R+D Inquiry
Submission No. ....46.........

SUBMISSION TO THE HOUSE OF REPRESENTATIVES STANDING COMMITTEE ON SCIENCE AND INNOVATION

INQUIRY INTO BUSINESS COMMITMENT TO RESEARCH AND DEVELOPMENT

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SUMMARY

- Manufacturing continues to be a significant contributor to national economic well-being and also continues to be a important component of international trade. In addition, the manufacturing sector, apart from providing employment directly, also generates employment in other sectors. In consequence, a viable manufacturing sector is a vital component of any advanced economy.

- Success in manufacturing is dependent on an adequate level of research and development (R&D) in that sector. The successful industrial nations devote considerable resources to such R&D.

- While Australia is among the world leaders in the terms of the proportion of gross domestic product (GDP) it devotes to R&D in the combined government and higher education sectors, our manufacturing industry's outlays on R&D are exceeded by twenty of the twenty eight countries that are members of the OECD.

- There is strong evidence that indigenous manufacturing R&D contributes substantially to national economic growth while there is little, if any, evidence that indigenous R&D in the publicly supported sectors is of significant benefit to the performing nation. Yet Australia continues to support a relatively high level of publicly supported basic research while neglecting R&D in the manufacturing sector.

- The very great majority of R&D in the manufacturing sector is design and development. The manufacturing sector undertakes very little basic research. This is true of all countries in the OECD area.

- Engineers predominate in the design and development field of R&D. Consequently, R&D in the manufacturing sector is largely in the domain of the engineering profession. Overwhelmingly, researchers in all industries except the relatively small chemical, pharmaceutical, food and textile industries are engineers.

- In giving consideration to proposals to markedly increase the level of industry R&D, thought must be given to the human resource implications of such proposals.

- Australia graduates fewer engineers per million population than most other OECD countries as well as Singapore and Taiwan. The evidence indicates that Australia's relative standing will decline.

- At the same time only one country graduates more persons with first degrees in the sciences (including information science) than Australia. Relative to population, the number of persons completing such science degrees in Australia is more than twice the median figure for the OECD as whole.

- Any significant across the board expansion of the R&D effort of the manufacturing sector would require a proportionate increase in the number of researchers qualified in electronic and mechanical engineering. Under the present circumstances there must be considerable doubt as to the availability of sufficient numbers of new engineering graduates to enable anything but a minor increase in the R&D effort of the manufacturing sector.

1. INTRODUCTION

It is now accepted in many other countries that it is essential that investment in the appropriate human resources and the appropriate type of research and development (R&D) is an essential factor in their future economic growth. But, even if it is now being acknowledged in some Australian circles that investment in R&D is crucial to our future economic well-being, it is not often that discussion focuses on the interrelated matters of the type of R&D that is required, the sectors of the economy wherein our R&D effort falls short and the precise nature of the human capital that might be needed. In the same manner, the issue of the precise nature of the relative deficiency in the numbers and types of Australian graduates from our higher education system is ignored.

Essentially, there are four questions that have not been properly addressed in the policy discussions on R&D policy that have taken place in Australia:

(a) In what sectors, if any, is Australian R&D relatively deficient?
(b) What type of R&D is needed in those sectors?
(c) What professional disciplines are involved in that type of R&D?
(d) Is Australia in a position to provide sufficient numbers of graduates in the appropriate disciplines to enable an expansion of R&D in the sectors and to a level commensurate to that prevailing in countries with whom we might hope to compete?

As I will argue, the only sector of our economy in which it will be found that our R&D performance falls far short of the levels attained in other industrial countries is the manufacturing sector. This raises the question as to whether that sector is all that important to a modern economy. Consequently in the next section of this submission I will briefly discuss the opinions of certain commentators in the United States regarding the significance of manufacturing industry to modern economies.

2. THE CASE FOR MANUFACTURING INDUSTRY

As has been stated by more than one commentator the manufacturing sector is an essential component of a viable economy. For example, an American study of the importance of manufacturing in the United States economy (U.S. Congress, 1988, p.6) concluded that the ... *United States cannot do without a strong manufacturing sector. Manufactured goods are indispensable for trade with other countries .... Demand for manufactured goods is as great as ever — greater for everything but the basics, food and fuel.*

In another section of the same study it was concluded that ... *the ability to make high-quality goods at reasonable costs without sacrificing our standards of living to get costs down - will be crucial if the United States is to remain a first-class economic power.* (ibid. p.7). The argument that a nation can rely on other sectors of the economy is rebutted with the response that ... *there is no choice to be made between manufacturing and services. The nation needs both. ... Moreover, to speak of services as taking the place of manufacturing in the economy is to overlook strong interdependence of the two kinds of activities* ... (ibid., p.6).

A further justification for the preservation of a manufacturing sector is the spillover into other areas of employment. The above-mentioned report points out that ... *if manufacturing production and employment is lost, services cannot simply and directly replace them.* Nor can services replace the employment benefits flowing from manufacturing. The same study has concluded that for each 100 manufacturing jobs there were 43 jobs in the services and other sectors that were tightly linked to manufacturing (ibid., p.53). Those jobs would not have existed without the presence of the manufacturing sector. I am aware of claims that, in the case of high technology manufacturing the job ratio is even greater; in some cases every manufacturing job resulted in the creation of as many as four non-manufacturing jobs.

An American study quotes a Volvo executive to the effect that, in Sweden, while ... *only 20 per cent of jobs in the economy were in manufacturing ... another 40 per cent grow directly out of manufacturing.* (Magaziner, I. and Patinkin, J., 1989, p.140 and 141).

Another report to the United States Congress by the Office of Technology Assessment points out that many governments promote manufacturing industries that they consider to be strategically significant. Among those countries they include Japan, Korea and Taiwan (U.S. Congress, 1990, p.21).

Perhaps one of the most significant studies of the importance of the manufacturing sector to the national economy is book by two American academics that concludes that, inter alia :

There is no such thing as a post-industrial economy. Manufacturing matters. The wealth and power of the United States depends upon maintaining mastery and control of production.(Cohen, S. and Zysman, J., 1987, p. 261).
These authors point out that in a world wherein several large economies such as Korea's and Japan's that are heavily influenced by government strategies directed at the development of specific industries, neutrality of industrial policy is not the most appropriate course for any one nation to follow.

Many of the arguments summarised in the foregoing are echoed in the major study of the American manufacturing sector by the MIT Commission on Productivity (Dertouzos, M. L., Lester, R.K. and Solow, R.M., 1989). This comprehensive study was undertaken by a number of noted academics from MIT. The authors indicated that their reason for focusing on manufacturing was that this particular sector was vital for America's economic well-being.

