Nano-technology Patenting in the USA

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Abstract: In January 2002, the Australian Research Council categorised research related to nano-materials and bio-materials as one of its four priority funding areas. Such projects are considered to be of paramount importance because of the recognised potential of these technologies to improve product efficiency, conserve natural resources and help alleviate environmental problems. This paper uses a Technological Strengths (TS) model based on patent statistics to: (1) analyse trends in the patenting of nano-technologies in the USA, using data from 1975 to 2000 for patents lodged at the US Patent and Trademark Office; and (2) examine Australia's contribution to the development of these technologies. The four elements of the TS model are: national priorities (captured by the technological specialisation index, which is 1.38 for Australia), international presence (as represented by the patents share, which is 0.73% for Australia), contribution of patents to further knowledge development (as measured by the citations index, which is 2.73 for Australia), and potential commercial benefits (approximated by the rate of assigned patents, which is 0.75 for Australia). The TS model applied to Australia demonstrates some potential in the field of nano-technology, but more concentrated efforts are needed to ensure that Australia makes a stronger impact in the global arena. International rankings of technological strengths in nano-technology are also compiled.

Keywords**:** Patents, nano-technologies, trends, technological strengths, international rankings.

1. Introduction

In January 2002, the Australian Research Council (ARC) categorised research related to nano-materials and bio-materials as one of its four priority funding areas (the other three areas being the genome-phenome link, complex systems, and photon science and technology). Nano-materials are considered to be of paramount importance because of the recognised potential of these technologies to improve product efficiency, conserve natural resources and help alleviate environmental problems through the combined advances in the development of materials science and biotechnology. According to the ARC [2002, p.1]: "Australia has extensive existing research strengths both in advanced materials science and in biotechnology". This paper evaluates the ARC's proposition by analysing Australia's performance in nano-technology through patent activities in the US market.

Protection of intellectual property has become extremely important within a globalised world and economic systems highly dominated by market mechanisms. The US patent system has been in existence for more than 200 years. Since the late 1970s, there has been an unprecedented interest in the US patent system from individuals and companies world-wide. The US economy is particularly attractive to innovators and entrepreneurs because of its large size and technologically advanced nature. Consequently, the US Patent and Trademark Office (PTO) receives by far the largest number of foreign applications [Archibugi, 1992], with close to 50% of all patents in the USA being granted to foreigners [Griliches, 1990]. Australia has followed this trend, and the USA has been the major foreign patenting system used by Australian inventors [Bryant et al., 1996].

The US government has adopted nano-materials as a priority funding and research area through its National Nano-technology Initiative. If Australia aspires to be a leading country in the development of these technologies, its presence in the American market will need to be significant and its intellectual property rights protected.

This paper analyses nano-patenting in the USA, with particular emphasis on Australia. Analysis of general trends in nano-technology patents in Section 2 is followed by a description of a Technological Strengths model based on patent statistics in Section 3. The model is used to assess Australia's current status and possible technological advantages in Section 4. Concluding remarks are given in Section 5.

2. Nano-technology patents in the USA

According to Crandall [1996], nano-technology (or molecular engineering) will soon create effective machines and molecular motors as small as DNA. This capacity to manipulate matter at the level of atoms and molecules with extremely high precision is expected to change the economic, ecological, and cultural fabric of society dramatically. Foresight experts saw the beginning of the nano-revolution in the late 1980s [Crandall and Lewis, 1992]. In addition to their importance in various sectors such as medicine, agriculture, manufacturing, construction, transport and communications, these technologies are also extremely promising from the ecological perspective.

When patented, nano-technologies are not always explicitly characterised as environmental technologies in their technical specifications. However, the fabrication and use of structures at the atomic and molecular scale [Regis, 1995] are intrinsically more ecologically sustainable than traditional technologies. Nano-technologies typically use few resources and can process all types of waste by rearranging their atomic structures and isolating dangerous atoms [Nicolau, 1999]. These technologies are inherently "green", and their deployment should decrease demand on the natural environment [Banks and Heaton, 1995]. As they have enormous potential for environmental implications, their economic importance has been reflected in the increasing number of nano-patent registrations.

