as shown in table 18.

Table 18 – PCT patent classes relevant to the biological and medical sciences

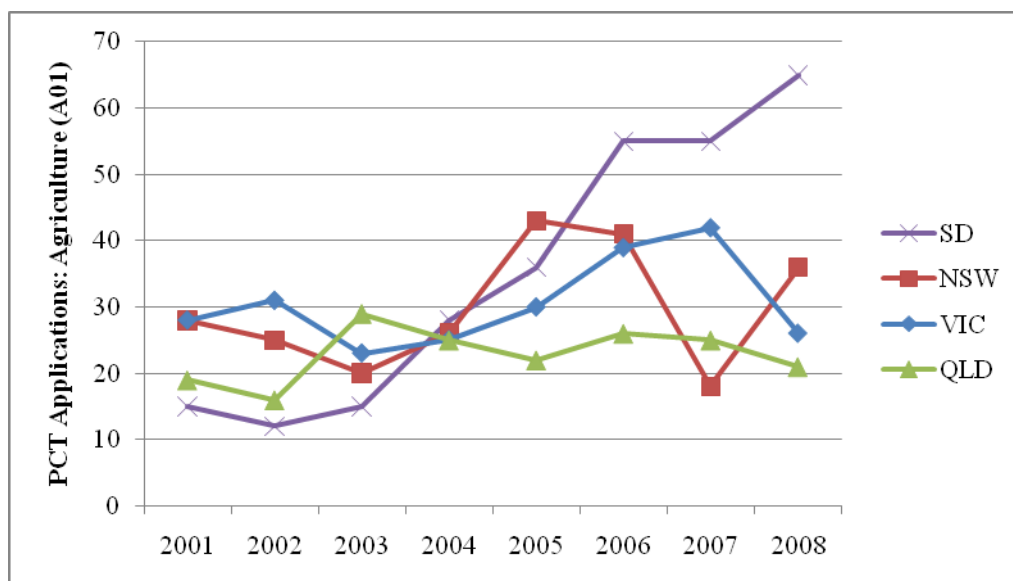
Class	Description
A01	Agriculture; forestry; animal husbandry; hunting; trapping; fishing
A23	Foods or foodstuffs; their treatment, not covered by other classes
A61	Medical or veterinary science: hygiene
C07	Organic chemistry
C08	Organic macromolecular compounds: their preparation or chemical working-up; compositions based thereon
C12	Biochemistry; beer; spirits; wine; vinegar; microbiology; enzymology; mutation or genetic engineering
G01	Measuring; testing

Note: International Patent classifications as listed in WIPO 2009. The OECD identifies biotechnology patents using a narrower subset of codes: A01H, A61K, C02F, C07G, C07K, C12M, C12N, C12P, C12Q, C12S, and G01N (OECD 2009).

Figures 19 to 23 show the international patenting activity within these classes that can be associated with each of our regions. These figures present total data, encompassing activity from both the private sector and from universities and non-profit organisations. In broad terms the evidence they present is consistent with the scale of industrial development in biotechnology in the four regions. This is as should be expected since patenting activity tends to be highly correlated with industrial investment in research and development.

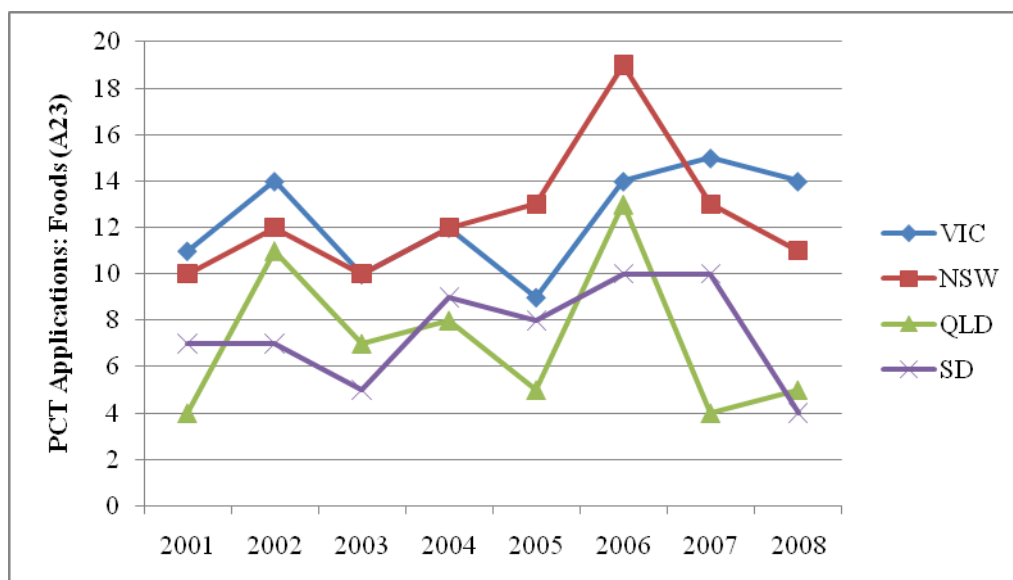
Some interesting, preliminary observations can be made however from these figures. For example, figures 19 and 20 show a historical strength in Australia relative to San Diego in patenting activity relevant to agriculture and food technology. This is consistent with evidence presented earlier about the relative strength of the underlying research base in Australia in these areas. There is additional evidence though in figure 19 that San Diego has experienced significant growth in the extent to which inventors in this region are choosing to patent inventions relating to agriculture. This may be significant for Australian researchers and industry operating in this space as it may foreshadow a new focus for San Diego and an intensification of international competition in this area.

Figure 19 – International patent applications in Agriculture



Note: Derived from WIPO database. Shows international patent applications in the designated class by year of publication, with applicant specifying an address in the region shown.

Figure 20 – International patent applications in Food Technology

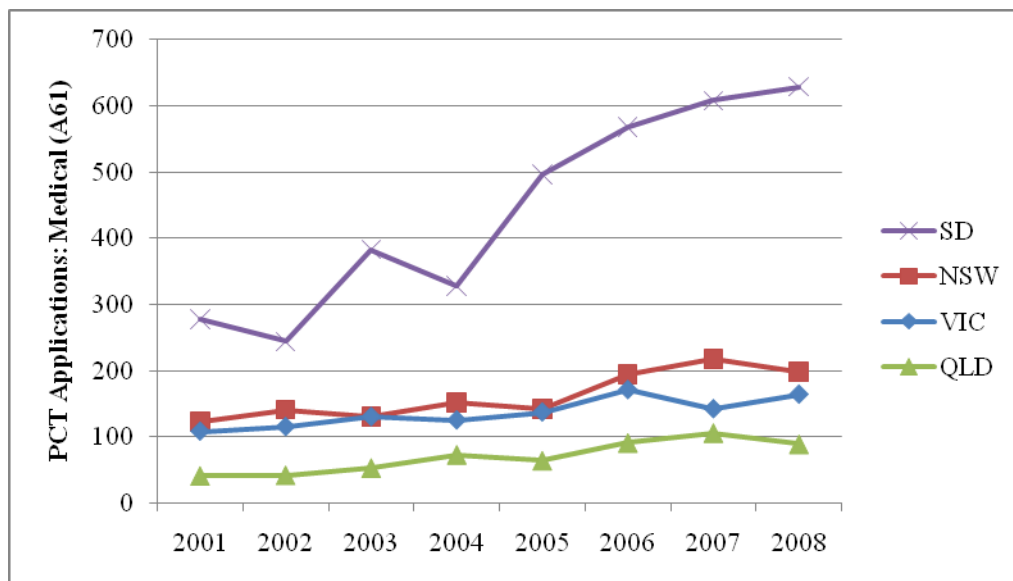


Note: Derived from WIPO database. Shows international patent applications in the designated class by year of publication, with applicant specifying an address in the region shown.

Figures 21, 22 and 23 provide the analogous data for the broad patent classes relating to medical technologies (including drug preparations), organic chemistry and biochemistry. It is in these categories that one really observes the decisive difference in the scale of inventive activity in San Diego compared with the three Australian states. Once again the data here is consistent with established patterns in business R&D investment relating to biotechnology, but to give a quantitative feel for the disparity, it can be noted that the number of international patent applications coming out of San Diego in 2008 was:

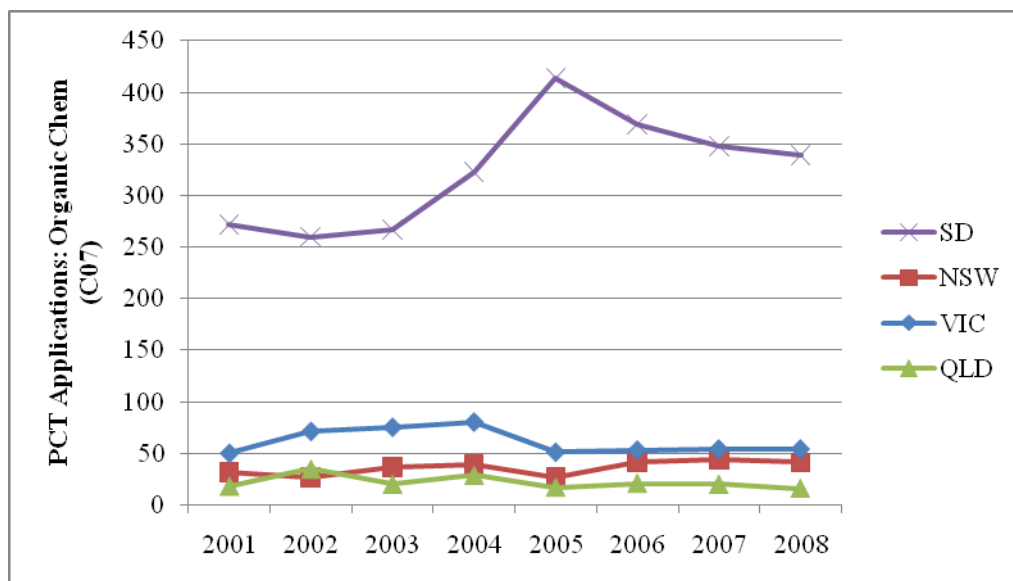
- 3 times that of NSW, 4 times that of Victoria, and 7 times that of Queensland in the medical and veterinary science class;
- 6 times that of Victoria, 8 times that of NSW, and 21 times that of Queensland in the organic chemistry class; and
- 3 times that of Victoria, 4 times that of NSW, and 9 times that of Queensland in the biochemistry class.

Figure 21 – International patent applications in Medicinal and Veterinary Science



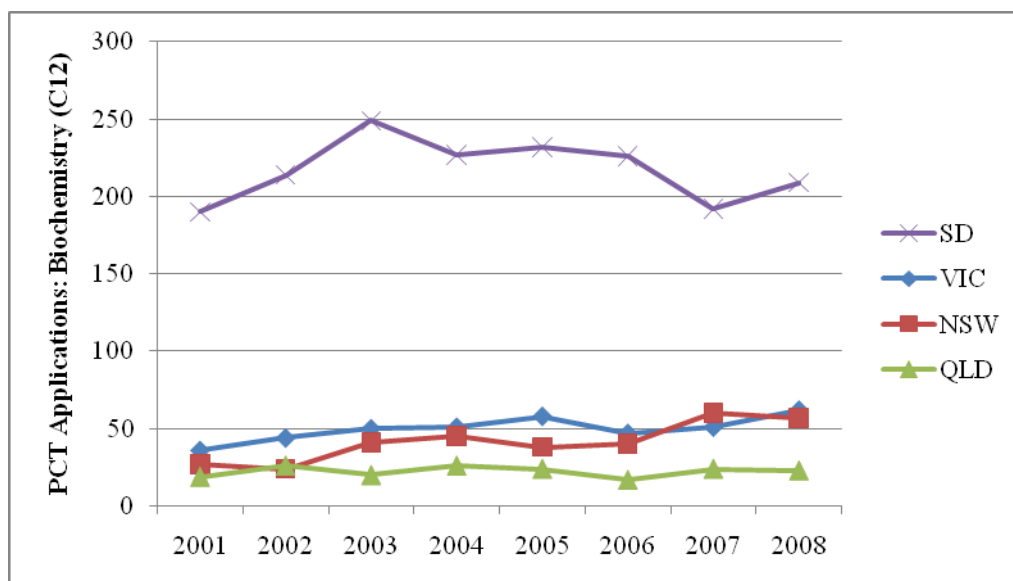
Note: Derived from WIPO database. Shows international patent applications in the designated class by year of publication, with applicant specifying an address in the region shown.

Figure 22 – International patent applications in Organic Chemistry



Note: Derived from WIPO database. Shows international patent applications in the designated class by year of publication, with applicant specifying an address in the region shown.

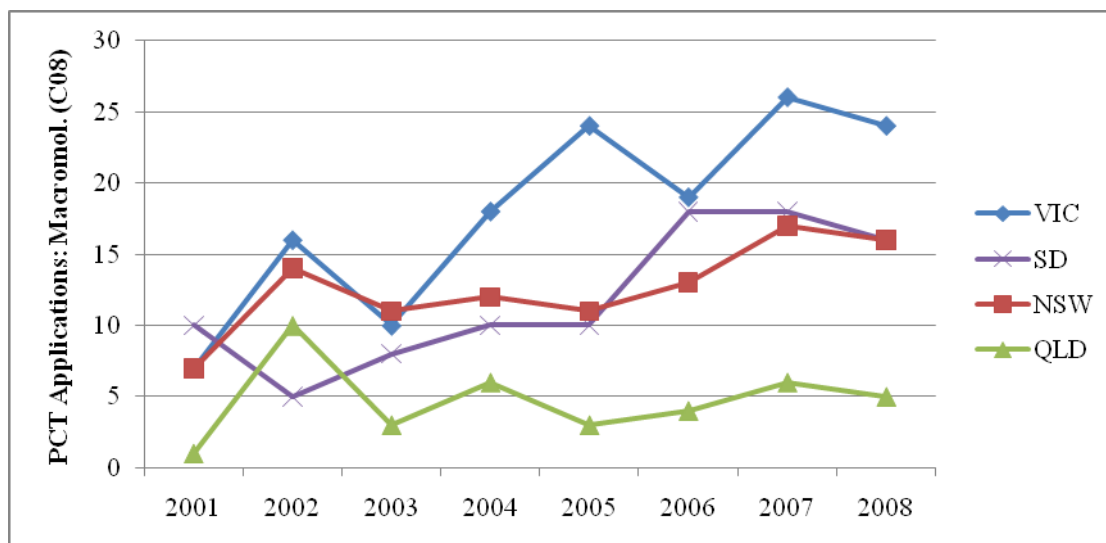
Figure 23 – International patent applications in Biochemistry



Note: Derived from WIPO database. Shows international patent applications in the designated class by year of publication, with applicant specifying an address in the region shown.