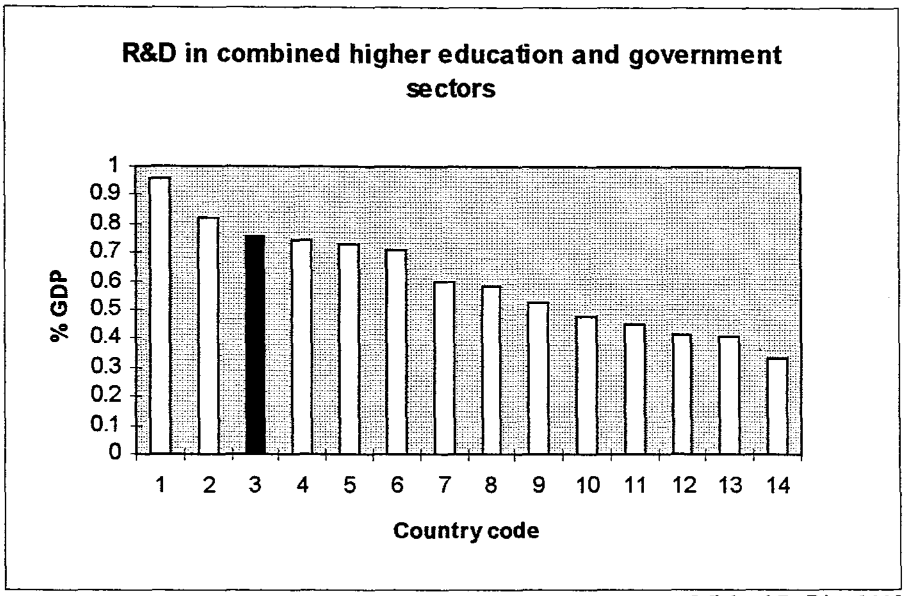
3. RESEARCH AND DEVELOPMENT IN THE BUSINESS SECTOR.

3.1 In what sector is Australian R&D relatively deficient?

3.1.1 The sectoral distribution of Australia's R&D effort.

It does not seem to be generally recognised that, in comparison with the great majority of OECD nations as well as Taiwan and Singapore, Australia's level of performance of public sector R&D when expressed as a proportion of gross domestic product (GDP) is relatively high (see Figure 1). By public sector I mean the combined higher education and government sectors. It is also easily demonstrated that the same has been true of the level of basic research in the public sector for some considerable time (see for example Table 1 of this submission).

FIGURE 1
INTERNATIONAL COMPARISON — PROPORTION OF GDP DEVOTED TO R&D IN THE COMBINED HIGHER EDUCATION AND GOVERNMENT SECTORS



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Country code :

Country	Country code	Country	Country code
Finland	1	USA	8
Canada	2	Czech Republic	9
AUSTRALIA	3	Italy	10
France	4	Poland	11
Germany	5	Spain	12
Japan	6	Hungary	13
U.K.	7	Ireland	14

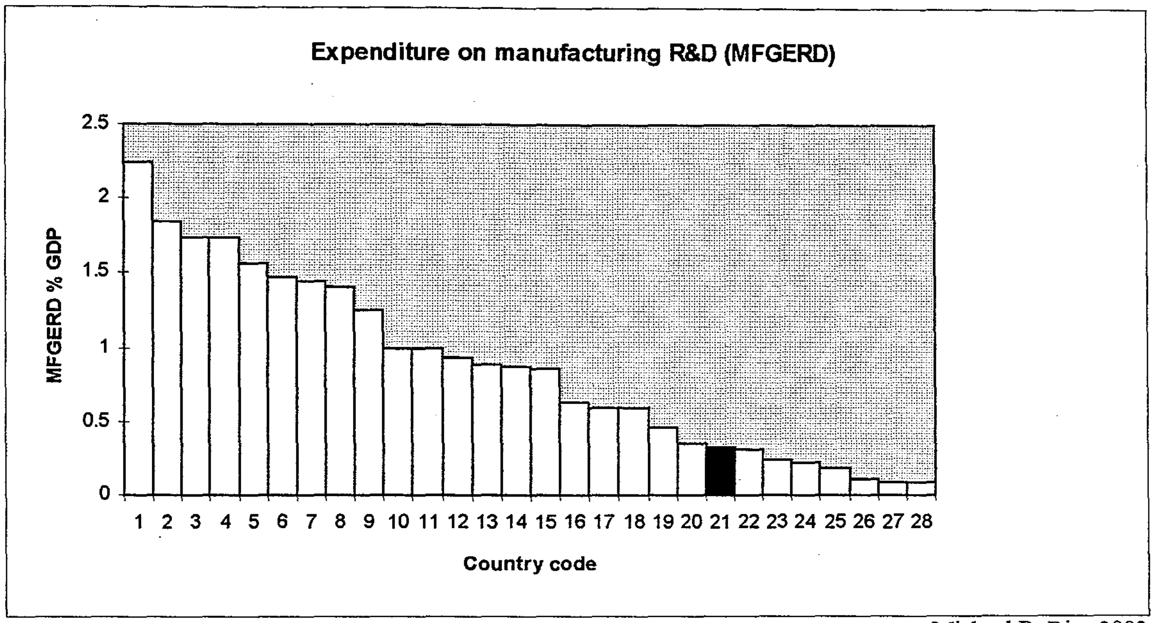
The sources for the data presented in the foregoing table are the most recently available, are the Australian Bureau of Statistics reports on R&D in the higher education and government sectors (Catalogue Nos. 8111.0 and 8109.0).

In contrast, the Australian business sector's R&D effort has been and continues to be comparatively poor. However, if one disaggregates that sector into its manufacturing and non-manufacturing elements it will be found that the level of R&D undertaken in the non-manufacturing group of industries compares very favourably with that attained in many other countries. **It is the manufacturing sector, and the manufacturing sector alone, that underperforms** (see Figure 2). Of the 28 countries for which I have reliable data only seven industrially significant countries devote a smaller proportion of GDP to R&D in the manufacturing sector than does Australia. **This is the sole explanation of the relative mediocrity of our total R&D effort.** Included in the seven countries that I referred to above are Greece, Hungary, Iceland, Mexico, New Zealand, Poland and Turkey. Recent trends indicate that, relative to GDP, the Australian manufacturing sector's is declining. This in marked contrast to the situation of other industrial countries.

The manufacturing sectors of Finland, Taiwan, Korea and Sweden attain expenditures, that, when expressed as a proportion of GDP, represent three to six times the level of expenditure attained by Australian manufacturing. Many other countries exceed the Australian level by a very large margin. This differential is only partly attributable to the structure and relative size of our manufacturing sector. I first pointed out the marked deficiency in Australian manufacturing R&D some time ago (Rice, M.R., 1991).

FIGURE 2

EXPENDITURE ON R&D IN THE MANUFACTURING SECTOR
(OECD COUNTRIES PLUS TAIWAN)
(% GDP)



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Country Code

Country	Country code	Country	Country code
Sweden	1	Denmark	15
Japan	2	Austria	16
Italy	3	Canada	17
Korea	4	Czech Republic	18
Switzerland	5	Norway	19
United States	6	Spain	20
Germany	7	**AUSTRALIA**	**21**
Finland	8	Iceland	22
France	9	Hungary	23
Taiwan	10	Poland	24
United Kingdom	11	New Zealand	25
Belgium	12	Turkey	26
Ireland	13	Greece	27
Netherlands	14	Portugal	28

Sources :

1. "Main Indicators of Science and Technology, 1998/2", OECD., Paris 1998.
2. Data for Taiwan : *Indicators of Science and Technology, Republic of China*, National Science Council, Taipei, 1999.

It would seem to be difficult to justify any proposal that Australian productivity should be increased by bolstering public sector R&D to the point that it caused Australia's total R&D effort (GERD) to equal the average level prevailing in the OECD area while, at the same time, leaving the level of manufacturing R&D unaltered. That would imply that publicly supported R&D would be have to be increased substantially above the present level. Such an increase would raise Australia's publicly supported R&D to a level well above that of the any other country.