Figure 1 shows the annual numbers of nano-patents registered at the US PTO from 1975 to 1998. Patent registrations refer to the date of patent application, not the date of patent issue, as the former is considered to be a more accurate measure of patent activity (for further explanations, see Chan et al. [2001] and Marinova and McAleer [2002a, b]). There is a significant delay between the date of application and the date of issue of patents, in some cases up to 10 years. Consequently, the data for 1999, 2000 and 2001 are still largely incomplete, and are not included in Figures 1 and 2.

The number of registered nano-patents in the USA (Figure 1) increased exponentially from 305 in 1975 to 4,467 in 1995, but there was a significant reduction in nano-patents to 3,642 in 1996. Although the numbers increased after 1996, US nano-patents for 1997 and 1998 at 4,313 and 4,376, respectively, were still lower than at their peak in 1995. However, as it takes an average of two years for a patent application to be approved, it is expected that the numbers of patents for the last 2-3 years of the sample period may eventually be higher than their present levels.

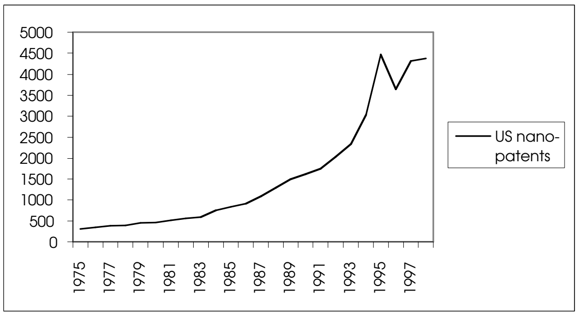

Figure 1. Annual US nano-patents by year of application, 1975-1998 (as at 5 March 2002)

Obviously, nano-technologies have been an area of significant patent activity in the mid- to late-1990s. It is interesting to note that the relative share of nano-technologies in the overall number of US patents has also been increasing (see Figure 2), with the highest share of 2.9% in 1995. Consequently, this group of technologies is becoming increasingly important for the economy. The correlation between the number of US nano-patents (Figure 1) and the share of nano-patents to total US patents (Figure 2) is high at 0.98, while the correlation between the number of US nano-patents and total US patents is even higher at 0.99.

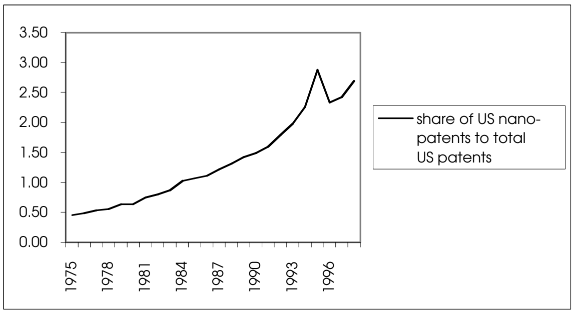

Figure 2. Annual share of US nano-patents to total US patents by year of application, 1975-1998 (as at 5 March 2002)

Australia's contribution to the development of nano-technologies, as represented by registered US patents, has been quite modest. With 313 patents in total, Australia held 0.73% of the total number of US nano-patents registered between 1975 and 2000. At 39%, a high proportion of Australian patents was lodged in 1998 alone, which indicates a very recent interest in the development of nano-technology. The following two sections address the claim that Australia has strategic technological and research strengths in this area relative to leading countries internationally.

3. Technological strengths model

Patents data have been used to describe national strengths and weaknesses in various technological areas [Campbell, 1983; Patel and Pavitt, 1991]. Information on patents can reveal early trends in technological change and is indicative of technological activity which can subsequently be transformed into market success [Ernst, 1997]. The Technological Strengths (TS) model, which can be used to assess Australia's potential in nano-technology, exploits the information in patents data (for a detailed discussion of the model, see Marinova [1999]).

There are four components of the TS model, represented solely in terms of technological strengths, namely: (i) contribution of patents to further knowledge development (or "knowledge"); (ii) potential economic benefits (or "market"); (iii) national priorities (or "local"); and (iv) international presence (or "global"). The TS model is based on patent statistics and can be used to assess the technological strengths of a country, region, industry sector or an individual company.