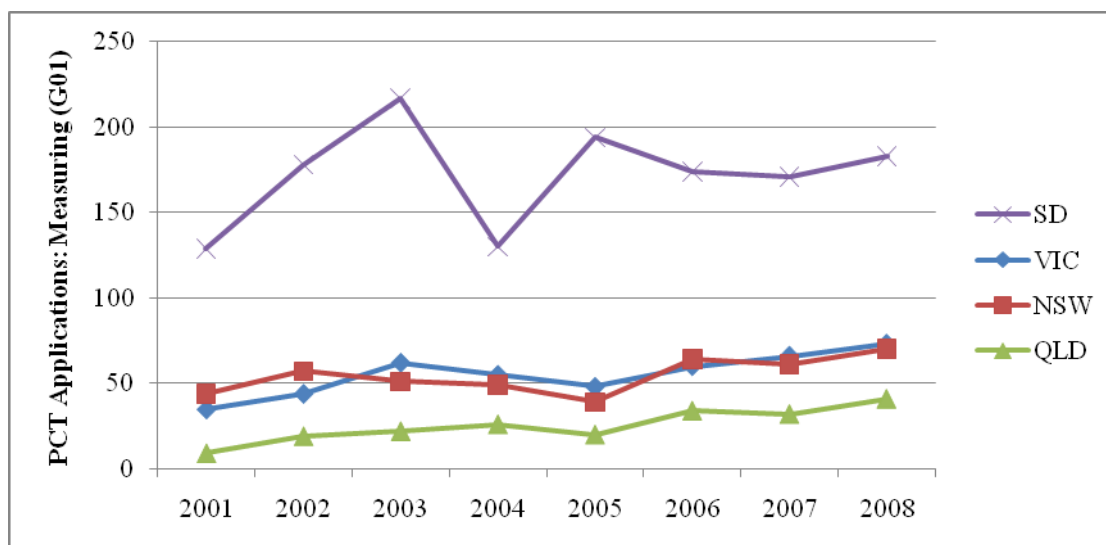
Figures 24 and 25 show patenting activity in the other two classes: in macromolecular organic compounds and in measuring and testing. The former is an area with very low (though similar) levels of patenting across all four regions, while the latter is an area with strong inventive activity in San Diego (though representing a very broad class of technologies, not all of which are relevant to bio-industry development). The data in these figures collectively show that there is no broad class of technology where Australian regions are displaying significant inventive capacity relative to San Diego.

Figure 24 – International patent applications in Macromolecular Organic Compounds



Note: Derived from WIPO database. Shows international patent applications in the designated class by year of publication, with applicant specifying an address in the region shown.

Figure 25 – International patent applications in Measuring and Testing



Note: Derived from WIPO database. Shows international patent applications in the designated class by year of publication, with applicant specifying an address in the region shown.

This is a significant finding and represents an important part of our regional comparison. The observed difference in broad patenting activity however is more likely to be a consequence of the scale in existing biotechnology industry than it is likely to reflect underlying capabilities in the public-sector research base. Given the perception of local strength in Australia’s public research base, we need then to ask what happens if we contrast patenting activity not in its totality but from universities and research institutes.

Table 24 does this in a particular way using the same set of patent classes. For each region, the dominant patenting organisations were identified in the WIPO database and all non-profit organisations were extracted from this list. In each region, the top 7 universities and other research institutions identified in this manner are ranked according to the average number of patent applications made annually by each institution between 2001 and 2008.

In this instance, institutions are ranked according to total output across all seven patent classes listed in table 18. The total number of patents from all seven institutions in each region combined is also specified – a figure which is generally smaller than the sum of patent applications from individual institutions due to joint applications.

The evidence here is intriguing insofar as it implies a relationship between regional patenting activity by non-profit research institutions and regional investment in fundamental biology as opposed to medical research. To put it plainly, despite the relatively similar levels of investment in medical and health sciences research, the leading institutions in San Diego are patenting in classes relevant to biotechnology at three times the level of leading institutions in each of the three Australian regions – i.e. in a way that is far more consistent with their differential levels of investment in fundamental biology.

Table 24 – PCT patent applications from non-profit research organisations, 2001-2008

San Diego – annual averages					
Institution	Total	A61K	C07K	C12N	G01N
UCSD	45	20	9	9	10
Scripps Research Institute	43	21	12	11	7
The Burnham Institute	10	6	5	2	3
The Salk Institute	9	4	3	4	1
San Diego State University	3	1	0	1	0
Sidney Kimmel Cancer Center	2	2	1	1	0
La Jolla Institute for Allergy and Immunology	2	1	1	1	0
Unique patents to 7 institutions combined	111	53	29	28	21

Victoria – annual averages					
Institution	Total	A61K	C07K	C12N	G01N
Monash University	10	7	3	2	2
CSIRO	8	2	2	2	2
The Walter and Eliza Hall Institute	7	5	4	2	2
University of Melbourne	4	4	2	1	1
Agriculture Victoria	4	0	2	3	0
Ludwig Institute for Cancer Research	2	2	2	0	1
Melbourne Health	2	1	1	1	0
Unique patents to 7 institutions combined	45	19	12	12	8

New South Wales – annual averages					
Institution	Total	A61K	C07K	C12N	G01N
CSIRO	14	1	1	4	3
UNSW	11	5	1	3	2
University of Sydney	9	4	1	1	1
Garvan Institute	4	2	1	1	1
University of Wollongong	3	1	0	0	1
University of Newcastle	3	1	0	1	1
University of New England	2	0	0	0	1
Unique patents to 7 institutions combined	44	14	4	9	8

Queensland – annual averages					
Institution	Total	A61K	C07K	C12N	G01N
University of Queensland	19	7	4	5	2
Queensland University of Technology	4	1	1	1	1
Queensland Institute of Medical Research	4	3	3	1	1
CSIRO	4	0	1	1	1
Queensland Department of Primary Industries	3	0	1	1	1
Order of the Sisters of Mercy in Queensland	2	1	1	1	1
Griffith University	2	1	0	1	0
Unique patents to 7 institutions combined	34	14	10	9	5

Note: (i) Derived from WIPO database. Shows international patent applications by year of publication, where the designated institution is an applicant. The total count shows patent applications specifying at least one of the following broad classes: A01, A23, A61, C07, C08, C12, or G01. (ii) The ‘unique patents to 7 institutions combined’ specifies the unique number of patent applications from the group – i.e. counting joint applications only once – so it is often less than the sum of entries in its column. (iii) Figures for CSIRO may be over-estimated due to the difficulty of attributing activity within this national organisation to different states.

The other thing that stands out though is the extent of technological focus by leading non-profit institutions in the four regions. The right-hand columns in table 24 show the primary 4 bio-related subclasses in which institutions in both San Diego and Australia are collectively applying for international patents. What is interesting about this data is that, despite their greater scale, the institutions in San Diego also exhibit a greater degree of strategic weighting in these subclasses within their patent portfolios.

This is summarised in table 25, which lists for the seven leading patenting institutions in each region: (a) what share of patents in bio-related classes are linked to one of the top-five specific subclasses relevant to biotechnology; and also (b) what share of patents in medical science (i.e. with an A61 classification) might be associated with pharmaceuticals or chemical compounds rather than with medical devices or other medical technologies. Both of these ratios provide rudimentary measures of the degree of specialisation in patenting activity – specialisation specifically in ways that are aligned with a narrower definition of biotechnology, such as that used by the OECD.

Table 25 – Specialisation by patent class in PCT patent applications from the leading seven high-patenting non-profit research organisations by region, 2001-2008

Region	Average annual patent applications in:		Dominant biotech subclasses / broad bio-relevant classes	Average annual patent applications in:		Preparations or chemical therapies subclasses / Medical science class
	broad bio-relevant classes (A01 or A23 or A61 or C07 or C08 or C12 or G01)	dominant biotech subclasses (A61K or C07K or C12N or G01N or C12Q)		main medical science class (A61)	preparations and chemical therapies subclasses (A61K or A61P)	
San Diego	111	98	88%	56	54	96%
Victoria	45	37	81%	22	19	87%
Queensland	34	25	75%	18	14	75%
NSW	44	29	68%	18	14	78%

Note: (i) Derived from WIPO database. Shows average annual patent applications published by WIPO between 2001 and 2008 with at least one of the regional institutions identified in table 24 as an applicant. (ii) The first column in this table is equivalent to the total figures shown for ‘unique patents to 7 institutions combined’ in table 24. (iii) Once again the figures should be treated as indicative, due to the difficulty of precisely attributing regional activities of non-regional organisations.

It is clear from this table that the leading non-profit research organisations actively patenting in bio-related classes in San Diego are far more focused in core areas of biotechnology than the equivalent set of organisations in Victoria, Queensland or New South Wales. Nearly 90% of the patents emerging from the cohort of institutions in San Diego carry one of the dominant biotechnology subclasses. This compares with roughly two thirds (68%) of patents emerging from the cohort of institutions in New South Wales.

Furthermore, one cannot interpret this effect simply in terms of Australian regional investment in agricultural technologies. It is an effect that carries across institutions as well as

across regions and it is an effect that exists within the specific class of medical patents. If one focuses for instance simply on the A61 class (“medical or veterinary science; hygiene”), one finds that less than 4% of patents in this class emerging from the San Diego cohort are classified outside the subclasses of A61K (“preparations for medical, dental, or toilet purposes”) or A61P (“therapeutic activity of chemical compounds or medicinal preparations”). This contrasts with the situation in New South Wales, where more than 20% of A61 patents from its cohort do not designate these two subclasses, implying a greater breadth of focus even within medical science, and also a greater public focus on medical devices and apparatus in Sydney than is true in San Diego.

Obviously this data has its limitations: what we are observing here may have as much to do with the attitudes and behaviours of patent attorneys in different regions as it does with the inventive orientation of researchers in universities and research institutes. But the fact that this analysis is consistent with earlier findings relating to publication outputs and R&D investment lends credence to what these patent data are telling us.

In San Diego, as we have established, there is much higher institutional investment in molecular biology relative to investment in medical sciences or in agricultural sciences. This is consistent with a high degree of activity in the core biotechnology codes listed in tables 24 and 25. In Australian institutions by contrast, the balance of investment between molecular biology, medical sciences, and agricultural sciences necessarily implies a broader technology focus. The existence of a relatively developed medical devices industry in Australia, as opposed to a molecular biotechnology industry, may also play a role.

The evidence then, if not conclusive, is strong. Non-profit research in Australian regions lags dramatically behind that in San Diego in scale of inventive activity as measured by patents. Victoria is the only Australian region that seems, within its public institutions, to have a degree of technological focus relevant to biotechnology approaching that of San Diego. But even there the scale of activity is relatively low. Contrary to widespread perceptions in Australia, this could be interpreted as a significant impediment to the development of biotechnology industry in this country.

By way of illustration in this respect it is useful to note the regional trends in total patenting activity in key patent subclasses across both the private and public sector shown in the appendix.

3.5 Australian regions need to strengthen their research base

Despite widespread perceptions to the contrary, the above analysis indicates that the historical focus of the biological research in Australian non-profit research organisations may not have been ideal for the development of a medical biotechnology industry. The hope that such investment might lead to the development of a biotechnology industry is of course not the sole reason, or indeed even the principal reason, that Australian society elects to invest in

medical or biological research. Yet with the right kind of investment, as the example of San Diego illustrates, it is not unreasonable to speculate that some sort of relationship between non-profit research and industrial innovation could occur – and to this end it is fascinating to contrast the research base in San Diego with that in our three Australian cities.

Compared with Melbourne, Sydney and Brisbane absolute, levels of spending on university R&D as a whole, and even on research in medical sciences specifically, are not wildly dissimilar from those in San Diego. However per capita spending within San Diego's research institutions is much higher than in the Australian cities and absolute spending on fundamental biology specifically is very much higher than in the Australian cities, reflecting a distinctive technological focus among institutions in San Diego.

The consequences of this focused investment in San Diego, and of the very different pattern of investment in Australian regions, are clearly evident in the research outputs from the four regions.

- On the one hand, researchers in NSW and Victoria recently overtook researchers in San Diego for the number of scientific articles published in medical research journals. Researchers in all three Australian regions publish significantly more scientific articles in journals relevant to agricultural, whole-organism, and environmental biology than do researchers in San Diego.
- But San Diego easily outstrips every Australian region for the number of scientific articles authored in molecular and cell biology journals. Collectively, San Diego researchers are also heavily outcompeting Australian researchers in publishing in the leading medical and biological journals. Indeed, this study raises significant questions about the quality of Australian medical research, at least when assessed in its totality rather than by the achievements only of its most successful practitioners.
- In addition, like the companies in their local regions, universities and non-profit research institutes are far more active in patenting inventions relevant to biotechnology in San Diego than is true in Victoria, New South Wales, or Queensland. This patenting activity also reflects a technological orientation that is consistent with elevated investment in molecular and cell biology relative to investment in clinical medicine or in agriculture or other areas of biology.

There are significant lessons here for policy-makers and industry advocates. As was reinforced in our preliminary survey, even informed opinions about biotechnology clustering in Australia tend to focus on the strength of the research base and on the inadequacy of other elements of the industrial ecosystem (such as government policy, lack of capital, inadequate social networks, or the role of flagship companies). These issues are undoubtedly important, but their significance in the Australian context must be reinterpreted in light of the above findings.

Australia's research base in medical and biological sciences unquestionably has its outstanding areas and its individuals of great talent. Relative to the San Diego region however the orientation of the public research base in Victoria, New South Wales, and Queensland actually looks like a strength that could use a lot of improving.