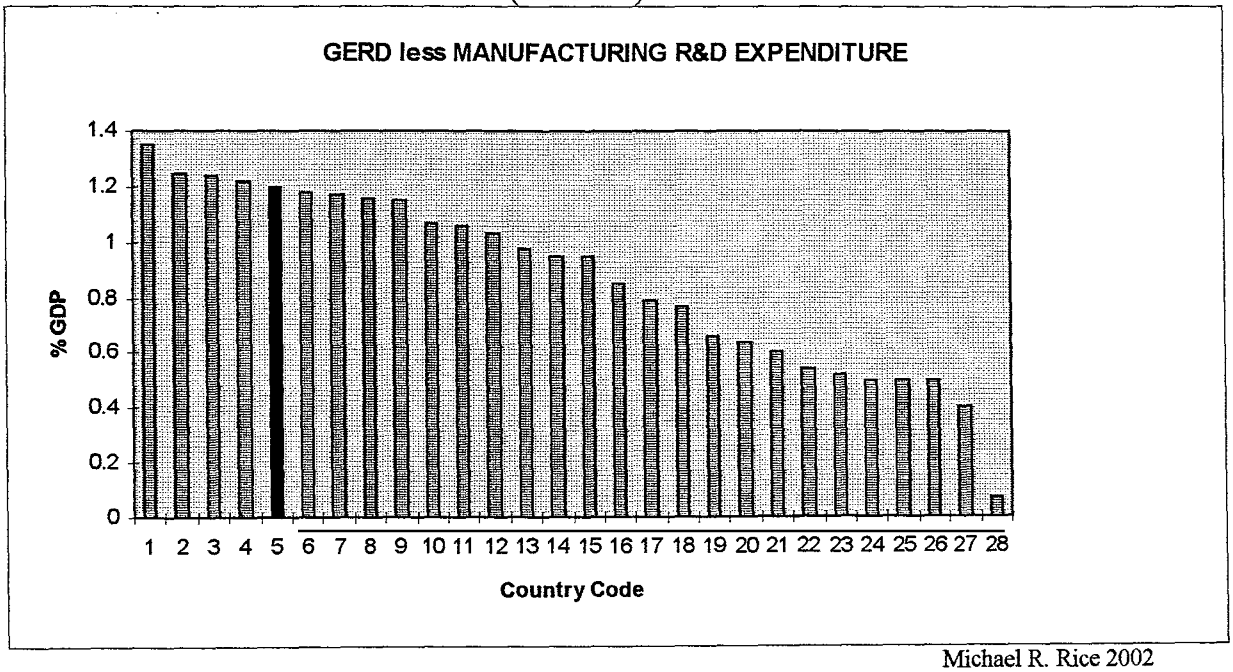
The level of Australia's publicly supported R&D is already very high (see Figure 1). Another way of showing Australia's R&D effort in a comparative light would be to deduct manufacturing R&D from the total R&D effort and to compare the resulting figure with that of other countries in the OECD area (see Figure 3). It is readily apparent that, on this basis of comparison, Australia's R&D effort compares more than favourably with that of other OECD member countries. Of the three countries that outperform Australia, both Norway and Iceland surpass the Australian level only to a marginal extent. The remaining country, Sweden, exceeds the Australian level of expenditure by only 12 per cent or so.

It is not likely that substantially increased R&D in the publicly supported sectors would have any immediate positive effect on productivity; rather the opposite since resources would have to be diverted from other productive uses. Such an increase might only result in long term economic payoffs, if at all. As is widely understood in many quarters, basic research in the academic sector is not likely to pay off in the short term except perhaps in relation to the biomedical and related industries, yet basic research is the principal component of academic R&D activity.

If the argument in the foregoing is accepted and it is proposed that there be should be an increase in Australia's GERD, it would follow that it is the business sector on which attention should be focused. More particularly, it can be argued that it would be most appropriate if efforts were concentrated on increasing manufacturing sector R&D. This is the R&D activity that results in shorter-term payoffs because it generates competitive products and improved manufacturing processes. Manufacturing is a large direct contributor to national value added. In addition the employment spin-offs in the service sector are a bonus that is often overlooked.

FIGURE 3

TOTAL EXPENDITURE ON R&D LESS EXPENDITURE ON MANUFACTURING R&D
(% GDP)



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Country	Country code	Country	Country code
Sweden (1995)	1	United Kingdom (1996)	15
Norway (1995)	2	Germany (1996)	16
Iceland (1997)	3	New Zealand (1995)	17
Netherlands (1996)	4	Taiwan (1998)	18
AUSTRALIA (2001)	**5**	Belgium (1995)	19
Switzerland (1996)	6	Italy (1997)	20
Finland (1996)	7	Czech Republic (1997)	21
Denmark (1997)	8	Poland (1996)	22
United States (1996)	9	Spain (1996)	23
France (1996)	10	Hungary (1997)	24
Korea (1996)	11	Ireland (1995)	25
Canada (1996)	12	Portugal (1995)	26
Japan (1996)	13	Greece (1993)	27
Austria (1993)	14	Turkey (1996)	28

Sources : As for Figure 2

With regard to increasing R&D expenditure in the non-manufacturing group of industries in the business enterprise sector I doubt that a major increase in such expenditure would be very beneficial to the national economy. The non-manufacturing industries include the following : wholesale and retail trade; finance and insurance; and property and business services. It would be difficult to make out a substantial case that markedly boosting R&D expenditure in those industries would have an effect on national productivity equivalent to that resulting from a similar increase in R&D expenditure in the manufacturing sector. The recent history of the debacle in the dotcom industry in the United States would appear to bear this out.

The marked beneficial effect of industry sector R&D on industry's value added was demonstrated in a paper that I presented in 1978 (Rice, M.R., 1978). The results of that analysis of international data were briefly discussed in my contribution to a book that was published by the then Association of Professional Engineers, Australia (Rice, M.R., 1979). I pointed out at that, at that time, it was difficult to obtain reliable comparative international data on manufacturing R&D expenditure so that I was forced to use business sector R&D expenditure as a proxy for manufacturing R&D expenditure. I do not believe that, in the circumstances prevailing at the time, such an approach invalidated the findings of my analysis since the greater proportion of business sector R&D was then undertaken in manufacturing industries.

In a subsequent analysis (Rice, M.R., 1993) I pointed out that, using recent data for a number of countries, there were, inter alia, significant positive correlations between :

- the number of business sector R&D personnel (a proxy for research engineers) relative to total manufacturing employment and the rate of growth of value added per head of manufacturing industry;
- the ratio of the number of engineers to the magnitude of the total work force and the rate of increase of per capita GDP;
- expenditure on machinery and equipment per head and the rate of growth of value added per head of manufacturing industry;
- expenditure on experimental design and development and increased productivity of manufacturing industry.

With one exception I found no such correlations between, inter alia :

- basic research expenditure and economic growth;
- government or higher education R&D expenditure and the rate of growth of GDP;
- the total number of lawyers, accountants or physicians relative to population and the rate of increase in per capita GDP;
- the proportion of people in the age group 25-34 years who completed degrees in the natural sciences and the rate of increase in per capita GDP;
- the total number of researchers relative to population and the rate of growth of GDP;
- the number of Nobel prizes in physics and chemistry relative to population and economic growth. In this case a correlation did exist. It was statistically significant, but was negative rather than positive.

In the case of the first two items in the second group of items, the correlation coefficients were close to zero. To some extent these results confirm each other since the greater proportion of publicly supported sector R&D is basic research. I realise that these findings are in conflict with the received wisdom in Australia that there are considerable returns from university basic research. However, I have yet to see an analysis that demonstrates that there is any great benefit to the performing country from indigenous basic research.

The findings of the recent report on the returns to basic research (Scott, A. et. al., 2001) prepared for the British Office of Science and Technology provide little in the way of an explicit substantiation of the still widely held belief that basic research leads to beneficial economic outcomes. Notwithstanding this, the protagonists of basic research continue to proclaim their belief that Australia needs more and yet more basic research in the publicly supported sectors.