The local and global components reflect the development of technologies and patents themselves. Evidence from innovation studies stresses the importance of two co-existing trends in the development of technologies, namely globalisation and localisation [Pavitt, 1995]. Locally developed skills and knowledge benefit from the interrelated global technological developments and globalised economy, while global technological trends are given a context in particular innovation milieux and local creativity.

The knowledge and market components indicate the potential power of patents. By their nature, patents represent both advancement of knowledge and potential tools for exploiting economic benefits. However, this does not happen automatically, and registered patents can remain unused for extended periods for a variety of reasons. If a patent (or cluster of patents) provides a technological strength, it will have to manifest its potential explicitly, such as through a contribution to further knowledge development and/or commercialisation.

Four patent-related indicators are used to evaluate technological strengths. At the country level, which is the focus of this paper, the TS indicators are given as follows:

(1) *Local*: The technological specialisation index (TSI) is a measure of the local development of technologies, or the comparative advantage of a local technology relative to international standards. Paci et al. [1997] stress the informative value of the index because it accommodates sectoral differences in patenting in the domestic (or local) economy compared with the world (or global) economy. They suggest the following ratio:

$$TSI_{ij} = (P_{ij}/\sum_i P_{ij}) / (\sum_j P_{ij}/\sum_i \sum_j P_{ij}),$$

where P_{ij} denotes patents in sector i (such as nano-technology) invented by residents of country j (e.g. Australia). The ratio $P_{ij}/\sum_i P_{ij}$ denotes patents in sector i for country j relative to all patents in country j, whereas the ratio $\sum_j P_{ij}/\sum_i \sum_j P_{ij}$ denotes total patents for sector i in all countries relative to all patents in all countries. Therefore, TSI_{ij} reflects the relative strength of sector i in country j to sector i in all countries. If $TSI_{ij} > 1$ for sector i in country j, this represents a technological strength at a national level compared with international standards. The higher is the value of TSI_{ij}, the greater is this relative technological advantage.

(2) *Global*: An indicator of the global impact of technologies in a given field [Patel and Pavitt, 1991] is the patents share (PS) of a particular technology in a country to total patents in the same field, namely:

$$PS_{ij} = P_{ij}/\sum_j P_{ij}, \quad 0 \le PS_{ij} \le 1,$$

where PS_{ij} denotes the patents share in sector i of country j to total patents in the same sector.

(3) *Knowledge*: The citations index (CI) measures the usefulness of a patent in subsequent patent documents, and hence in the creation of new knowledge. The CI is calculated relative to the total number of patents granted in a given field [Ernst, 1995], as follows:

$$CI_{ij} = CP_{ij}/P_{ij},$$

where CP_{ij} represents the number of citations of all patents issued in sector i to country j. The higher is the index, the more frequently cited are patents. Compiling the CI from the US PTO's Internet database is an extremely labour intensive exercise, requiring each US patent to be checked against subsequent US patents for referencing. For industries where the number of patents is far greater than for nano-technologies, the CI would best be compiled using sampling techniques.

(4) *Market*: When a patent application has been approved and a patent issued, the applicant has the

right to assign the commercial exploitation of the patent to one or more individuals and/or companies in one or more countries. The rate of assigned patents (RAP) in a given field [Marinova, 1999] is a measure of the (perceived) proximity of patents to commercial exploitation. When a patent is assigned, the legally-protected prototype is closer to commercialisation. Although this does not mean that an unassigned patent cannot be commercially exploited, assigning a patent indicates an explicit intention to use it for commercial purposes. The rate of assigned patents is given by:

$$RAP_{ij} = AP_{ij}/P_{ij},$$

where AP_{ij} is the number of patents in sector i assigned to residents of country j. The RAP_{ij} equals 0 when there are no assigned patents, and equals 1 when the number of patents in sector i assigned to residents of country j equals the number of patents in sector i invented by residents of country j. The rate can exceed 1 when $AP_{ij} > P_{ij}$, that is, when patents in sector i invented by residents of non-j countries (e.g. non-Australian residents) are assigned to country j (e.g. Australia).