4. Testing assumptions about the importance of flagship companies, access to capital, and the role of government

Biotechnology is an industry whose genesis and growth worldwide has been strongly underpinned by discoveries being made in universities, government laboratories and other non-profit research institutions. This engenders the perception that where regional strength in public-sector biosciences research is accompanied by only modest industrial development in biotechnology then there *must* be other impediments to growth.

The findings reported in the previous section of this report refute the use of the word “must” in this context for the Australian environment. Our analysis shows that it is no longer possible to rule out the differences in the research base in explaining the differing performance of the Australian and San Diego biotechnology industries and this consequently increases the uncertainty about the role that should be attributed to other purported impediments.

The US Studies Centre’s ongoing evaluation of the role of government policies and of the actions taken by members of the San Diego community in dealing with the challenge of remoteness should be instructive in this respect. It will enable Australian business leaders, policy-makers, and researchers to gain new perspectives about what really drives clustered industrial development in biotechnology. In anticipation of this evaluation however, some contextual data is useful.

Below we summarise several essential points that should be useful in calibrating the Australian response to any evaluation of the challenges to biotechnology cluster development in San Diego.

4.1 Testing assumptions about the importance of flagship companies

First we provide some basic data in relation to the issue of flagship companies. In our survey about the main impediments to biotechnology cluster formation, a significant share of opinion leaders across the Australian biotechnology sector identified the need for major corporate successes or for attracting ‘flagship’ companies into their local region as a key ingredient for future clustering of biotechnology. Indeed, the lack of a major success story in biotechnology or the lack of a flagship company was seen as one of the top three impediments historically and as the most commonly cited impediment to the future development of a biotechnology cluster in Australia.

Table 26 provides a perspective to temper this view slightly, albeit with some caveats. For the Australian regions in our study, this table lists some of the best-known biotechnology and medical technology companies and compares their scale with some of the largest life sciences companies headquartered in San Diego. Note that large and successful Australian companies operating in areas like pathology services, primary healthcare services, medical IT, or mature

Biotechnology Clustering – Landscape Analysis

medical products (firms such as Sonic Healthcare, Sigma Pharmaceuticals, Ramsay Health Care, Healthscope, Ansell, and iSoft) have not been included in this list. Such firms do not tend to operate as R&D intensive businesses and arguably do not fit even within a broad definition of biotechnology.

Table 26 – Flagship company comparisons in biotech and medical technology, 2007-08

Company	Sector	Region	Revenue (USD million)	Net income (USD million)	R&D spend (USD million)
CSL	Biopharm	Melb	3,384	626	201
Invitrogen	Tools	SD	1,620	31	143
Amylin	Biopharm	SD	840	(315)	293
ResMed	Devices	SD / Syd	835	110	61
Illumina	Tools	SD	573	50	100
Cochlear	Devices	Syd	537	103	71
Gen-Probe	Diagnostic	SD	473	107	101
Nuvasive	Devices	SD	250	(28)	26
Biota	Biopharm	Melb	35	(8)	9
Peplin	Biopharm	Bris	-	(25)	20

Note: Data obtained from 2008 annual reports. All figures are provided in US dollars. The exchange rate for conversion from Australian dollars was 0.89 (E&Y 2009). Note that data for Invitrogen includes 5 weeks of data from Applied Biosystems, which merged with Invitrogen in November 2008 to form Life Technologies.

The important observation to be made from this table is that Melbourne does arguably already have a flagship company in the form of CSL. It is also evident that Sydney has two firms with significant scale in the medical devices area: Cochlear and ResMed. Beyond this, though, the scale of operation of Australian firms shrinks very rapidly.

The fact that companies with the scale of CSL, Cochlear and ResMed have grown up in Australia is a proof of the principle that success in biotechnology and medical technology is possible in this country. But the existence of such companies also arguably contradicts claims that one of the impediments to clustering in Australian cities (or at least in Melbourne and Sydney) is a lack of such companies. In comparison with San Diego, the real issue for Australian industry would appear to be not the lack of a flagship company or of a success story, but rather the lack of repeat successes, or the absence of *multiple* competing companies in this area operating at reasonable scale.

One response to this argument is that these Australian success stories are not really biotechnology companies. Cochlear and ResMed are perhaps more accurately thought of as engineering firms operating in medical markets, rather than firms that are developing new biological technologies. CSL is primarily a blood plasma business rather than a technology development business. It has relatively low R&D intensity (i.e. R&D investment normalised against revenues) compared with the large-scale biotechnology firms in the US, much of its growth has occurred through acquisitions, and a significant proportion of its operation is actually based overseas.

These are legitimate points and may strengthen the case that Australian cities do have a problem in attracting or retaining flagship companies. It is interesting in this respect that the Brisbane firm, Peplin, was recently acquired by the Danish firm LEO Pharma for approximately US\$290 million and will be operated in the future as a US-based subsidiary of LEO Pharma.

However, even if one accepts the critique, the existence of firms like CSL, Cochlear and ResMed still provokes serious questions about the extent of the benefits that can really accrue from nurturing or attracting flagship companies in the current Australian context. At a practical level, the critique implies that Australian cities don't just need flagship companies – they need the right kinds of flagship companies, operating in just the right sectors. This adds an interesting dimension to the problem of nurturing flagship companies and implies a particular challenge of selection for those policy-makers who are interested in trying to attract international pharmaceutical or biotechnology companies to their regions.

More substantively, whatever sector these companies may be in, the fact remains that they are successful technology companies. Their existence at least proves the possibility that firms selling into global health and medical markets can and have grown to a significant size, with a serious management presence in Melbourne or Sydney; and one still has to consider why multiple success stories – the emergence of just a few more firms of reasonable scale – haven't emerged behind these leading companies, even within their own specific sectors.

There is long-standing evidence from San Diego that the existence of a successful company does assist in the creation and growth of other companies in a region within the same sector (DeVol 2004). Yet, judging by the experience in Australia over the past decade, generating wider benefit from one or two successful firms does not happen spontaneously. The evidence does not indicate that CSL has acted as a nucleus for a cluster of Victorian blood product and vaccine companies. There are some indications that individuals formerly associated with Cochlear and ResMed have been involved with other Australian companies in the medical technology space, but these activities remain small in scale relative to what has occurred in the biotechnology sector in San Diego.

This suggests that other issues may well be of equal or of much greater importance in cluster formation than the existence of flagship companies. Large firms may be beneficial, they may even be necessary, but they are clearly not sufficient for the formation of industrial clusters.

Part of the problem here may simply be the shortage of high quality intellectual property emerging from the Australian public-sector research system, as presented in the previous section of this report. This fact alone would mean that whatever advantages have been afforded by the existence of CSL or Cochlear, even within their own particular industrial niches, the ability to exploit such advantages could be limited. But there are likely to be other factors at play here too, perhaps relating to differences in the culture of entrepreneurship or in the extent to which individuals with expertise in Australian and US societies are driven to leave salaried employment and to build and grow their own firms. It is hoped that some

insight along these lines will emerge from the analysis of the role that flagship companies have historically played in the San Diego biotechnology cluster.

Flagship companies do have a role to play in the development of biotechnology clusters in Australian cities, but it should be acknowledged that other factors will inevitably temper this role. Whether one chooses to define biotechnology narrowly or broadly, the idea of the flagship company should not be seen as a panacea that will instantaneously cure the lack of industrial clustering in the Australia context. Ultimately, the difficulty for Australian business networks and policymakers in exploiting successful companies in order to promote the development of industrial clusters is likely to be just as great as, if not greater than, figuring out how to create or attract flagship companies to begin with.

4.2 Testing assumptions about access to capital

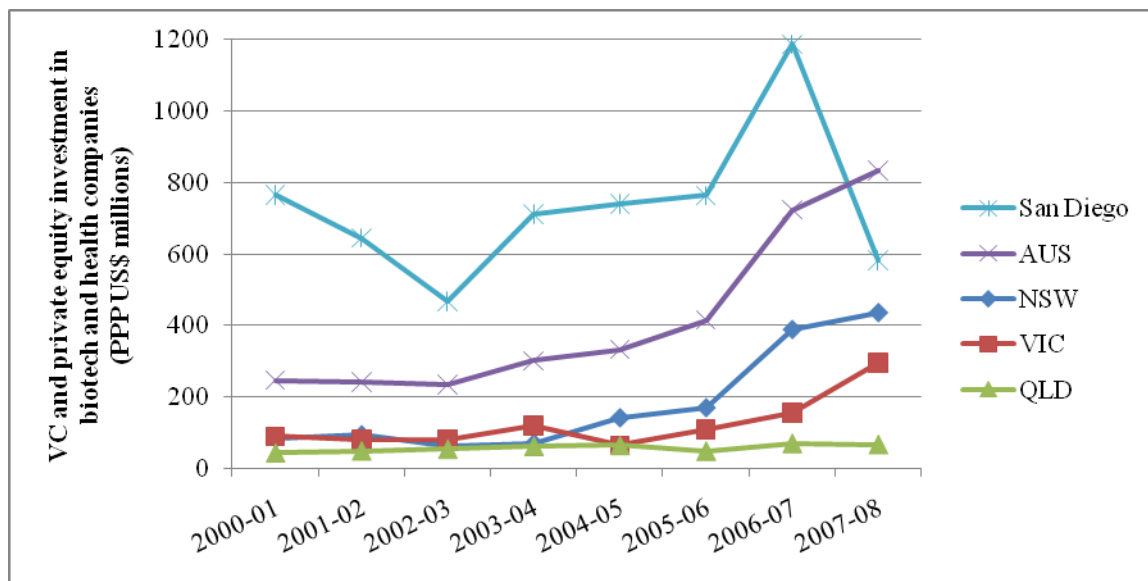
The second issue that we will discuss briefly is the challenge that exists for Australian firms operating at a distance from the majority of their customers, regulators and partners. Australia's geographic position has long played an important role in determining Australian comparative advantage in commerce (see for example Blainey 1966 and CEDA 2007) and it is reasonable to imagine that this might play a role too in determining the nature of Australia's industrial development in biotechnology (see Gilding 2008).

Interestingly, in our survey of key opinion leaders from around Australia, it was evident that not everybody involved in the Australian biotechnology industry feels the 'tyranny of distance'. Some of those interviewed noted the large time spent travelling by Australian biotechnology executives, the challenges of building relationships and doing deals remotely, and the disadvantages posed by Australia's relatively small capital markets. Yet others observed that distance was much less an impediment to business than it used to be, that technology made international collaboration increasingly straightforward, that capital tends to flow globally to great ideas and good business teams, and that distance is no longer a critical issue for Australian firms.

Clearly there is some ambivalence about the impacts of Australia's location relative to global markets. Constraints relating to distance however were raised sufficiently often for this subject to warrant discussion and further analysis. As with the other themes identified in our survey, we are confident that a close study of San Diego will present a very interesting perspective in this respect. After all, firms in San Diego have their own geographic challenges.

It is interesting though to study one particular issue relevant to the problem of distance, which should provide some context for drawing comparisons about the impacts of geography. A moderately popular theme from our survey related to the ease with which Australian firms, in contrast to overseas firms, were said to be able to access capital. This concern, as it was usually expressed, related especially to the level of access in Australia to private investment.

Figure 27 – Venture capital and later-stage private equity investment in biotechnology and health, 2001 to 2008



Note: Derived from ABS 5678.0 and PWC 2009. Australian data has been adjusted to US dollars using purchasing power parity ratios derived from OECD 2009a.

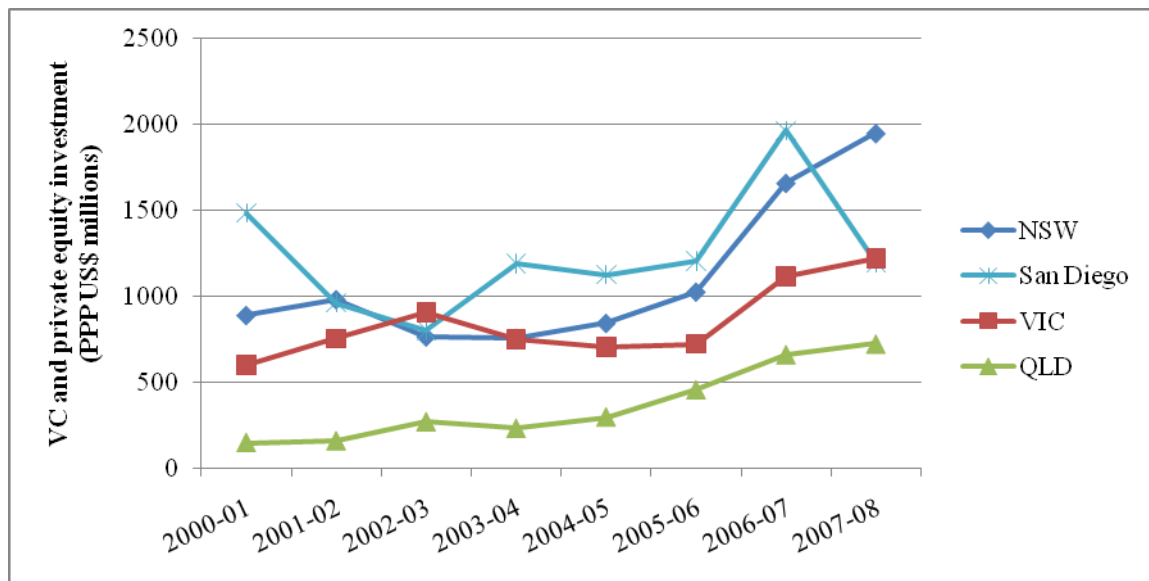
Figure 27 lends some credence to this view. It shows US venture capital and later-stage private equity investment in biotechnology and health, as derived from a Price Waterhouse Coopers dataset and compares it with Australian Bureau of Statistics data. One has to be cautious in interpreting these data, as there are differences in the survey methodologies and very large differences in the sample sizes. Nonetheless, the figure here probably does convey a sense of the reality, even if only in an indicative sense, and what these data show do seem to be well aligned with community impressions.

Consistent with the concerns raised by many individuals working in the Australian biotechnology industry, it would seem that there is significantly more private capital investment in biotechnology and health in the city of San Diego alone than there is in the whole of Australia. This however does not point conclusively to a funding problem for Australian entrepreneurs and inventors. Rather it raises two secondary questions. Does this apparent investment gap represent a failure of capital markets? Or does it simply imply that there is less cause for investment specifically in biotechnology in Australia?