3.1.2 Basic research

In regard to expenditure on basic research and, in particular, basic research in the combined publicly supported research sectors, Australia has nothing to be ashamed of. Since 1973 at least, the level of basic research expenditure in those sectors has ranged from 0.29 % of GDP to 0.40 % of GDP. For the last 10 years the level of expenditure not fallen below 0.35 % of GDP. By way of comparison, in the same period Japan's basic research expenditure in those sectors has never exceeded 0.26 % of GDP and has averaged 0.23 % of GDP. In recent years it has been lower than that average. While expenditure on basic research in the publicly supported sectors in the United States has exceeded that of Japan it has been quite consistently lower than the level that has prevailed in Australia. At present, both Korea's and Taiwan's expenditure on publicly supported basic research are about half the current Australian level.

A erroneous belief that has been current in Australia academic circles for the last few years is that industry is heavily dependent upon the results of research in the public institutions such as universities. This belief has been supported by claims regarding the influence of public sector research on industrial innovation based on statements to the effect that in America *...73 per cent of US patents cite publicly funded research, 52% cite publicly funded university research.* (Group of Eight, 2000, p.19). A similar claim has been made in an address to the National Press Club presented by the President of the Australian Vice-Chancellors Committee and published in the papers of the national Forum of the Federation of Australian Scientific and Technological Societies (Niland, J., 1998, p.11) These statements appear to assume that it is implicit that "public sector" means the publicly supported sector indigenous to the country in which the patents are filed. Such statements represent a serious misinterpretation of a study undertaken in the United States.

National Science Foundation's summary of the American study on which such claims as the foregoing purport to be based stated:
Seventy-three percent of the papers cited by US industry patents are public science, authored at academic, governmental, and other public institutions; ...

This is not the same as saying that 73 per cent of industry patents cite research results emanating from the public sector since only a proportion of such patents cite research papers. Nor does it mean that all of the citations relate to basic research alone nor that all of the cited papers originated in **American** public institutions only. Furthermore, it does not mean that the stated percentage is applicable across the spectrum of technologies used in industry. In fact, analysis of the relevant data indicate that only about 17 per cent of American industry patents cite research papers emanating from publicly supported institutions whether national or international. An even smaller proportion of American industry patents cited papers published by American academics. My estimate is that it was less than 8 per cent. So much for the claim by the coalition of "Australia's Leading Universities" (Group of Eight, 2000, p.19) concerning the influence of university research on innovation. A detailed analysis of the incidence of patent citations of research papers will be found at Appendix A.

In the light of the foregoing it would require a considerable act of faith to assume that an increase in public sector basic research would be of benefit to Australian industry in the long term let alone the short term. Table 1 seems to indicate that the advanced knowledge-based industries of Japan and the United States have managed to maintain a commanding lead without those countries devoting as many resources to basic research in the public sector as has occurred in Australia.

TABLE 1

COMPARISON OF BASIC RESEARCH EXPENDITURE IN THE PUBLICLY-SUPPORTED SECTORS OF AUSTRALIA, JAPAN AND THE UNITED STATES

YEAR	BASIC RESEARCH EXPENDITURE (% GDP)		
	AUSTRALIA	JAPAN	UNITED STATES
1973/74	0.320	...	0.229
1976/77	0.290	0.222	0.238
1978/79	0.336	0.226	0.251
1981/82	0.342	0.220	0.263
1984/85	0.351	0.215	0.281
1986/87	0.349	0.258	0.292
1988/89	0.315	0.234	0.288
1990/91	0.365	0.214	0.325
1992/93	0.398	0.240	0.331
1994/95	0.382	...	0.319
1995/96	...	0.220	0.315
1996/97	0.399	0.217	0.313
1997/98	0.400	...	0.312
1998/99	0.380	...	...
1999/00	...	...	...
2000/01	0.350	...	...

Sources:
Derived by the author from data in:

1. *Research and Experimental Development, Higher Education Organisations,* Catalogue Number 8111.0, Australian Bureau of Statistics, Canberra, various years.
2. *Research and Experimental Development, Government and private Non-profit Organisations,* Catalogue Number 8109.0, Canberra, various years.
3. *Basic Science and Technology Statistics,* OECD, Paris, various years.

3.1.3 Engineering research in the publicly funded sectors

When engineering R&D is excluded from the total R&D expenditure my analysis indicates that only six or seven countries are likely to exceed Australia's level of R&D expenditure in the combined higher education and government research fields. **When engineering R&D is considered separately, Australian higher education outperforms only three of the sixteen countries for which data are available.** (See also the discussion of the comparative educational and R&D emphases of the Australian and Singapore economies in Appendix B.)

3.2. What type of R&D is needed in the manufacturing sector?

The second of the questions that I suggest should be addressed relates to the type of research and development in the manufacturing sector that merits priority treatment. The type of R&D activity that preponderates in the manufacturing sectors of all industrial nations is experimental development and design, that is the design and development of products and processes for commercial purposes. More than 75 % of business sector, and more specifically, manufacturing sector R&D expenditure and human resources are devoted to that type of research activity. Another 20 % of expenditure and resources are devoted to applied research. That type of R&D activity is also aimed at commercial outcomes. Only about 5 % of business sector R&D is in the field of basic research and less than 20 % of that basic research may be classified as pure basic research.

The distribution of manufacturing R&D expenditure between the types of R&D is surprisingly uniform from country to country. I would suggest that this indicates that the highest priority for Australia is the expansion of applied research and experimental development effort in the manufacturing sector. An increase in pure basic research expenditure is of least importance. In this regard it is noteworthy that major American corporations are now directing their basic research effort into strategic basic research rather than pure basic research as a consequence of the limited commercial benefits flowing from undirected research (Buderi, R., 2000, pp. 30 and 31). Buderi quotes one historian of science :
The shibboleths of the this new age were that basic science and well-funded scientists produced dramatic new technologies and that scientists knew better than generals, engineers, or industrialists what science to pursue, which new technologies to develop, and how best to deploy those new technologies. (ibid., p.99).

3.3. What professional disciplines are involved in that type of R&D?

The third question that needs to be addressed relates to the professional disciplines appropriate to the type of type of R&D activity that preponderates in the manufacturing sector. That is the sector that, incidentally, employs the greatest number of researchers in industrial countries.

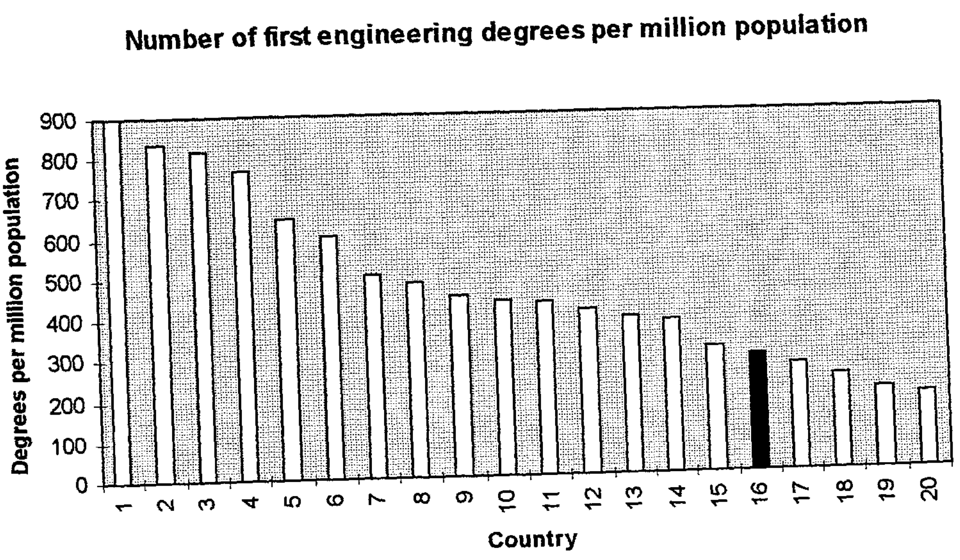
I have demonstrated that in several major industrial countries the majority of those professionals who were engaged in R&D in the manufacturing sector were engineers (Rice, M.R., 1994). This result often comes as a surprise to those who have accepted that R&D is a matter of "science". The reality of the situation is illustrated by such facts as the high proportion of technical professionals in the American and Japanese manufacturing sectors who are engineers and the proportion of R&D activity in countries such as Japan and Taiwan that is devoted to engineering.