None of the indicators included in the TS model has a time dimension. Such strengths can be established over an extended period when patents are evenly spread, or over a relatively short period when there is high concentration of patents. For example, as a relatively small but rapidly increasing contributor to nano-technologies, if Australia is to demonstrate technological strength in their development, it will be primarily on the basis of the high patenting activities which have occurred since 1998.

It is important to draw a distinction between technological strength and commercial strength because the latter does not necessarily follow from the former. For example, Narin et al. [1987] found that patent data are positively correlated with various measures of a company's technological strengths but not with their financial performance. Suppose a country is successful at developing bio-technologies, particularly recombinant DNA techniques. Whether it will also be in a position to develop the associated commercial capabilities would depend on the appropriability of the technology, that is, whether it is possible to exploit the commercial benefits. The national system of innovation, government regulations and social ethics, among other factors, play important roles in such commercial exploitation.

4. Australian nano-technologies

Table 1 presents the total number of US nano-patents (P) and the values of three of the indicators used in the TS model, namely the technological specialisation index (TSI), patents share (%) of total nano-patents (PS), and rate of assigned nano-patents (RAP), for the top twelve foreign patenting countries in the USA. The three indicators have been calculated using data from the US PTO for the period 1975 to 2000.

Country	P	TSI	PS	RAP
Japan	3,856	0.51	9.05	0.97
France	1,817	1.42	4.26	0.85
Germany	1,524	0.50	3.57	0.74
Canada	1,249	1.33	2.93	0.48
Great Britain	603	1.37	1.41	0.55
Switzerland	502	0.83	1.18	0.55
The Netherlands	384	0.89	0.90	0.59
Italy	334	0.62	0.78	0.66
Australia	313	1.38	0.73	0.75
Taiwan (China)	253	0.40	0.59	0.88
Sweden	179	0.44	0.42	0.70
Korea	175	0.44	0.41	0.81
Mean	*932*	*0.84*	*2.19*	*0.71*

Table 1. US nano-patents by country, 1975-2000 (as at 5 March 2002)

For Australia, the TSI for nano-technologies is 1.38, which indicates an existing specialisation and *local* importance of nano-materials. Of the top twelve foreign patenting countries in the USA (namely, Japan, Germany, France, Canada, Switzerland, Italy, The Netherlands, Taiwan, Sweden, UK, Korea and Australia [see Marinova, 2001]), only France has a higher TSI of 1.42, while Great Britain and Canada have TSI values similar to that of Australia. In fact, Australia's TSI is considerably higher than the mean TSI for all countries of 0.84. Thus, at the national level, Australia is concentrating research and development efforts and producing nano-technology inventions at a higher rate and of greater strength than for the average area of patent specialisation.

The PS of total US nano-patents for Australia is 0.73%, which is rather low even for a country with a relatively small population, especially in comparison with Canada, Switzerland and The Netherlands. However, if Australia is to have any impact on the global development in this class of technologies, such a contribution needs to increase significantly. For purposes of comparison, the PS of total US nano-patents for Japan is 9.05%, France 4.26%, and Germany 3.57%. Of the twelve top foreign patenting countries in the USA, only Taiwan (China), Sweden and Korea have lower PS values than does Australia.

The RAP, which is an indication of the proximity of patents to development market and export orientation, is 0.75 for Australia, so that 3 of every 4 Australian patents are close to commercialisation. This figure ranks Australia in fifth position, and is slightly higher than the average rate of 0.71 for the top twelve patenting countries in the USA. In Asia, Japan, Taiwan (China) and Korea have higher rates of 0.97, 0.88 and 0.81, respectively, while in Europe only France with 0.85 has a higher rate of assigned nano-patents than Australia. Thus, although Australia's market orientation and intention to preserve market segments is above average, it can still be improved.

Table 2 shows the rankings of the top twelve patenting countries in the USA according to these three indicators, namely TSI, PS and RAP, as well as their overall ranking using the average rank score. Australia is in third position behind only France and Japan, which shows a strong performance relative to the top twelve nano-patenting countries.