Unfortunately, there are difficulties in assessing these questions from the available investment data. Given what we have already found about the production of intellectual property relating to biotechnology in San Diego compared with that in Melbourne, Sydney, or Brisbane, it seems quite reasonable to hypothesise that the latter suggestion is probably closer to the truth. But proving this is not straightforward. The best that we can do here is to point to a couple of features in the investment landscape that appear consistent with this perspective.

Figure 28, for instance, uses the same datasets as were used in figure 27 to contrast total venture capital and private equity investments across all sectors in our four cities. This figure creates a very different impression to that afforded by figure 27. It implies that while San Diego attracts a disproportionate level of private investment in biotechnology and health, the same cannot necessarily be said when one looks at other sections of the economy. The underlying message, in other words, seems to be that private capital markets do exist in Australian cities but that the investors in these markets don't perceive opportunities in biotechnology to the same degree as is true in San Diego.

Figure 28 – Total venture capital and later-stage private equity investment across all sectors, 2001 to 2008



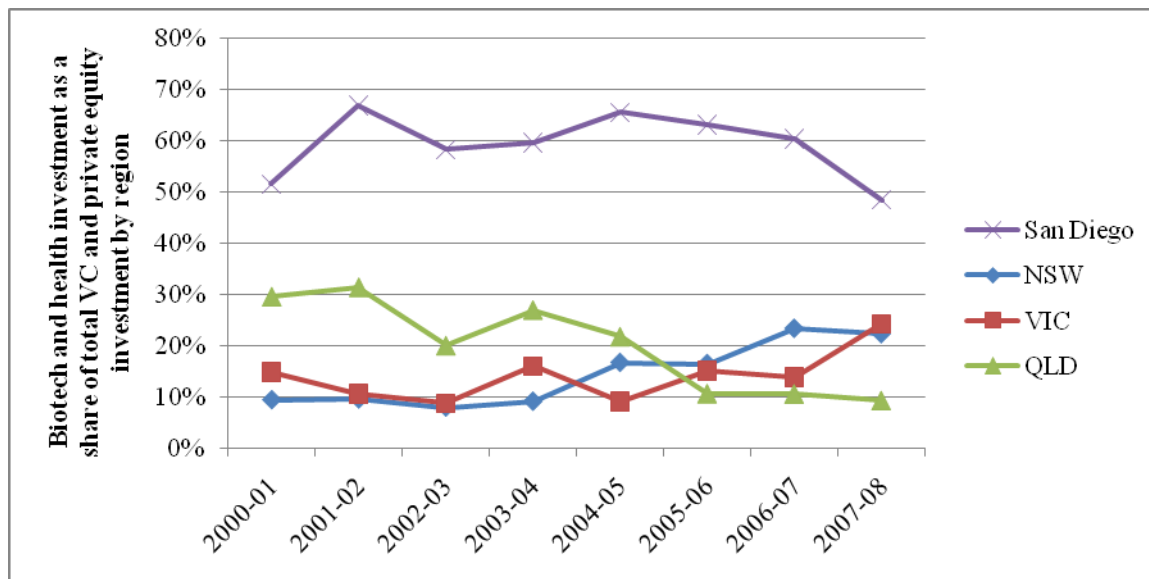
Note: Derived from ABS 5678.0 and PWC 2009. Australian data has been adjusted to US dollars using purchasing power parity ratios derived from OECD 2009a.

To put it another way, the distinctiveness of San Diego compared with Sydney, Melbourne or Brisbane may not lie in the scale of private investment so much as in its focus. This point is further illustrated in figures 29 and 30, which show what an extraordinarily high share of private capital investment in San Diego is being channelled into firms operating in the biotechnology or health sector. In Australia, by contrast, it would seem that firms operating in other sectors are strongly out-competing biotechnology firms for private investment. The money exists, but it is largely being put to other uses.

Now it is important to reiterate that the data used here should be treated with considerable caution. The surveys may be incomplete, and the two datasets may not, strictly speaking, be directly comparable. Some comfort in our conclusions can be taken however by contrasting the ABS data that we use in figures 27 to 30 with a separate, quite distinctive dataset that is collected by the Australian Private Equity and Venture Capital Association Limited (AVCAL). AVCAL looks only at investments made by Australian firms (i.e. it excludes international investments in Australia) and the survey methodology differs significantly from

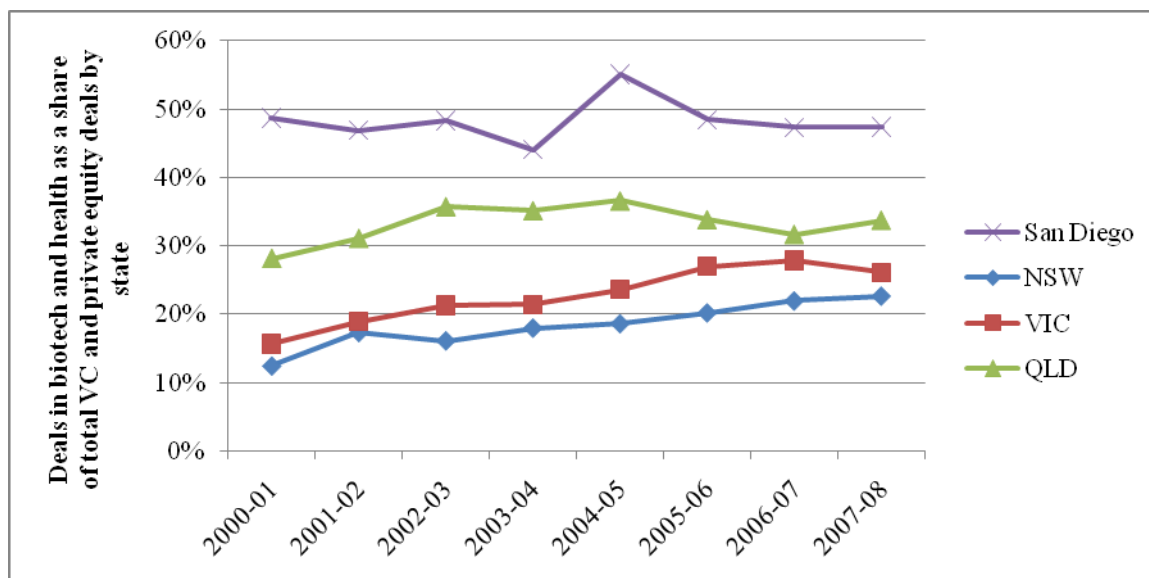
that used by the ABS. Yet both datasets seem to convey the same message: that investments in bio-related industries have typically constituted only a relatively modest fraction of venture capital and private equity investment in Australia (see figure 31).

Figure 29 – Biotechnology and health as a share of regional venture capital and later-stage private equity investment, 2001 to 2008



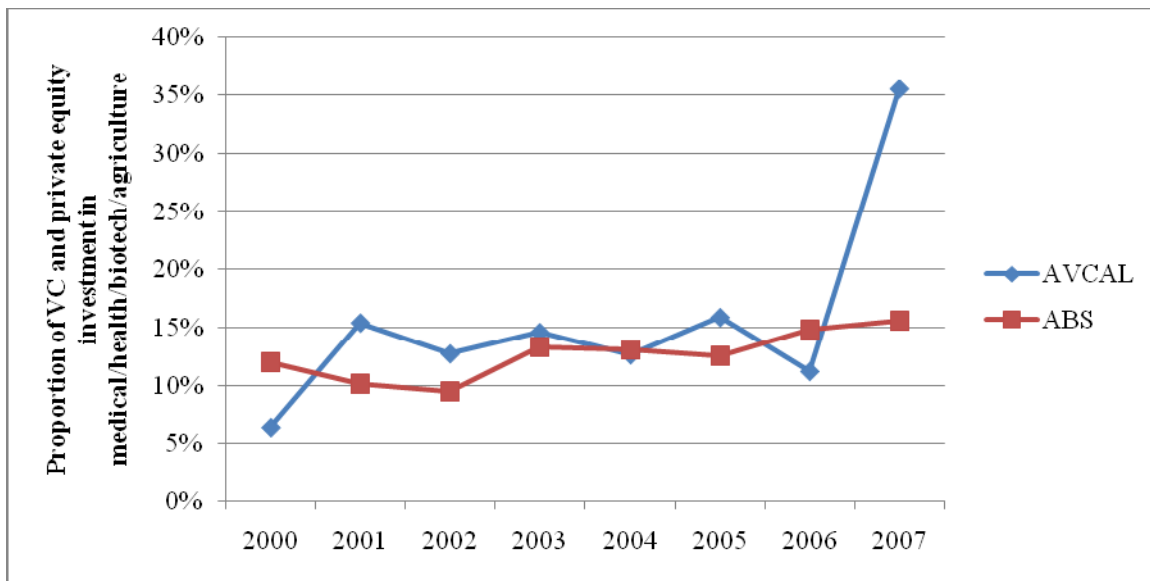
Note: Derived from ABS 5678.0 and PWC 2009. Australian data has been adjusted to US dollars using purchasing power parity ratios derived from OECD 2009a.

Figure 30 – Biotechnology and health as a share of regional venture capital and later-stage private equity deals, 2001 to 2008



Note: Derived from ABS 5678.0 and PWC 2009. Australian data has been adjusted to US dollars using purchasing power parity ratios derived from OECD 2009a.

Figure 31 – Australian venture capital and later-stage private equity investment, 2001 to 2008



Note: Derived from ABS 5678.0 and AVCAL 2009. Australian data has been adjusted to US dollars using purchasing power parity ratios derived from OECD 2009a.

Once again, one has to remember the caveats. What we are observing here may reflect common biases in the different survey approaches, generating an equally unrepresentative picture in both cases. But our proposition is that there is an element of validation in the fact that these two independent datasets seem to point in a similar direction; and there is surely some additional comfort in the fact that the conclusions we draw from this are congruent with our understanding of the knowledge base.

The evidence suggesting that private investment in Australia is flowing preferentially to other sectors is consistent with the scale of intellectual property outputs being produced from the three Australian regions in our study. If local researchers really were developing fewer and less attractive investment propositions in Melbourne, Sydney and Brisbane relative to San Diego, one would naturally expect relative levels of private investment in this area also to be lower than in San Diego. Under this scenario, Australia private investors would naturally tend to look preferentially either (a) to invest in other sectors in Australia or possibly even (b) to invest in places like San Diego, if they are particularly interested in investing in biotechnology.

The inference from all this is probably that private investment specifically in the biotechnology sector is more likely a consequence of intellectual clustering than it is a cause of commercial clustering. The problem, ultimately, is not straightforward though. We have not looked here at the breakdown of funds by investment stage. There may be special problems in Australia in accessing funds at a particular stage in the funding cycle. We also haven't analysed the relative attractiveness of the four cities to international investors. It is interesting, for example, that not all the private investment in San Diego has been American.

Novartis and Jafco Ventures represent two global organisations that have created significant venture capital funds in San Diego in recent years. Perhaps there are specific geographic effects that do reduce the likelihood of such investment in Australia.

But these hypotheses would need to be tested. In the absence of other information, it would seem that concerns about the lack of private capital in Australia really constitute displaced concerns about a lack of great investment opportunities. Clearly this is an effect that needs to be borne in mind whenever contemplating impediments to cluster formation that are attributed to distance.

Fortunately, it is an effect that one can control for to some degree in the case of San Diego itself, since San Diego clearly has no shortage of intellectual firepower in the biotechnology area. With this in mind, a study of the impacts of distance on doing business in biotechnology from San Diego may provide some especially useful insights for Australians about which, if any, of the constraints imposed by distance really are of genuine importance for business development.

4.3 Testing assumptions about the role of government

The final issue that must be addressed relates to the role that should be played by governments in high-tech cluster formation. In Australia there is a long-standing culture that elevates the importance of government policy in fostering new industries. This was reflected in our survey of key individuals associated with the Australian biotechnology industry. There was a marked view among those interviewed that government – especially state government – has a valuable role to play in fostering regional biotechnology clusters.

Testing this belief is not a simple exercise. As a starting point, it is instructive to have a sense of the level of government support that exists in our different jurisdictions – and this is what we will consider here. But obviously a proper assessment of government programmes requires extensive qualitative as well as quantitative analysis. It is plausible, for instance, that one government could spend a lot of money on a particular industry and achieve nothing useful, while another could spend very little and achieve a great deal.

It is also much easier to obtain comparative public data about the levels of government financial support for industrial R&D activity generally than it is to collate information about the forms of government support that are specifically targeted to the biotechnology and medical technology industries. With these caveats noted, and recalling that biotechnology companies are highly R&D-intensive, we analyse below the levels of broad government support for industrial R&D in California and Australia.

In financial terms, governments tend to support biotechnology companies through two dominant mechanisms: (i) through tax concessions or credits for performing R&D; and (ii) through direct funding of specific technology development projects. We can get a sense of

the relative willingness of Australian and US or Californian governments to adopt these mechanisms from the budgeted outlays of governments and from industrial R&D surveys.

In the first instance, let's look at the R&D subsidies provided through the tax systems:

- In 2005, US businesses spent US\$226 billion on R&D. In that same year the US Federal Internal Revenue Service specified the US federal tax credit to be worth US\$6.4 billion, or 2.8% of total R&D spending. (Note that we use 2005 data throughout this analysis, as this is the most recent year for which comparable data is available from all jurisdictions.)
- In California however there is also a state government credit. In 2005, Californian businesses spent US\$51 billion on R&D and the California Franchise Tax Board estimated that the research tax credit was worth US\$953 million, or 1.9% of total industry R&D spending in the state. By this reckoning, in 2005, firms in California accrued a combined R&D tax credit equivalent to 4.7% of their total R&D spending.
- In Australia by contrast, businesses spent AUD\$10 billion on R&D in 2005/06 and the Australian Government reports an R&D tax concession worth AUD\$737 million that year, or 7.1% of total business investment on R&D. Australian state governments, by contrast with California, have provided no explicit R&D subsidy through the tax system.

The conclusion from the above is obviously that Australian businesses have received a much higher proportion of support for R&D activity through the taxation system compared with businesses in California. But this isn't the end of the story. Businesses in both regions also receive government support for innovation through other programmes and the easiest measurement to make here relates to direct government grants for R&D activity by businesses.