In the case of American manufacturing, the number of technical professionals in manufacturing in 1992 was estimated by the US National Science Foundation (NSF) to be a little under 980,000 (National Science Foundation, 1995a). Of these, approximately 760,000 were engineers, 102,000 computer specialists and 108,000 were natural scientists including mathematicians. Of the natural scientists 24,700 were life scientists, 52,000 were chemists and less than 3,000 were physicists. At that time total manufacturing employment was 21 million - more than 20 times the number of manufacturing employees in Australia.

According to the US National Science Foundation (National Science Foundation (1995b) the American manufacturing sector employed about 620,000 researchers in 1990. Consequently, at the most, 210,000 (102,000 computer specialists plus 108,000 natural scientists) or one-third of the researchers were not engineers. This estimate depends upon the doubtful assumption the all natural scientists and computer specialists in industry are engaged in R&D. NSF data indicate that only about 40 % of physical scientists and about 20 % of information science specialists in industry are employed in R&D. Applying that information to the foregoing data it appears to be likely that little more than 12 % of researchers in manufacturing industry were not engineers. This estimate represents a substantial confirmation of the conservatism of my estimate in my 1994 report in which I calculated that between 62 % and 83 % of researchers in the US manufacturing sector were engineers.

I believe that the foregoing demonstrates that the role of the research engineer in industry is a subject worthy of greater attention in Australia. Yet to date there has been little thought given to this vital topic. This should be a matter of serious concern because in considering the fourth question above it will become apparent that there is little likelihood of any great increase in the number of engineers engaged in manufacturing sector R&D in the immediate future. As will be noted from a perusal of Figure 4 the level of engineering graduations in Australia does not compare well with that of most other industrial countries. The black column in the bar chart refers to Australia.

FIGURE 4
INTERNATIONAL COMPARISON OF THE NUMBER OF FIRST DEGREES IN ENGINEERING RELATIVE TO POPULATION



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Country code

Country	Country code	Country	Country code
Korea	1	Netherlands	11
Singapore	2	Sweden	12
Japan	3	France	13
Finland	4	United Kingdom	14
Denmark	5	Israel	15
Taiwan	6	**AUSTRALIA**	**16**
Norway	7	Ireland	17
Germany	8	United States	18
Belgium	9	Austria	19
Switzerland	10	Italy	20

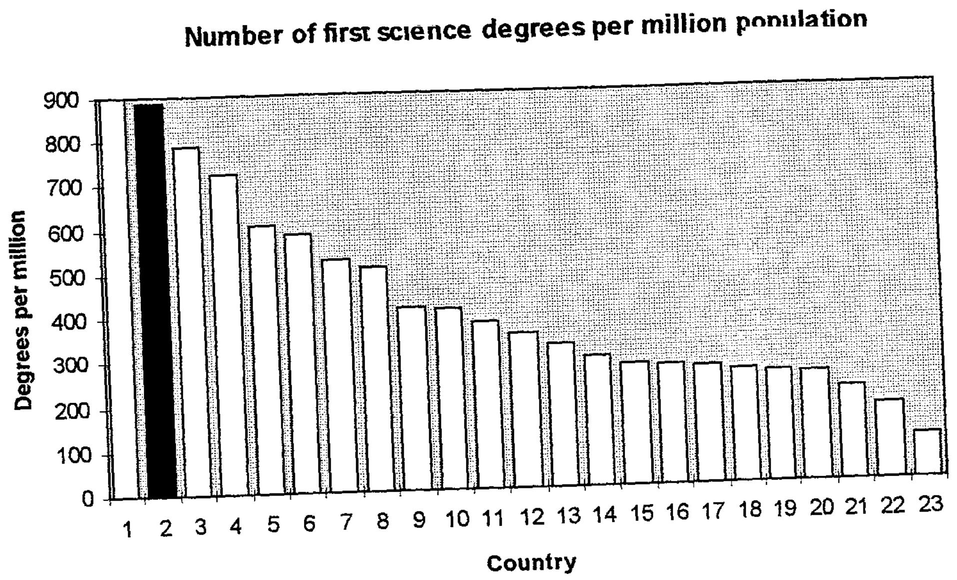
Notes : 1. The Australian data relate to non-overseas students only.
2. Science degrees include degrees in the natural and information sciences.

Source :
Derived by the author from data in the following sources :
1. With the exception of Australia, Singapore and the United States the data relating to the number of degrees are taken from "Science and Engineering Indicators 2000", NSB - 00- 0, National Science Board, National Science Foundation, Arlington, VA, 2000.
2. Australia — "Students 2000, Selected Higher Education Statistics", Department of Education, Training and Youth Affairs, Canberra, 2001.
3. Singapore — "Yearbook of Statistics Singapore 2001", Singapore Department of Statistics, 2001.

4. United States — "Science and Engineering Degrees 1966-1998", NSF 01-325, National Science Foundation, Arlington, VA 2001.

FIGURE 5

INTERNATIONAL COMPARISON OF THE NUMBER OF FIRST DEGREES IN THE SCIENCES RELATIVE TO POPULATION



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Country Code

Country Code	Country	Country Code	Country
1	Ireland	13	Denmark
2	**AUSTRALIA**	14	Netherlands
3	United Kingdom	15	Italy
4	Korea	16	Austria
5	Canada	17	Switzerland
6	Spain	18	Japan
7	USA	19	Sweden
8	Taiwan	20	Greece
9	Finland	21	Portugal
10	France	22	Norway
11	Germany	23	Belgium
12	Singapore		

Note : The Australian data relate to non-overseas students only.

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1. With the exception of Australia, Singapore and the United States the data relating to the number of degrees are taken from "Science and Engineering Indicators 2000", NSB - 00- 0, National Science Board, National Science Foundation, Arlington, VA, 2000.