Country	TSI rank	PS rank	RAP rank	Average rank scores	Rank
France	1	2	3	2.0	1
Japan	8	1	1	3.3	2
Australia	2	9	5	5.3	3
Germany	9	3	6	6.0	4
Great Britain	3	5	10	6.0	4
Canada	4	4	12	6.7	6
The Netherlands	5	7	9	7.0	7
Switzerland	6	6	10	7.3	8
Italy	7	8	8	7.7	9
Taiwan (China)	12	10	2	8.0	10
Korea	10	12	4	8.7	11
Sweden	10	11	7	9.3	12

Table 2. Rankings of countries for US nano-patents, 1975-2000 (as at 5 March 2002)

Of the four factors comprising the TS model, the patents CI has not yet been analysed empirically. Although containing useful information, the CI seems to be highly sensitive to patent novelty. For example, if a patent has been recognised only recently, it would be unrealistic to expect it to have an influence on technological development, and hence to be well cited. This is particularly so for the bulk of nano-patents, including those from Australia. The majority of recognised patent applications from Australia (48%) have been lodged since 1998, with the patents subsequently issued in 1999, 2000 and 2001. Not surprisingly, they presently have a low CI value.

Table 3 presents the CI values for the top twelve foreign patenting countries in the USA. The mean number of citations for Australian nano-technology patents over the period is 2.75, which holds generally for the higher citation rates of older Australian patents, and is less than the average CI value of 4.12. Only Great Britain and Korea have a lower CI value. For established nano-patents, France is clearly the leader for the maximum number of citations (Max) for a single nano-patent at 283, while Australia at 50 is below the mean of 92. On the other hand, the four lowest ranked countries in Table 3 have had around 50% of their nano-patents lodged since 1998, which is not sufficient time for them to have been cited widely. From this group, the CI of Taiwan (namely 3.4) is considerably higher than that for Australia at 2.75. However, if calculated only for cited patents, the Australian CI of 6.43 is slightly higher than for Taiwan at 6.28.

The overall impact of Australia on knowledge development and intellectual property in the field of nano-technologies has so far been quite modest, the main reason being the fact that the Australian nano-technology industry is still in its infancy.

Country	CI rank	CI for cited nano-patents rank	Max for a single nano-patent rank	Shares since 1998 (%) rank
Canada	6.00 (1)	9.22 (2)	106 (4)	22 (9)
Switzerland	5.82 (2)	9.94 (1)	136 (3)	22 (9)
The Netherlands	5.00 (3)	7.48 (4)	52 (8)	17 (11)
Sweden	4.95 (4)	8.53 (3)	49 (10)	25 (7)
Japan	4.59 (5)	6.82 (5)	149 (2)	26 (5)
Germany	4.17 (6)	6.64 (7)	87 (5)	24 (8)
Italy	3.89 (7)	6.65 (6)	62 (7)	3 (12)
France	3.88 (8)	6.63 (8)	283 (1)	26 (5)
Taiwan (China)	3.40 (9)	6.28 (10)	36 (11)	52 (1)
Australia	2.75 (10)	6.43 (9)	50 (9)	48 (3)
Great Britain	2.63 (11)	6.06 (11)	64 (6)	40 (4)
Korea	2.35 (12)	5.51 (12)	30 (12)	49 (2)
Mean	*4.12*	*7.18*	*92*	*29.5*

Table 3. Ranking by citations and shares of US nano-patents, 1975-2000 (as at 5 March 2002)

The TS model applied to Australia indicated some potential in the field of nano-technology, particularly in the perceived domestic importance of this class of technologies. In terms of overall performance, however, Australia needs a more concentrated effort to make its presence felt more strongly in the global arena.

5. Conclusion

Nano-technologies can have significant impacts on society, the economy and the environment. The Technological Strengths model was shown to be a useful tool in assessing Australia's potential in the field of nano-technology. With a small population, Australia's strengths might best be concentrated in a relatively small number of selected technological fields, such as nano-technology. While it is premature to claim that Australia has extensive research strengths by international standards, the current priority funding by the Australian Research Council should contribute to a substantial development in this industry in the years ahead.

6. Acknowledgements

The authors are most grateful to Felix Chan for helpful discussions. The first author wishes to acknowledge the financial support of the Australian Research Council and the University of Western Australia, and the second author wishes to acknowledge the financial support of the Australian Research Council.

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