In Australia and the US, support of this nature is recorded as part of the national R&D surveys according to principles laid out by the OECD (OECD 2002). This process includes a special category designating industrial R&D activity that has been directly funded by a federal (and in some cases by a state) government. These figures thus represent subsidies distinct from those accrued through the tax system and are outlined as follows:

- In 2005, in the Australian Bureau of Statistics' annual R&D survey, Australian businesses reported that they had received US\$388 million in federal government grants and US\$32 million in state government grants for their own internal R&D. By this reckoning Australian businesses received an additional subsidy worth 3.8% of their total R&D expenditures from the federal government and an additional subsidy worth 0.3% of state government subsidy.

- In a similar survey conducted by the National Science Foundation though, Californian businesses reported that they received US\$5 billion in direct federal government funding for R&D programmes, a subsidy equivalent to 10% of total business R&D spending in that state. Unfortunately equivalent data on state government subsidy for R&D through direct funding is not publicly available.

Table 32 summarises these levels of government support, rounding percentage estimates of R&D subsidy to the nearest integer.

Table 32 – Estimates of government subsidy for industrial R&D by region, 2005

Proportion of industry R&D expenditure funded by:	California	Australia
Federal tax concessions or credits	3%	7%
Federal grants	10%	4%
<i>Total Federal Government</i>	<i>13%</i>	<i>11%</i>
State tax concessions or credits	2%	0%
State grants	NA	0%
<i>Total State Government</i>	<i>2%</i>	<i>0%</i>
Total Government	~15%	~11%

Note: Estimates are rounded to the nearest integer and are derived from a wide variety of sources: ABS 8104.0, Budget 2008, CAFTB 2006, IRS 2005, and NSF 2005. Note that 2005 data is used (or 2005/06 for Australia) due to a difficulty in accessing more recent Californian data from the California Franchise Tax Board.

There are several observations to make from this table. First, it should be recognised that the level of federal funds directly supporting R&D activity in Californian businesses would almost certainly not be anywhere near as high as 10% in the biotechnology industry. This particular metric is likely to be highly influenced by US federal funding of defence R&D within Californian-based companies.

In 2005, the US Department of Defense spent US\$54 billion on R&D in the US, of which US\$37 billion (or 69%) was allocated directly to US industry (NSF 2008). A similar ratio has been maintained in subsequent years. Now there is usually a discrepancy between what the Department of Defense reports and what businesses acknowledge in national surveys, possibly due in large part to the various ways in which such funds are distributed, but it is perfectly reasonable to expect from these figures that a significant proportion of US federal funding going to support industrial R&D in California are defence oriented and not at all relevant to our comparisons here. Indeed it is quite possible that this effect balances out the apparent advantage that research-intensive companies have in the US in accessing government subsidy.

The second point to make is that the balance between the provision of direct funds and the provision of tax advantages appears to favour the former in the US and the latter in Australia. The relevance of this point may be significant. However once again, this observation should not be over-interpreted at this stage. Depending upon the sectoral focus of direct funding programmes it may have been that firms in Australia were actually receiving a greater

amount of direct support in biotechnology (relatively speaking) than has been true in the US. For example, until its demise in 2007, the Australian Government's Commercial Ready Programme provided direct subsidies to biotechnology firms on a scale that was clearly and deliberately incommensurate with their existing significance in the wider economy.

Interpreting the balance in government support for R&D in Australia and California should be clearer when further information emerges from San Diego about the precise nature of direct financial support that has actually been received in the biotechnology industry there.

The third point to be made about table 31 is the striking level of state government subsidy for R&D activity through tax credits. At face value, this particular form of state government support merely contributes to an existing federal tax exemption in order to create a total tax incentive for R&D that is operating on a scale similar to that in Australia. But it may also signal a difference in attitude among policy-makers at the state level compared with the situation in Australia.

It would be interesting to know, for example, whether the different approaches adopted in California and the Australian states in this regard have non-financial as well as financial consequences. It is easy to imagine a scenario where active investment correlates with a broader willingness to provide support for industry in ways that don't necessarily have further direct financial implications for taxpayers – e.g. through planning laws, training schemes, regional promotions, or regulations. Contrasting the experience in San Diego with that in Sydney or Melbourne should provide some qualitative insights on this subject.

More broadly, it is noteworthy that state government financial support for the development of R&D intensive industry is negligible in Australia, regardless of state, compared with the situation in California. This raises the interesting possibility that the differences in state government support for biotechnology across the three Australian states, so noticeable and significant in a national context and so frequently commented upon by participants in the biotechnology industry around Australia, are actually irrelevant in a global context.

This completes our observations about the comparative levels of government support for industrial R&D. But no commentary about the role of government in biotechnology cluster development would be complete without some assessment also of the non-profit research base. Across all four regions of our comparative study, federal governments fund the vast majority of research performed in universities and other non-profit research institutions. There are some differences though. There is considerable diversity in the level of state government support for non-profit research activities and there is arguably a very significant difference in the mechanism by which federal resources for research are distributed in San Diego and across Australia.

With respect to the first of these two points it can be observed that more than 3.7% of university R&D expenditures at UCSD are funded by the Californian state government while only 0.5% of R&D activity at the Scripps Research Institute is funded by state government

(NSF 2010). This compares with the diverse levels of state government support for university activity around Australia: 2.0% of university R&D activity across all NSW universities, 3.7% across all Victorian universities, and 5.2% across all Queensland universities (ABS 8111.0).

Given the difference in the performance of research in biology and medicine in San Diego compared with that in Australia, it could be argued that the relative level of investment in universities by state governments is less important than its focus or its implementation. Relative to their scale, for example, Victorian universities evidently gain as much resourcing from state government as UCSD does. Yet the performance of Victorian institutions in developing intellectual property relevant to a biotechnology industry is nowhere near as strong as that of UCSD. Understanding the particular role of state government funding for San Diego's institutions and for defining their areas of scientific focus could be instructive for policy-makers back in Australia.

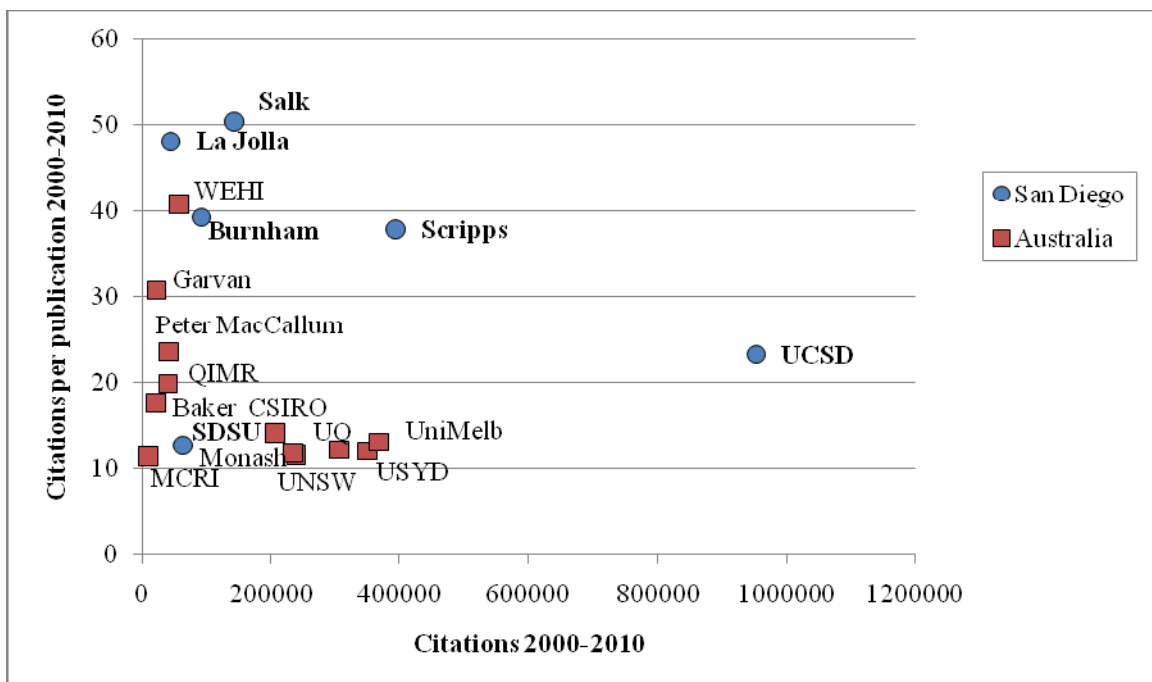
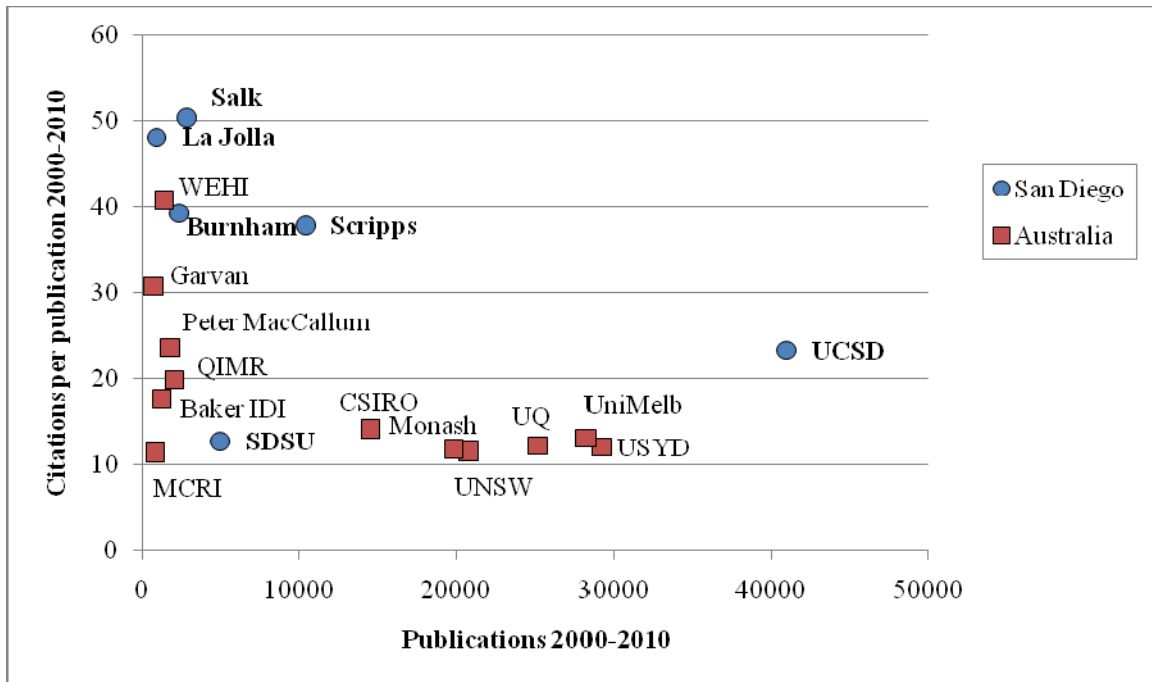
More important, though, is the second issue about how federal investment in R&D is made across the non-profit research base in San Diego and in our three Australian cities.

One of the most remarkable attributes of the leading research institutes in San Diego is how much funding they receive through federal competitive processes from the National Institutes of Health. A rudimentary estimate based on NSF R&D expenditures and NIH data on awards to all US institutions (NIH 2005), suggests that more than two thirds of all the life sciences R&D activity occurring in UCSD, the Scripps Research Institute and San Diego State University is directly funded through NIH grants. This contrasts massively with the situation in Australia, where a similar calculation suggests that in none of our three states do NHMRC grants constitute more than 20% of total reported R&D expenditures in medical or biological sciences (NHMRC 2008).

Such figures are not directly analogous, not least since some (though not all) of the indirect costs associated with NHMRC grants have still been supplied to institutions by the Australian Government, but channelled via other agencies – a practice different to that in the US. This acknowledged, the underlying implication of the data is that a far higher proportion of researchers in San Diego's non-profit institutions are funded through competitive processes than is true in Australia. Although it is only a hypothesis at this stage, it could be that the differing dependence on competitive funding processes in Australian and San Diego is an important determinant of the differing quality of research outputs.

There is tentative evidence, it should be added here, that the role of competitive funding mechanisms in driving research performance is visible in Australia even without the benefit of the San Diego comparison. A recent bibliometric analysis of Australian biomedical research has demonstrated that medical research institutes (which tend to fund a disproportionate share of their research through national competitive grants) do gain significantly higher average citations per publication than is true for universities, hospitals or government research agencies (Henadeera 2009).

Figure 33 – Citations per publication versus total publications and citations, for key institutions



Note: (i) Institutional data are derived from the ISI Essential Science Indicators, covering a 10-year and 4-month period from 1 January 2000 to 30 April 2010. (ii) Institutional abbreviations are as follows: Baker = Baker IDI Heart and Diabetes Institute; Burnham = Sanford-Burnham Medical Research Institute; CSIRO = Commonwealth Scientific and Industrial Research Organisation; Garvan = Garvan Institute of Medical Research; La Jolla = La Jolla Institute for Allergy & Immunology; Monash = Monash Univ.; Peter MacCallum = Peter MacCallum Cancer Institute; QIMR = Queensland Institute of Medical Research; Salk = Salk Institute for Biological Studies; Scripps = Scripps Research Institute; SDSU = San Diego State Univ.; UCSD = Univ. of California, San Diego; UQ = Univ. of Queensland; UniMelb = Univ. of Melbourne; UNSW = Univ. of New South Wales; USYD = Univ. of Sydney; and WEHI = Walter & Eliza Hall Institute.

In figure 33, we replicate part of this analysis, using a slightly different dataset, in order to contrast publications, and citations per publication, from Australian universities and medical research institutes with those emerging from similar organisations in San Diego.

Unsurprisingly, and in line with the bibliometric analysis just mentioned, we find that many of the medical research institutes in Brisbane, Melbourne, and Sydney do garner more citations per paper than is true of Australia's leading universities. This is consistent with the hypothesis that the competitiveness of research funding processes may be an important determinant of research quality.