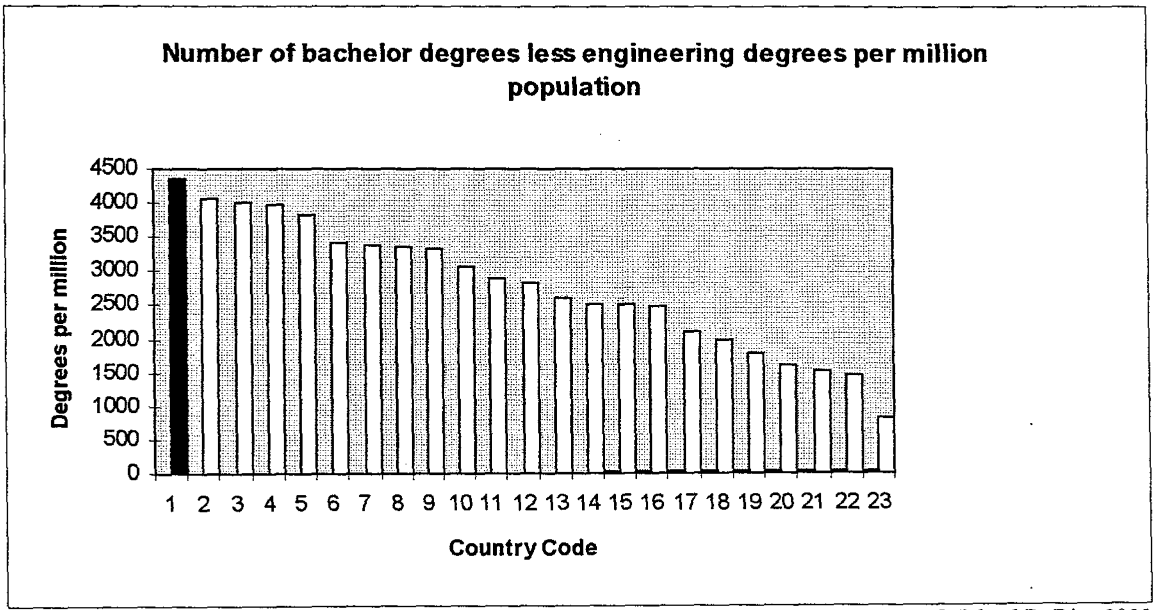
2. Australia — "Students 2000, Selected Higher Education Statistics", Department of Education, Training and Youth Affairs, Canberra, 2001.
3. Singapore — "Yearbook of Statistics Singapore 2001", Singapore Department of Statistics, 2001.
4. United States — "Science and Engineering Degrees 1966-1998", NSF 01-325, National Science Foundation, Arlington, VA 2001.

On the other hand, if one examines an equivalent comparison of the number of science graduations the situation will be seen to be entirely the opposite. Few countries, if any, graduate as many nationals with first degrees in science as does Australia. Figure 5 illustrates this point. Once again the black column refers to Australia. I should point out that the data presented in that figure relate to graduates in the combined fields of the natural sciences, mathematics, agricultural science and information technology.

Interestingly, when the normalised data for engineers and scientists are added together Australia ranks fifth out of 19 countries. Australia is ahead of Japan, Taiwan, Germany, France, the United States and the UK. Figure 6 illustrates Australia's advantageous position in relation to the number of first degrees granted in **all disciplines other than engineering** relative to other countries. This result should give pause to those who maintain that Australia needs to increase the total number of graduations from the higher education system. Australia's problem is not the total number of graduates but the imbalance between science and engineering education.

FIGURE 6

TOTAL NUMBER OF BACHELOR DEGREES OTHER THAN ENGINEERING DEGREES RELATIVE TO POPULATION (SELECTED OECD COUNTRIES)



Michael R. Rice 2002

Note : The Australian data relate to non-overseas students only.

Country code :

Country	Country code	Country	Country code
Australia	1	Switzerland	13
United States	2	Finland	14
United Kingdom	3	Ireland	15
Spain	4	Sweden	16
Canada	5	Germany	17
Netherlands	6	Singapore	18
Korea	7	Italy	19
Denmark	8	Greece	20
Japan	9	Austria	21
Norway	10	France	22
Portugal	11	Belgium	23
Taiwan	12		

On the basis of DETYA data regarding commencements (DETYA, 2001) I have projected future Australian completions in engineering up to 2003. This projection indicates that the ratio of engineering graduations relative to Australia's population will decline. The indications are that this decline will continue thereafter. Bearing in mind that most other countries will at least maintain the number of engineering graduates implied by the data presented in Figure 3, it is almost inevitable that Australia's ranking in such comparisons will decline.

Since the table was prepared both Singapore and Japan have increased their annual numbers of engineering graduates; Japan to 110,000 and Singapore to nearly 3,320 as of 2001. Consequently, the ratios of engineering graduates to population in those countries will have increased to about 870 and 980 respectively.

One may deduce from current enrolment data that Singapore will graduate over 4,000 engineers in 2005. This will place Singapore well and truly at the top of the league table. By that time the rate of graduation of Singaporeans with higher degrees in engineering will also have increased spectacularly.

As I have pointed out (Lloyd, B.E. et al., 2002, p.146) there are interesting sidelights to the above. Nearly 50 % of Singapore's male university graduates are engineering graduates. Certain other countries also attain very high levels of involvement of their male graduates in engineering studies. In the case of Finland the proportion of male graduates who are engineering graduates is 43 % while in the case of Korea and Japan it is 31 % and 27 % respectively. Other countries such as Germany, Sweden, Denmark and Norway are in the same league. Australia lags badly; only 12 % of male graduates are engineering graduates.

Another interesting comparison relates to the relative weight given to of engineering in the higher education systems of various countries. Twelve per cent of the relevant male cohort of Singaporeans complete engineering degrees. Nearly 10 % of Finnish males and 9 % of Japanese males complete engineering degrees. About 3.3 % of Australian males qualify as professional engineers.

Singapore's emphasis on engineering education explains the fact that R&D in the engineering field represented 50 per cent of total R&D expenditure in the higher education sector. R&D expenditure in computing amounted to an additional 9 per cent of total higher education R&D expenditure while R&D expenditure on the natural sciences represented 17 % of the total. In the Australian higher education sector 11 % of R&D expenditure is devoted to engineering research whereas more than 37 % of university R&D expenditure is devoted to the sciences. It may be worth adding that, in Japan and Taiwan, engineering R&D sector represents 36 % and 41 % respectively of total R&D expenditure in the higher education sector. At the same time, natural science R&D expenditure represents 14% and 15 % respectively of the total R&D efforts of the higher education sectors of the two countries.

3.4. Is Australia in a position to provide sufficient graduates in the appropriate disciplines to enable an expansion of R&D to a level commensurate to that prevailing in countries with whom we might hope to compete?

The issue that needs to be addressed is whether, at current levels of graduation, Australia will have sufficient numbers of engineers to enable manufacturing organisations to devote resources to R&D at a level commensurate with that prevailing in nations with which we might hope to compete. As I have demonstrated in submissions to the relevant parliamentary inquiries (Rice, M.R., 1993, Rice, M.R., 1995 and Rice, M.R., 2001) it is clear that the answer to this question is in the negative.

Without developing the detailed argument that was presented in the submissions that I have forwarded to the inquiries suffice it to say that Australia would only be able to achieve markedly increased level of R&D in the manufacturing sector by 2010 if there were a marked and prompt increase in the rate of graduation of electrical, electronic, computer, communication and mechanical engineers.

At the moment Australian industry deploys 7,930 researcher person years in manufacturing R&D. To lift the level of human resources to say, the level that prevails in the average OECD country an additional 12,000 or so researchers would probably be required. Of these, perhaps 10,000 would be engineers with the above mentioned specialisations. This number of such engineers is equivalent to about four times the number graduating with these specialisations each year. Since the economy requires many of these engineers in other functions than R&D and losses from the engineering profession are taking place at an increasing rate there is little hope of achieving such an increase in the immediate future.

The attainment of even such a modest target for manufacturing R&D as the OECD average could not be realised until the end of the decade at the earliest unless there is a prompt and substantial increase in the annual number of engineers graduating in the specialisations that I have referred to in the previous paragraph. I should add that the problem cannot be handled by substitution of scientists for engineers any more than university research is substitutable for the product and process development undertaken in the manufacturing sector. The formation of engineers is entirely different from that of scientists with the consequence that the mind set of most scientists is such that they would not capable of undertaking engineering design functions without considerable further education and subsequent on the job training. Some years ago the US Defense Department sponsored a study (National Science Foundation, 1984) that, among other things, demolished the argument that scientists could readily be substituted for engineers.