By including the international comparison, however, we also find:

- (a) that almost every Australian institution has room for improvement in its research performance, at least by the high standards of San Diego's institutions;
- (b) that research outcomes even for Australia's leading universities look closer to those for San Diego State University than for the globally prestigious University of California, San Diego;
- (c) that the current public policy approaches for supporting research are creating remarkably consistent outcomes for the major Australian east-coast universities, compared both with San Diego's research organisations and with Australia's medical research institutes; and
- (d) that the Walter & Eliza Hall Institute does show that it is entirely possible for Australian institutions to operate at those elevated standards found in San Diego.

Now there are a couple of caveats that must be made at this point. One potential criticism of this analysis is that it favours institutions with a high proportion of medical research activity, as these tend to be the more highly cited fields. With this in mind, it must be acknowledged that the patterns are essentially same even when one breaks the data down by field. For instance, the graphs of publications and citations per publication in the ISI disciplines of 'clinical medicine' or 'biology and biochemistry' or 'molecular biology and genetics' are all analogous to the graphs shown in figure 33.

It should also be recognised that the spread of performance among the smaller medical research institutes is not untypical and may have a very simple explanation. Smaller institutions globally usually do tend to have significantly greater variation in citation-per-publication performance compared with larger institutions. This is most likely a consequence of the impact that even a very small number of highly cited articles (or a high proportion of uncited articles) can make on citation-per-publication figures when an organisation only produces a small number of total publications.

Organisational scale effects may also be relevant, though. Large institutions tend to have an elevated lower bound on normalised performance measures due to the strategic advantages conferred by their scale. This is because large institutions typically have strong reputational advantages and the capacity to shift resources to where they are needed, both of which tend to support good quality recruitment. But large institutions also have an upper bound on normalised performance measures due to the law of averages: the challenge of finding people of the calibre to continuously raise average institutional performance becomes ever greater as an organisation expands in size.

Both of these effects tend to diminish the variation in institutional performance as organisations grow in scale – but not to the extent experienced among Australia’s larger universities.

Given the challenges of teasing out those differences of institutional performance in figure 33 that relate to statistical accident or to scale factors from those that relate to overlaying funding mechanisms or to underlying organisational processes, it would be premature to make conclusive statements about government research support from this analysis. Nonetheless, the remarkable consistency of performance in Australian universities (as shown in figure 33 and articulated as point (c) above) strongly implies that government policy rather than variability in internal organisational processes is most likely to be the critical determinant constraining research performance in Australian universities.

These are clearly issues that warrant further, detailed study. Coupled with all the evidence presented previously in section 3 of this report, the data do suggest that both the scale and the mechanisms for distributing public resources for medical and biomedical science ought to be revisited as areas requiring significant policy attention in Australia. Certainly, in contrasting the situation in Australian cities with that in San Diego, it seems credible to suggest that the nature of the policy mechanisms supporting the public research base currently constitutes a far more important topic for contemporary government attention than those differences that exist in policies for the provision of industrial support.

The latter may well be important too of course, but the marked differences in the public research base and the apparent disparity in the competitiveness by which public research funds are distributed suggest very strongly that Australia’s public research funding system is the more immediate priority for attention when thinking about the role of government in fostering local industrial development in biotechnology.

4.4 Australian cities still present opportunities for industrial development in biotechnology

Our comparative study of three popularly perceived impediments to biotechnology cluster formation in Australia presents a complex picture.

First, with respect to the need for a flagship company or for success stories in the sector, clearly the issue is not the lack of *a* flagship company or of *a* success story, but rather the lack of repeat successes. Something in the Australian industrial landscape has prevented the development of *multiple* competing companies in the bio/medical area operating at reasonable scale – even though we know the Australian industrial system has enabled at least three such companies to emerge.

Second, with respect to the challenge of accessing private capital, there is evidently much more venture capital investment in biotechnology and health in the city of San Diego alone than there is in the whole of Australia. But this does not necessarily imply a failure of private capital markets in Australia. On the contrary, the data suggest that reasonably large private capital markets do exist in Australian cities but that the investors in these markets don't perceive opportunities in biotechnology to the same degree as is true in San Diego.

Third, with respect to total government support for industrial development, it is difficult to claim that industry in San Diego is financially advantaged due to government subsidy relative to industry in Australia. This recognised, some points of difference are evident. Compared with the level of R&D subsidy provided by the Californian Government, the differences in state government support for biotechnology industry in Australia are arguably negligible when re-considered in a global context. There is also a dramatic difference in the scale and in the mechanism by which federal governments invest in non-profit research in Australia and in San Diego.

The most important point, though, is not what this analysis tells us in isolation. Any of these perceived deficiencies could be highly influenced by the extent to which globally significant intellectual property is emerging from the Australian public-sector research system – and our evidence suggests that this is not occurring in Australian cities on the same scale as is true in San Diego. Without first increasing the scale, quality, and focus of the research base in Australia, it is impossible to establish the extent to which any of these other purported deficiencies really do represent genuine problems that will impede ongoing industrial development.

In fact, even under current arrangements, Australian cities may conceivably represent excellent environments for the growth of biotechnology industry, but for the fact that these environments cannot be appropriately exploited due to a shortage of globally leading and commercially exciting ideas.

5. Conclusions

This report has provided a broad survey of activities relevant to the development of a biotechnology industry in San Diego, Melbourne, Sydney and Brisbane. For the purpose of our research, we have chosen where possible to consider biotechnology broadly, contrasting a large number of metrics, some of which are relevant to several different bioscience sectors, including agribiotech and medical devices as well as biopharmaceuticals. Our scope has been deliberately broad so as not to bias our analysis in favour of particular regions that may have a particular technology focus.

Some of our most interesting findings are summarised in table 34, which compares several of our key metrics as derived for San Diego and Melbourne. Melbourne has been selected among the Australian cities for this table, as it is widely perceived to be the closest thing Australia has to a city with a biotechnology cluster. Entries in this table are organised in various categories, but the most revealing thing is what emerges when these metrics are ranked according to the entry in the third column – the ratio of San Diego's value against Melbourne's. At the top of this list are:

- R&D spend of the second largest R&D spending public company;
- the number of articles in high profile journals like Cell and Nature Biotechnology;
- the level of venture capital and private equity investment in biotechnology and health;
- the level of total patenting in core areas relevant to biotechnology as well as the patenting activities of non-profit organisations; and
- the scale of R&D spending by publicly-listed biotechnology companies and by universities specifically in biological science fields.

What are clearly must less significant points of differentiation are:

- the number of articles being published in medical science journals generally or in areas of biology outside of molecular and cell biology or medical science;
- the level of venture capital and private equity investment across sectors outside of biotechnology and medical industry;
- the levels of R&D being spent by universities in medical science fields;
- the levels of R&D tax concessions or credits; and

Biotechnology Clustering – Landscape Analysis

- the scale (including the R&D spend) of the largest life sciences company.

Table 34 – San Diego versus Melbourne

(All dollars are US\$)		San Diego	Melbourne	San Diego / Melbourne
R&D activity	R&D spend of public companies (2007-08)	\$1.7bn	\$300m	5.7x
	University R&D spend in biological sci (2006)	\$407m	\$84m	4.9x
	University R&D spend in medical sci (2006)	\$367m	\$282m	1.3x
Scientific output	Articles in Cell (2001-2008)	202	25	8.1x
	Articles in Nature Biotechnology (2001-2008)	71	16	4.4x
	Articles in molecular & cell biology (2006)	3837	2335	1.6x
	Articles in medical sciences (2006)	4424	4933	0.9x
	Articles in other areas of biology (2006)	1240	885	0.7x
PCT patents	Organic chemistry patents: class C07 (2007)	348	54	6.4x
	Medical patents: class A61 (2007)	608	142	4.3x
	Biochemistry patents: class C12 (2007)	192	51	3.8x
	Annual bio-related patent applications by 7 leading public institutions (2001-2008)	98	37	2.7x
Industry structure & support	R&D spend of 2nd largest R&D-spending co.	\$143m	\$9m ⁽ⁱⁱ⁾	16x
	VC & private equity in biotech/health (2006-07)	\$1.2 billion	\$155 million	7.7x
	Federal funding / Industrial R&D	10% ⁽ⁱⁱⁱ⁾	4%	2.7x
	VC & private equity in all sectors (2006-07)	\$2.0 billion	\$1.1 billion	1.8x
	R&D spend of largest R&D-spending co.	\$293m	\$200m ^(iv)	1.5x
	R&D tax credit or concession / Industrial R&D	5%	7%	0.7x
	Revenue of largest company (USD)	\$1.6bn	\$3.4bn	0.5x

Note: (i) Summarises data derived throughout this report. (ii) The second highest R&D spending company in the Melbourne life-sciences sector and the highest spender among pure medical biotechnology companies was Biota, with R&D spending at ~US\$9m (PPP). (iii) The San Diego value for 'Federal funding / Industrial R&D' is an estimate for California as a whole and is likely to be a very dramatic over-estimate as it would be heavily influenced by US Department of Defense funding. (iv) The largest R&D-spending life sciences company in Melbourne was CSL, with R&D expenditure in 2008 at around ~US\$200 million (PPP).

It is clear that there is much for Australian policymakers and biotechnology entrepreneurs to learn from the evolution of biotechnology industry in San Diego. Over the coming months, important details will emerge from the US Studies Centre's ongoing analysis of (a) the role that government has played in nurturing a biotechnology cluster in San Diego and of (b) how companies in San Diego have responded to their own particular challenges inherent in operating at a distance from many of their partners and customers elsewhere in the US and around the world.

Originally, this landscape analysis was intended simply to inform the interpretation of this ongoing research agenda as it emerges from San Diego. It has yielded a considerable surprise however in challenging widespread Australian perceptions about the quality and scale of the research base in Melbourne, Sydney and Brisbane as it relates to the development of a biotechnology industry.

Australia's public research base is weak in fundamental biology, and especially in molecular and cell biology. As a consequence, our public institutions have relatively low patenting activity compared with similar institutions in San Diego and it is likely that these institutions are not the wellsprings of valuable intellectual property that Australians might desire them to be. So long as this situation persists it is difficult to make definitive statements about other impediments to biotechnology cluster development in the Australian context.

It is evident that Australian regions do have some very interesting strengths in the bioscience area:

- a good research base in agricultural and related areas of biology;
- a vibrant (if somewhat parochial) medical research community;
- a small number of genuinely successful companies clearly demonstrating that commercial success is possible in this sector;
- reasonable access to capital locally (assuming of course that genuinely competitive commercial projects can be put forward for investment);
- an educated workforce, though this is not an issue we have considered in this report; and
- a nascent, if uncertain, appetite among policymakers and public institutions to try to build higher scale and higher quality research on the molecular side (as exemplified by the Institute for Molecular Bioscience at the University of Queensland).

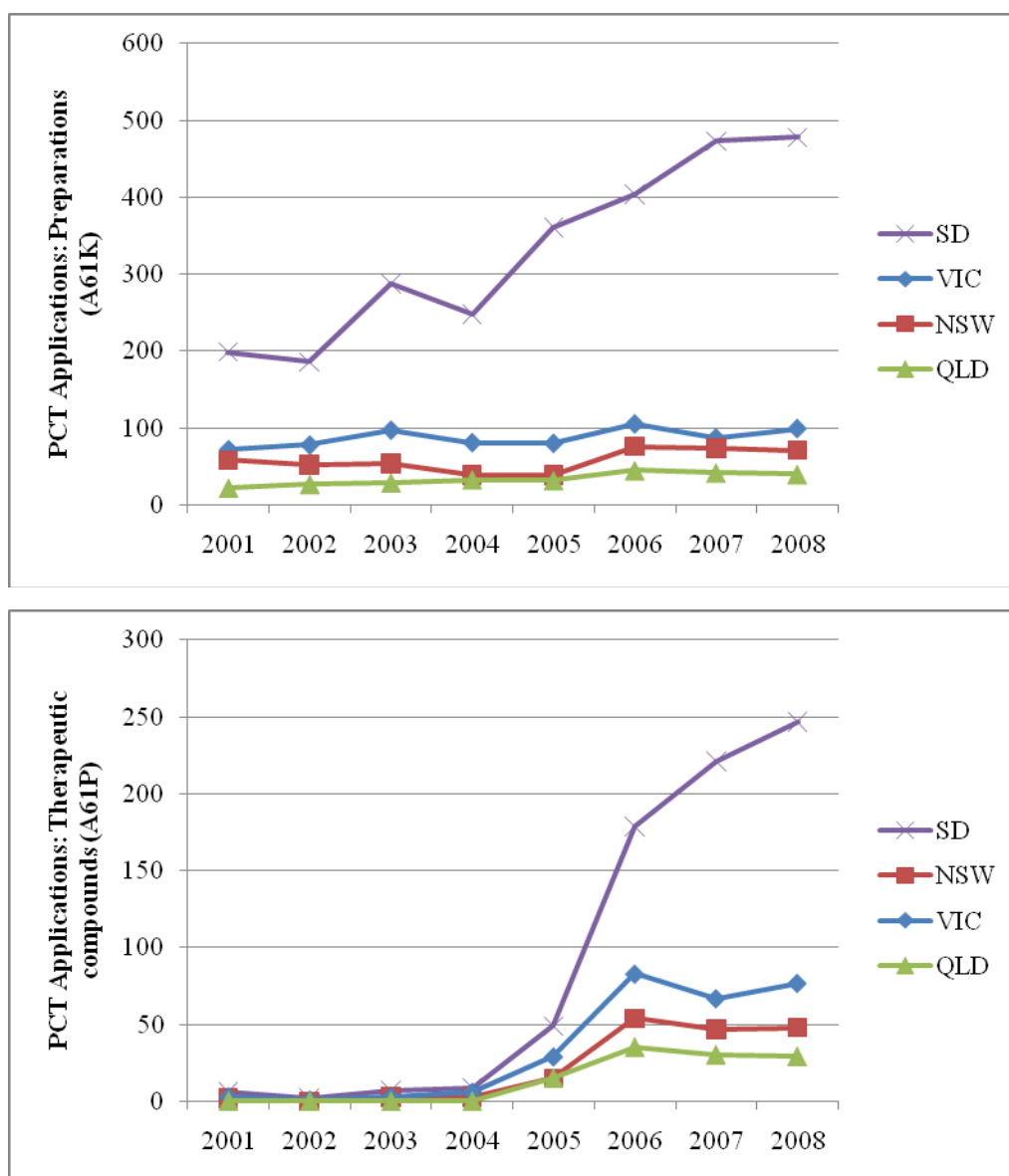
But our analysis provides a new sense of perspective about Australia's existing research base and throws into question the popular interpretation of why the development of biotechnology clusters has been slow in Australia, relative to a leading city like San Diego.