4. CONCLUSION.

Australia's failure to recognise the contribution that manufacturing industry makes to national economic well-being as well as to employment in other sectors has led to a failure to pay attention to the vital topic of manufacturing R&D. In addition, ignorance of the essential contribution that engineers make to manufacturing R&D in other countries has led to a lack of urgency concerning the need for an adequate supply of engineers qualified in the appropriate disciplines for the performance of manufacturing R&D. Any attempt to bolster manufacturing R&D in Australia will be likely to be constrained by the lack of engineering human resources. Consequently policy moves to encourage manufacturing R&D should go hand in hand with a consideration of the adequacy of Australia's engineering education system to cope with the resulting human resource requirements.

The reasons for Australia's relatively low level of engineering graduations need to be sought out. One of the reasons is the virtual invisibility of the engineering profession in this country. As a consequence, the status of engineers and engineering activity is lower than is warranted by their actual and potential contribution to national welfare. In this regard there is a substantial cultural difference between Australia and the Asian and European nations that have been or are likely to be industrially successful. In those countries as well as America the contribution of engineers to industrial economies and the relative roles of engineers and scientists are well understood.

One has only to compare such business publications as "Business Week" from the United States and Australia's "Business Review Weekly" to realise that there is a problem of perception in this country. Whereas the former magazine frequently mentions engineers in their roles as researchers and designers as well as managers, "Business Review Weekly" rarely refers to professional engineers at all. Australia's public media often ascribe the feats of engineers to "science". To a large extent this is a consequence of Australia's cultural inheritance from Britain relating to a community misperception of the role of engineers and the nature of engineering work. This misperception is constantly reinforced by the Australian media and even science magazines such as "Australian Science". It needs to be overcome before any real progress is achieved in encouraging more young men and women into a demanding but rewarding profession.

APPENDIX A

REFERENCES TO PUBLICLY SUPPORTED RESEARCH PAPERS ON AMERICAN INDUSTRY PATENTS

The available data indicate that, in 1995, 23 per cent of US patents referenced scientific or technical articles emanating from public sector institutions. In other words only 17 per cent of industry patents (23 % of 73 %) referenced research papers from public institutions, national or international. Only 60 per cent of the papers from public sector institutions were of American origin. Consequently, only about one-tenth (60% by 17%) of industry patents cited papers originating from American public sector institutions. Less than three-quarters of these public sector papers were published by staff of academic institutions. I estimate that, as a result less than 8 per cent of industry patents cited papers emanated from American academic institutions. That is a far cry from 73 per cent.

What is equally significant is the fact that 5 per cent of industry patents cited papers published by industry itself. While that is lower than the figure for citations of publicly funded research on industry patents it was not insignificant bearing in mind that basic research expenditure in American industry is only half that of the publicly supported sectors. I should add that, by 1999, the fraction of US patents that cited research papers had declined from 23 per cent to 21 per cent.

For every reference to a research articles on patents there were 14 references to other sources of information. In the case of industry patents, not all of the research papers from the public sector related to science. A proportion related to technology (engineering). Likewise not all of the cited papers resulted from basic research. Moreover, most (62 per cent) of the citations to publicly supported research were in the fields of medicine, biomedical science and biology. Other fields tended to cite research papers to a lesser extent.

In those areas of industry in which the greatest amount of industrial R&D is undertaken, namely the electronic, transport and machinery industries, the degree of so called dependence on public science is relatively low compared with the biologically-based industries. In the case of the communication equipment and electronic component industries the level of citation of scientific articles was one-sixteenth of that of the drugs and medicines industry. What is more a smaller proportion of the citations in the electronic components industry related to publicly supported R&D. The recently published American Report *Science and Engineering Indicators - 2002* summarises a study of the IT sector thus :

... IT patents cite scientific literature less extensively (than other areas of technology). ... The analysts concluded that ... IT patents cite other technology

patents more extensively than scientific papers because IT is moving too fast for scientific research to keep up. (National Science Board, 2002, Vol. 1, p.80).

One other point that is ignored by many commentators is that only about 5 % of patents are actually used. Most patents are taken out for protective reasons rather than as a precursor to their application in industry. In any case as noted in the National Science Board's report :

... Most patents do not cover specific marketable products but might conceivably contribute in some fashion to one or more such products in the future. (Ibid., Vol. 1, pp. 50 and 51, note 41).

APPENDIX B

A COMPARISON OF THE BALANCE BETWEEN ENGINEERING AND SCIENCE FACULTIES IN AUSTRALIA, SINGAPORE AND THE REPUBLIC OF CHINA

Introduction

Australia's higher educational system differs from those of many countries in that, in the technical fields of study, that is engineering and science, the emphasis is placed on science. As a result, relative to population Australia graduates more persons with bachelor degrees in science and information science than any other country. Although this is not generally recognised the consequence is that the distribution of Australian research and development expenditure between engineering and science is markedly different from that of nations such as the Republic of China (Taiwan) and Singapore and other nations with which Australia has been compared.

University Graduates

1. Singapore

Perhaps no country places more emphasis on engineering education than Singapore. In relation to the education of engineers and scientists Singapore could well be considered to be the mirror image of Australia. Only a small proportion of university graduates in that country complete studies in the natural sciences, whether at the undergraduate level or the post graduate level. Not only is the annual number of graduations in science comparatively small but the number of natural science graduates at bachelor degree level has increased only by 14 per cent between 1993 and 1999. In contrast the number of engineering graduates has increased by 54 per cent over the same period. The levels of undergraduate enrolments in both these fields of study indicate that over the next three years at least the ratio of engineering graduates to science graduates will continue to increase. While, on the basis of enrolment trends, it may be anticipated that the number of persons completing science degrees might increase by only 7 per cent, the number of new engineers is likely to increase by 40 per cent or more.

Undergraduate enrolments in engineering have increased from 30 per cent of total undergraduate enrolments in 1993 to 41 per cent of total enrolments in 1999. Undergraduate enrolments in natural science represented 10 per cent of all undergraduate enrolments in 1993. By 1999 the proportion of science undergraduates had declined slightly to 9 per cent of all undergraduates.

The number of completions of higher degrees in engineering has increased at least six-fold over the period 1993 to 1999. The number of persons completing higher degrees in engineering is now over five times the number completing higher degrees in the natural sciences. The relative enrolment data in these two fields indicate that this ratio is likely to persist over the next few years. It may be anticipated that completions in engineering higher degrees will display continuing vigorous increases in the next four years.

The proportion of enrolments in higher degree courses in engineering has increased from 34 per cent of all higher degree enrolments in 1994 to 44 per cent of enrolments in 1999. The proportion of enrolments in higher degree courses in the natural sciences has declined from 8 per cent in 1994 to 7 per cent in 1999.

2. Republic of China (Taipei)

The Republic of China (ROC) also devotes considerable resources to engineering education. In 1997, 29 per cent of all undergraduate completions were in the engineering field of study. In contrast only 12 per cent of bachelor degree level graduations were in the natural science fields.

In the case of higher degrees a similar emphasis is placed on engineering. Nearly 35 per cent of all master degrees were granted to engineering graduates in 1997. In the case of the natural sciences 9 per cent of all master degrees were awarded in that field of study. Similarly, 36 per cent of all doctoral degrees awarded in 1997 were in engineering whereas only 14 per cent of doctoral degrees were awarded in the natural sciences.