Our assessment strongly suggests that some of the past policy focus in this area has been misguided. It would seem that the great challenge for Australia is not removing the impediments to industry formation in order to ensure that Australian businesses can make the most of this country's remarkable knowledge base. On the contrary, it would seem that Australia's greater challenge is still actually to make its knowledge base remarkable.

6. Appendix

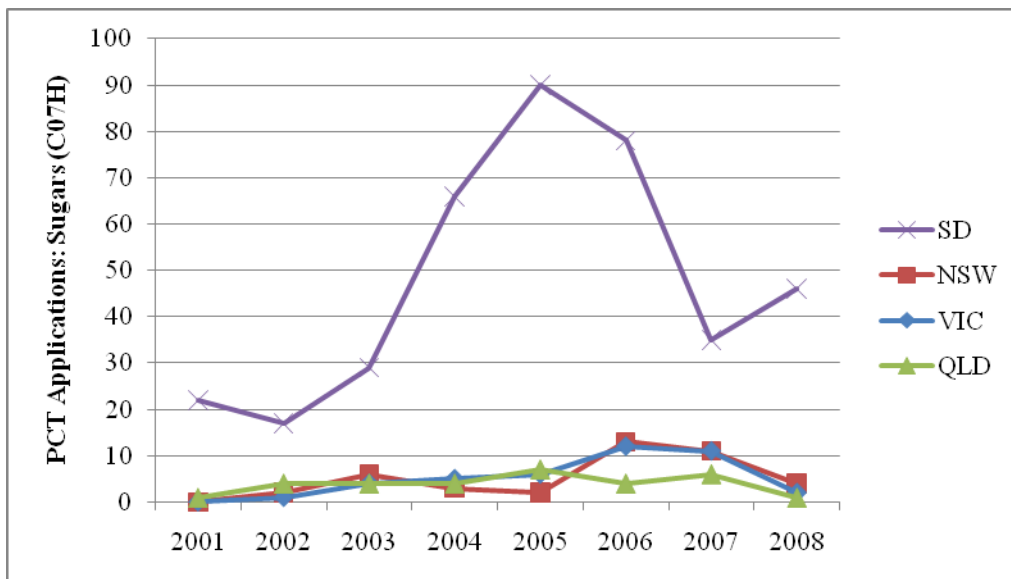
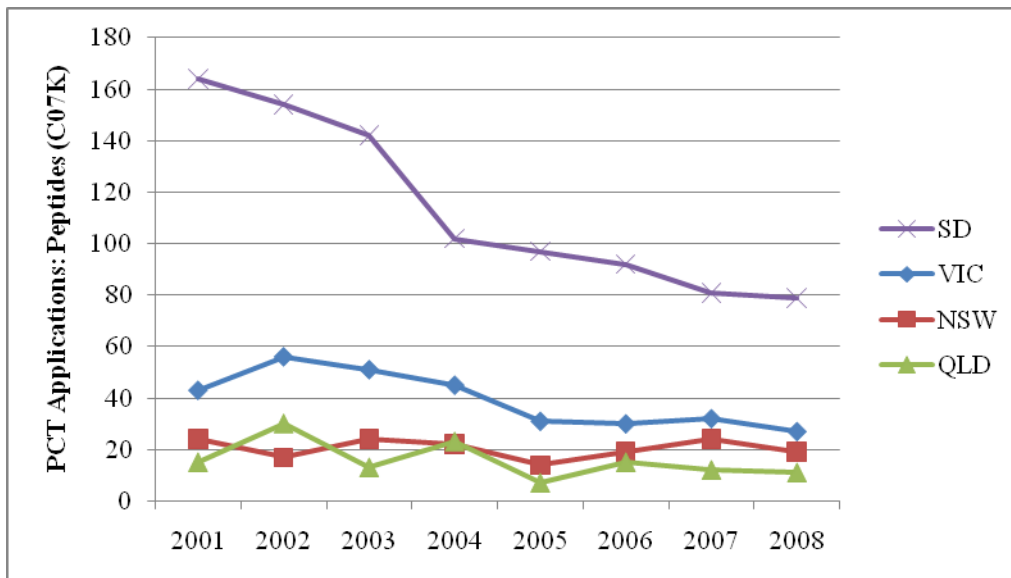
The ensuing figures show total international patent applications with an applicant (private or public-sector) from a given region, across a range of patent subclasses. Subsequently, at the end of the appendix, table A8 lists a number of international patent subclasses that are relevant to the analysis in this report. The consistent impression from the figures below is of intensive activity in San Diego in core areas of biotechnology, compared with modest activity in the Australian states.

Figure A1 – International patent applications in key preparations and therapeutics



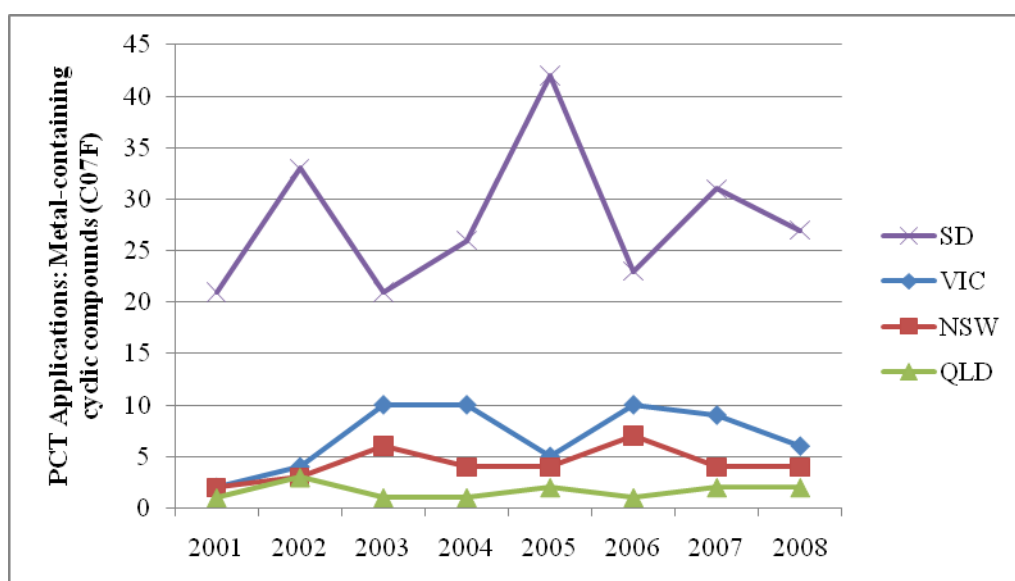
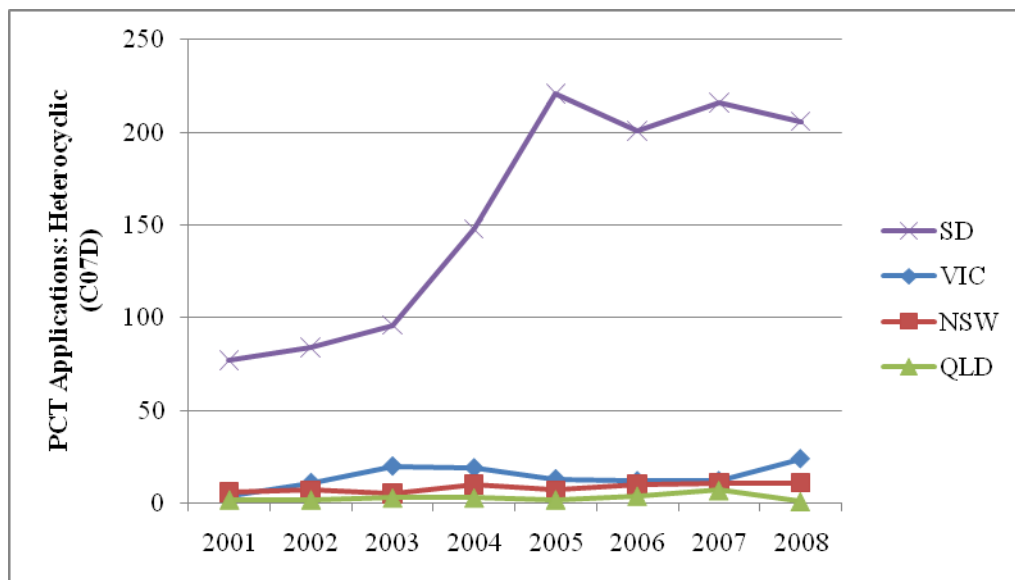
Note: Derived from WIPO database.

Figure A2 – International patent applications in peptides and sugars



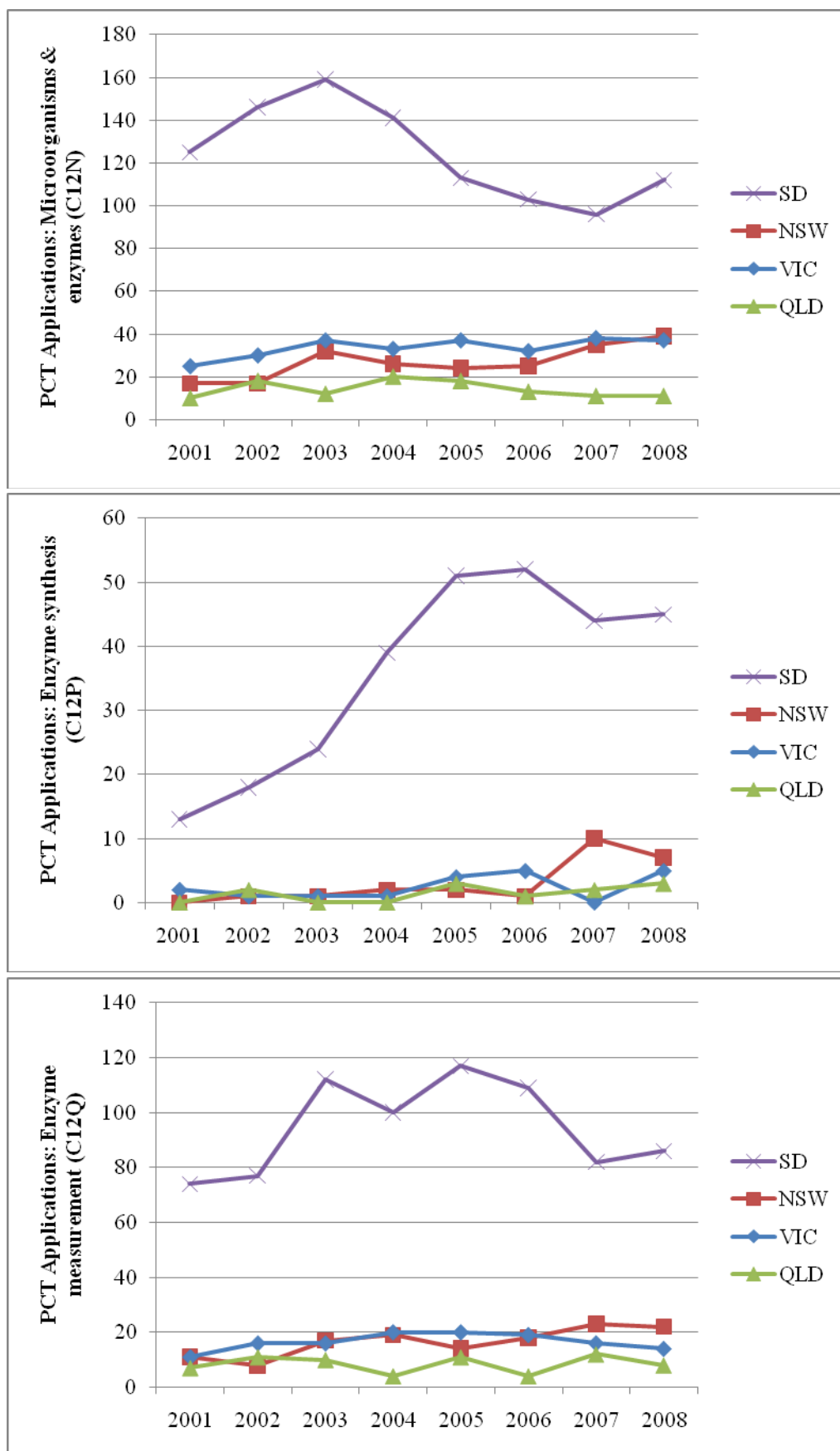
Note: Derived from WIPO database.

Figure A3 –International patent applications in small organic compounds



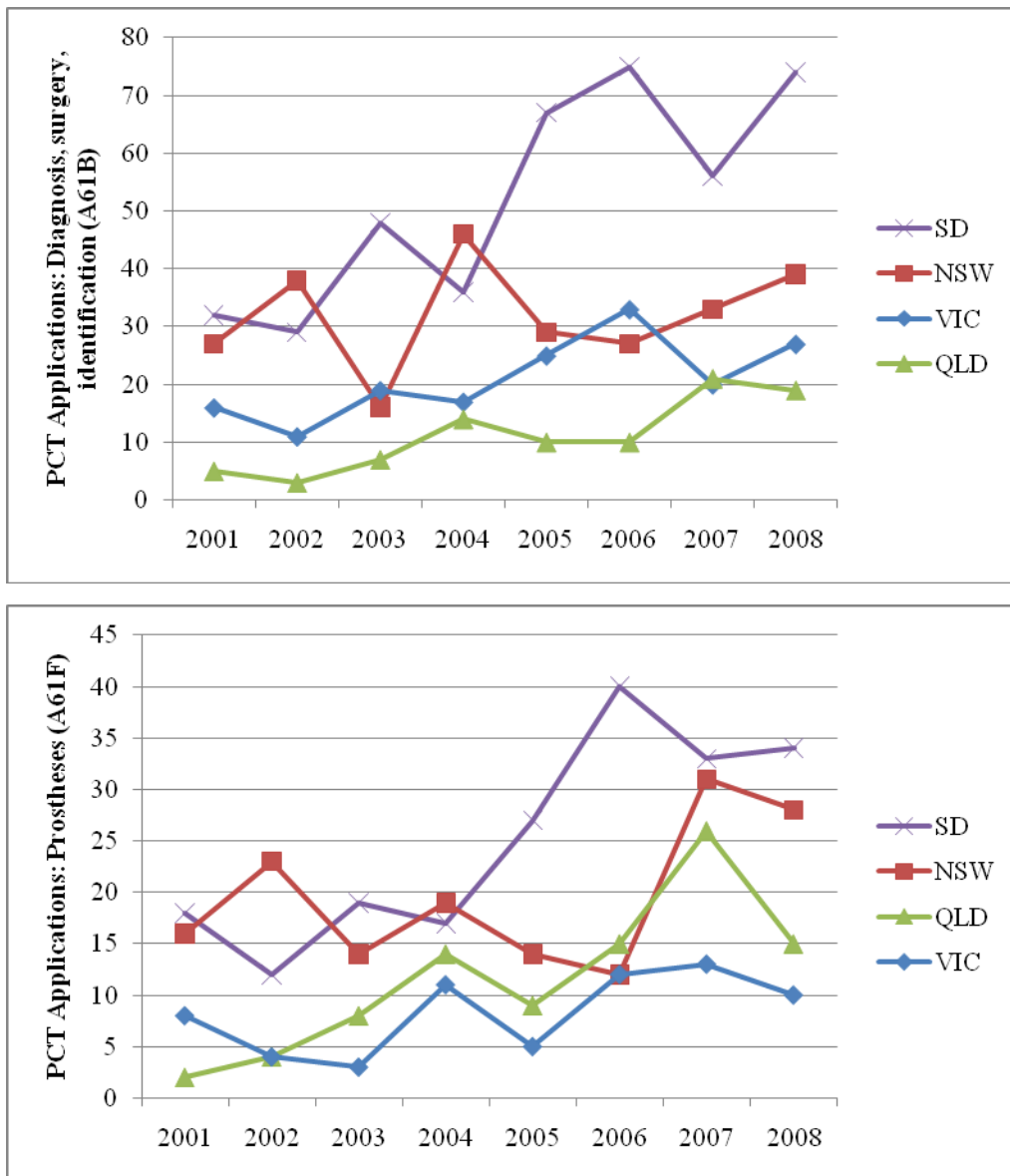
Note: Derived from WIPO database. Note that the formal definition for subclass C07F is “acyclic, carbocyclic, or heterocyclic compounds containing elements other than carbon, hydrogen, halogen, oxygen, nitrogen, sulfur, selenium, or tellurium”.

Figure A4 –International patent applications in biochemistry



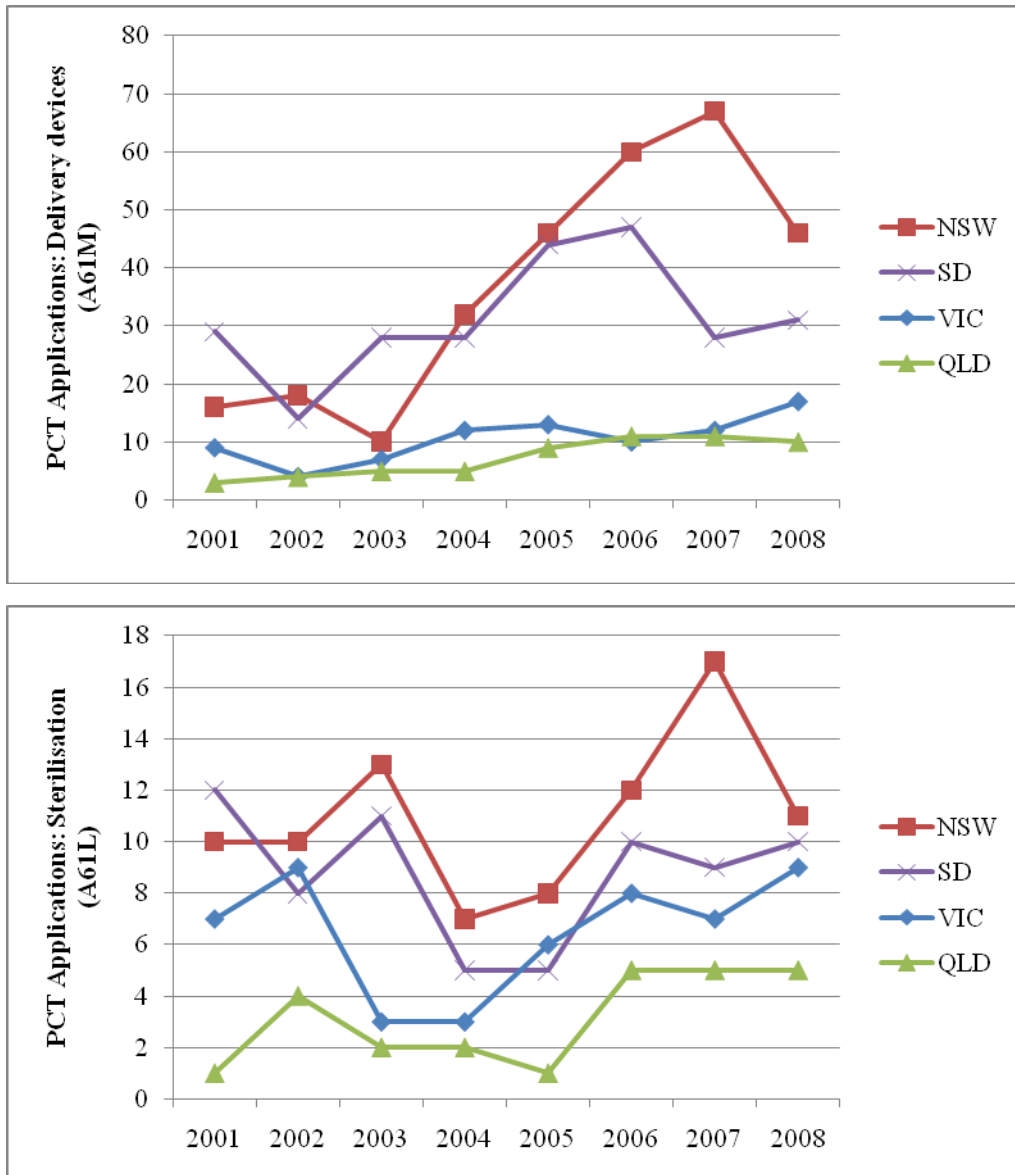
Note: Derived from WIPO database.

Figure A5 – International patent applications in diagnosis, surgery and prostheses



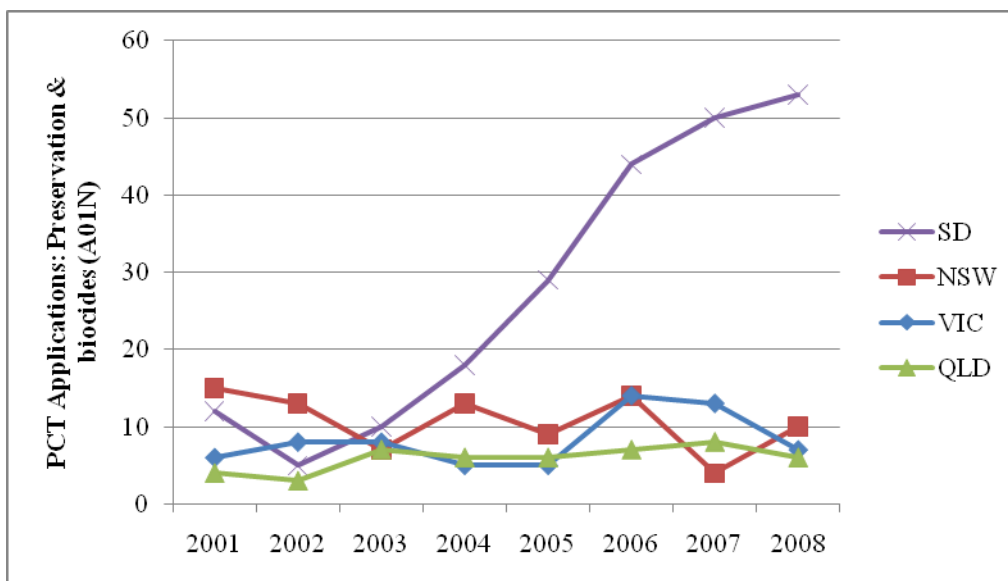
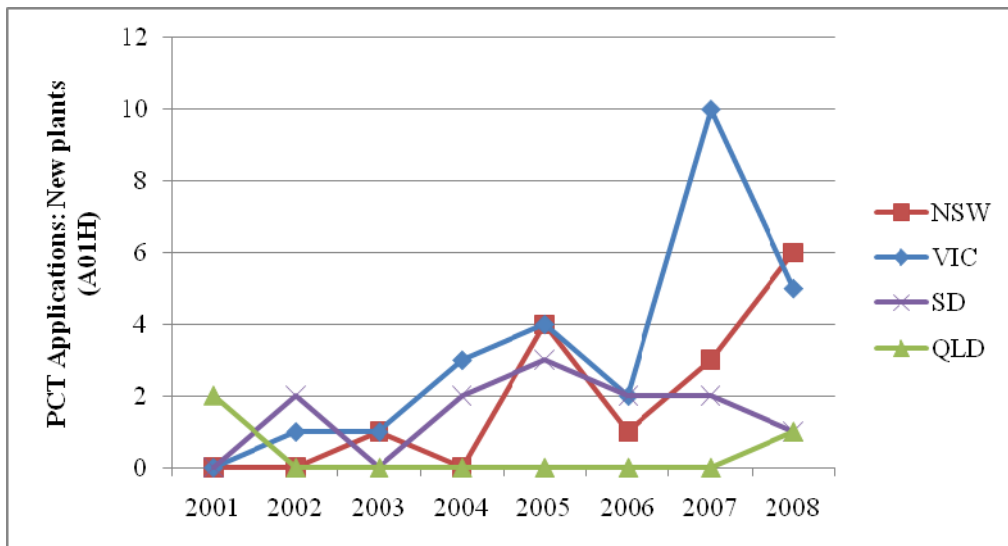
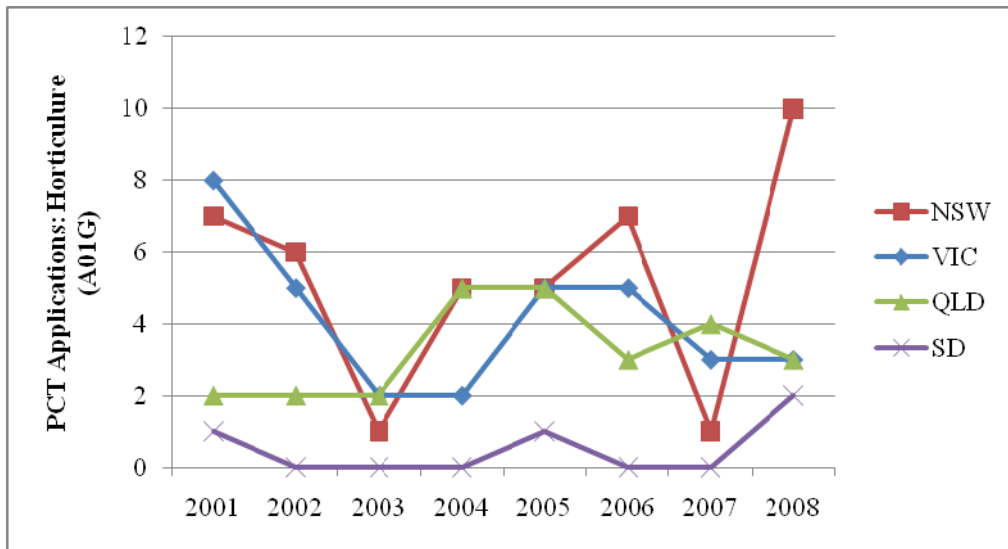
Note: Derived from WIPO database.

Figure A6 – International patent applications in delivery devices and sterilisation



Note: Derived from WIPO database.

Figure A7 – International patent applications in horticulture, plants, biocides



Note: Derived from WIPO database.

Table A8 – Classifying PCT Patents by subclass

Subclass	Description
A01G	Horticulture; cultivation of vegetables, flowers, rice, fruit, vines, hops, or seaweed; Forestry; Watering
A01H	New plants or processes for obtaining them; Plant reproduction by tissue culture techniques
A01N	Preservation of bodies of humans or animals or plants or parts thereof; Biocides, e.g. As disinfectants, as pesticides, as herbicides; Pest repellants or attractants; Plant growth regulators
A61B	Diagnosis; Surgery; Identification
A61F	Filters implantable into blood vessels; Prostheses; Orthopaedic, nursing or contraceptive devices; Fomentation; Treatment or protection of eyes or ears; Bandages, dressings or absorbent pads; First-aid kits
A61K	Preparations for medical, dental, or toilet purposes
A61L	Methods or apparatus for sterilising materials or objects in general; Disinfection, sterilisation, or deodorisation or air; Chemical aspects of bandages, dressings, absorbent pads, or surgical articles; Materials for bandages, dressings, absorbent pads, or surgical articles
A61M	Devices for introducing media into, or onto, the body; Devices for transducing body media or for taking media from the body; Devices for producing or ending sleep or stupor
A61P	Therapeutic activity of chemical compounds or medicinal preparations
C07D	Heterocyclic compounds
C07F	Acyclic, carbocyclic, or heterocyclic compounds containing elements other than carbon, hydrogen, halogen, oxygen, nitrogen, sulfur, selenium, or tellurium
C07H	Sugars; Derivatives thereof; Nucleosides; Nucleotides; Nucleic acids
C07K	Peptides
C12N	Micro-organisms or enzymes; compositions thereof; propagating, preserving, or maintaining micro-organisms; mutation or genetic engineering; culture media
C12P	Fermentation or enzyme-using processes to synthesise a desired chemical compound or composition or a separate optical isomers from a racemic mixture
C12Q	Measuring or testing processes involving enzymes or micro-organisms; compositions or test papers therefor; processes of preparing such compositions; condition-responsive control in microbiological or enzymological processes

Note: International Patent classifications as listed in WIPO 2009.

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