The degree of emphasis the ROC places on engineering education is exemplified by the fact that over the period 1992 to 1997 the annual number of engineering graduates increased by 36 per cent while over the period 1993 to 1997 the number of bachelor level degrees in the natural sciences increased by only 6 per cent.

In the case of master degrees similar high rates of growth occurred in the engineering field while the number of master degrees in the natural sciences rose at a somewhat slower pace. In the case of doctoral degrees the rate of growth of the annual number of awards was, if not identical, fairly similar for the two fields of study.

3. Australia

The difference between Australia and the above two countries is immediately evident when the relative balance between engineering and science enrolments in the three countries is examined. In 1999, total bachelor degree enrolments by Australians in science, including information technology, represented 18 per cent of all bachelor degree enrolments. In contrast, enrolments in engineering represented 8 per cent of total enrolments.

It should be pointed out that in the case of published Australian educational statistics the science field of study includes both the natural sciences and information technology. It can be reasonably assumed that natural science represents about two-thirds of the number of students in the science field of study. Therefore , while there can be no direct comparability between the Australian data for science and the data for natural science in the ROC and Singapore, the comparisons between the countries may be taken as being reasonably indicative of the relative educational emphasis that exists. Even if only fifty per cent of Australian science graduates completed degrees in the natural sciences, relative to population Australia would still lead the world in the bachelor degree completions in the natural sciences.

In the case of higher degrees, enrolments in science represented 14 per cent of all higher degree students whereas engineering enrolments were 7 per cent of total enrolments. For the purposes of this analysis only master and doctoral level degrees have been considered. Graduate diplomas have been ignored. This has been done to maintain consistency with the analysis of the enrolments in the two Asian countries.

In 1998, the pattern of bachelor degree completions in Australia was somewhat similar to that indicated by the data for total enrolments. Engineering course completions were equivalent to 6 per cent of all course completions; science course completions represented 17 per cent of all course completions. There are over three science graduates for every engineering graduate; in Singapore there are approximately 60 per cent more engineering degrees awarded than for science. The indications are that the likely future increase in engineering graduations in Singapore will result in there soon being as many as three engineering graduates for every science graduate. At the post-graduate level in Australia, engineering graduates and science graduates represented 7 and 13 per cent of higher degrees respectively.

The relative weight that is given to engineering and science studies is emphasised by the relative growth rates of the number of commencements in each field. At both the undergraduate and the post-graduate levels science has done better than engineering. Undergraduate commencements in engineering have increased only by 11 per cent between 1993 and 1999. On present indications the number of engineering graduates is not likely to grow above current levels to any great extent in the next few years. Commencements in science courses have increased 35 per cent over the same period. Recent enrolment trends indicate that the number of graduates is likely to increase substantially over the next few years.

At the post-graduate level engineering commencements have declined 19 per cent between 1993 and 1999. Commencements in the science field of study have increased by 31 per cent over the same period.

4. Conclusion

The foregoing comparisons indicate that, while the two Asian nations have focused their principal educational effort on engineering education, Australia has placed the emphasis on science education. Not only are the relative patterns of education entirely different but the consequences for the development of qualified manpower differ quite substantially. Australia leads the world in terms of the annual number of science graduates per million population but trails most countries of the world in the relative number of engineering graduates. The ROC and Singapore educate natural scientists at a level approximately equivalent to the average for industrial nations but are, along with Japan, Korea and Finland, in the top six nations in terms of the level of engineering graduations relative to population. The consequences of this for the distribution of research and development expenditure between the sciences and engineering are discussed in the following section.

Research and Development Expenditure

It would be reasonable to expect that there would be a rough proportionality between the number of students and the number of academic staff in any technical field of study in a higher education institution. Because one of the major roles of academic staff, is apart from teaching, the performance of research, it would also be reasonable to expect that rough proportionality to carry across to the levels of research in the natural science and the engineering fields of study. The following table demonstrates that the level of R&D expenditure in these fields in certain countries does tend to be related, albeit only crudely. Unfortunately, the data relating to the distribution of R&D expenditure in the higher education sector of Singapore was not available but the relativity between the levels of engineering and natural science R&D expenditure is very likely to be predominantly in favour the engineering field of study.

RATIO OF R&D EXPENDITURE TO ANNUAL NUMBER OF GRADUATIONS IN THE HIGHER EDUCATION SECTOR

Country	Year	Science graduates as a proportion of engineering graduates (per cent)		Annual expenditure on R&D in the natural sciences as a proportion of engineering R&D expenditure (per cent)	
		Engineering	Natural science	Engineering	Natural science
Japan	1995	100.0	19.5	100.0	44.6
Republic of China	1997	100.0	26.9	100.0	38.1
Singapore	1999	100.0	35.6.	100.0	n.a.
Australia	1998	100.0	244.4	100.0	229.3

Notes : (a) The total number of graduates includes both first degrees and higher degrees.

<u>Sources</u>

Australia : "Research and experimental development, all sector summary, Australia, 2000-01" (Cat. No. 8112.0), Australian Bureau of Statistics, Canberra.
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Singapore : "Yearbook of statistics, Singapore, 2000", Singapore Department of Statistics, Singapore, 2000.

It is readily apparent from the table that :
1. The Asian nations all placed an emphasis on engineering education.
2. The relative levels of expenditure reflected the relative numbers of graduates.

3. Both the ROC and Japan expend a considerably greater proportion of GDP on engineering R&D in their higher education sectors than does Australia. It is likely that Singapore does the same.

In discussions of Australia's R&D effort it is frequently maintained that we should imitate such nations as Singapore, Korea, Finland or Ireland and thus increase our expenditure on R&D in the higher education sector. Such comments ignore certain realities. The first of these is that all but one of these of these countries, Finland, expend a smaller proportion of their GDP on R&D in the higher education section than does Australia. The second is that, with the exception of Ireland, the pattern of education in these countries places considerable emphasis on engineering education. Thus, it is very likely that the pattern of R&D expenditure in the higher education sector reflects this distribution of effort. In the case of the ROC we know this to be so.

Conclusion.

As in the case of education, it is readily apparent that, relative to the level of R&D in the higher education sector of at least some of the countries with which Australia is compared, engineering research in the Australian higher education sector is at a low level. In contrast the level of R&D expenditure in the natural sciences in Australia is comparatively high. One wonders whether in urging the Australian government to emulate such countries as Singapore the leaders of the higher education lobby groups realise that they are seeking a marked expansion of engineering education in Australia.

An examination of R&D expenditure in the government sectors of the other countries discussed in the foregoing demonstrates that, once again, the successful exporting nations of Asia devote a greater level of their national R&D effort to engineering research in the government sector than Australia. These are issues that are ignored by Australian commentators on research policy. This leads one to question the quality of much that passes for informed comment on R&D policy in Australia.

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Science and Innovation
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3 September, 2002

Dear Ms. Mcinnis,

Please find enclosed my submission to the Inquiry into Business Commitment to Research and Development.

If you have any queries concerning my submission please do not hesitate to contact me at the above address. My telephone and fax number is : 03 - 9878 6026.

Yours sincerely,

M. R. C. Rice

Michael Rice

ENCL.

File

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3 September, 2002

Dear Ms. Mcinnis,

On rechecking my copy of the submission that I forwarded to your office today I found that the list of references on page 30 contained an error. I enclose an amended copy of that page. I would be pleased if you would substitute the replacement page for the one that was included in the document that I had already forwarded to you. Please accept my apologies for the error.

Yours sincerely,

M. R. Rice

Michael Rice

ENCL.