ECONOMIC CONSIDERATIONS IN THE SELECTION OF GENERIC TECHNOLOGIES*

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A vast array of new processes and product innovations can arise from a single broad-based generic technology such as biotechnology. A small country like Australia faces some difficult choices in determining which science-based generic technologies should be supported and to what extent. This paper explores the economic factors that should be taken into account by firms and by Government in determining the choice of generic technology. It considers the problem of identifying ex ante the particular technologies in which Australia may have a comparative advantage. It also shows why certain facets of the existing industrial structure are relevant to the selection of generic technologies.

Keywords: Generic technology, government assistance, comparative advantage, industrial development, Australian manufacturing.

INTRODUCTION

Economists have long recognised that technological change, broadly defined, is a major contributor to economic growth. In the 1950s and 1960s, several pathbreaking studies[1] endeavoured to measure the extent to which technological change has contributed to economic growth in a number of advanced countries. While such measures can only be broad approximations, it can be safely concluded that the increasing wealth of modern nations depends not so much on the growth of the stock of capital and the utilisation of labour as on improvements in skills and education and in methods of production and distribution.

But the relationship between technological change and economic growth is not just in one direction. Economic growth also tends to lead to a more rapid rate of technological change. A number of empirical studies have shown that the industries in which sales are growing most rapidly are usually industries in which there is substantial investment in innovation. In other words, the growth of demand, as well as the emergence of scientific and technological opportunities, is an important determinant of the pace and direction of technological development.[2]

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In Australia, the direction of scientific and technological effort over the next few years will be strongly influenced, I suggest, by a number of economic imperatives. First among these is the nation's current balance of payments problem and the manner of its resolution. In the short-run, the rate of economic growth may be held back by the balance of payments constraint and the need to stabilise the nation's external debt. This could imply that the total volume of resources made available for investment in research and technological development both by business and government will continue to be tightly constrained over the next few years.

In the medium to long term, however the structure of the economy is likely to change as a result of the substantial real devaluation of the $A, with greater emphasis on the production of internationally tradeable goods and services and less on the production of non-tradeable goods and services destined for the home market. The production and export of manufactured goods will tend to become relatively more important, since the outlook for our traditional primary exports remains uncertain. In short, Australia will be seeking to reduce its reliance on the sale of standardised products and instead placing more emphasis on selling differentiated products based on quality, design and superior technology. Manufacturers will increasingly aim to gain overseas markets on the basis of the unique characteristics of some of the goods they produce rather than on the basis of price alone. The technology and design content of manufactured exports seems certain to grow, and the demand for R&D personnel can be expected to increase commensurately. In addition, the structural changes in the economy and the changing pattern of demand will certainly affect the allocation of resources between different areas of science and technology.

Even if the present serious balance of payments problem had not emerged, internationally competitive high technology industries would probably have become far more prominent among Australia's export industries. As may be seen in Table 1, products with high research and development intensity have represented one of the fastest growing areas of world trade in the past 15 years. Such products have increased their share of the total exports of OECD countries from just over 16 per cent in 1970 to almost 22 per cent in 1985. Imports of high technology products by the OECD countries have also increased at a similar rate.

Australia has also increased its exports of high technology products over this period, but from a very low base. In 1985, Australia was ranked above only Greece and New Zealand in the proportion of its manufactured exports represented by high R&D intensive products (see Table 1). Imports of high technology products into this country outweigh exports by a very substantial margin, while the growth of such imports in the past 15 years has been somewhat faster than the growth of exports.

However, the volume of world trade in high technology products is expected to continue to show strong growth and this is one reason why these products are an area of potential future comparative advantage

TABLE 1
Share of High R&D Intensity Industries in Exports and Imports of Manufactures[a,b]
Per Cent

	Exports		Imports	
	1970	1985	1970	1985
Portugal	7.6	9.9	15.5	17.0
Belgium	7.2	8.6	12.9	11.5
Denmark	11.9	16.1	15.6	16.6
Greece	2.4	3.3	12.3	11.6
Ireland	11.7	36.0	14.1	27.6
Netherlands	16.0	14.0	18.1	19.3
Spain	6.1	8.5	17.7	23.6
Australia	*2.8*	*4.2*	*21.1*	*24.2*
Canada	9.0	9.6	16.9	19.6
New Zealand	0.7	2.4	15.2	20.1
Austria	11.4	14.3	14.3	18.1
Finland	3.2	8.0	13.5	20.3
Norway	4.7	7.8	12.2	18.7
Sweden	12.0	16.6	16.2	21.9
Switzerland	30.2	28.0	14.7	17.7
France	14.0	18.8	15.7	18.3
Germany	15.8	18.1	13.0	20.5
United Kingdom	17.1	27.5	13.7	24.1
Japan	20.2	31.9	18.0	19.4
United States	25.9	35.6	12.4	22.0
Total EEC	14.1	17.3	14.5	19.5
Total OECD	16.3	21.8	14.6	20.3

Source: OECD.

a. High R&D intensity industries comprise: aerospace, computers, electronic equipment, drugs, scientific instruments, electrical machinery.

b. Intra-EEC trade included.

for Australia. Another reason is that, as levels of tariff protection are gradually reduced, the products with the greatest potential in export markets are likely to be those which make intensive use of the country's relatively abundant resources of educated manpower. By contrast, we will find it increasingly difficult to compete internationally in goods and services in which unskilled and semi-skilled labour is a major input.

Aside from these broad macroeconomic imperatives which will tend to determine the direction of Australia's science and technology efforts, there is a further microeconomic imperative. It has become increasingly recognised that economic welfare can be increased by improving the efficiency with which scientific and technological manpower and equipment are used. Closer collaboration between research scientists and industry is likely to contribute to such an improvement. Moreover, in determining the allocation of resources to scientific and technological projects greater attention needs to be paid to the prospects of commercialising Australian inventions than seems to have been the case in the past.

The particular focus of this paper is on generic (or enabling) technologies and in the following sections of the paper four main questions are explored:

- what are the important economic characteristics of generic technologies?
- what is the economic rationale for any Government support of generic technologies?
- how can we identify the technologies in which Australia could have a comparative advantage? and
- why are the links with downstream industries important in making a choice among generic technologies?

IMPORTANT ECONOMIC CHARACTERISTICS OF GENERIC (OR ENABLING) TECHNOLOGIES

There are some special economic characteristics of generic technologies that have important implications for Government and business decisions. First, many of the new generic technologies (e.g., biotechnology, micro-electronics, new materials) are science-based and arise initially from discoveries in the research laboratories of universities and research institutions. This close relationship between science and technology has important advantages. However, it also can produce some tensions. For example, most research scientists are keen to disseminate the results of the research as widely as possible. Their rewards derive in part from the disclosure and publication of the results. On the other hand, firms seeking to exploit these technologies will generally achieve a greater commercial advantage by non-disclosure and by avoiding leakages of information to their competitors. These apparently conflicting objectives of scientists and industrial firms are not irreconcilable. But sometimes new institutional arrangements (e.g., the funding of co-operative research) will be needed to achieve both a high rate of scientific discovery and a rapid rate of commercial innovation.

Secondly, almost by definition, new generic technologies create a broad range of commercial opportunities and impact on a large number of different industries. For example, industries manufacturing new products arising from the technology, industries adopting cost-reducing innovations and industries servicing the new activities will experience changes in their output. Moreover, new science-based generic technologies frequently lead to the creation of a large number of new firms. This new firm creation is important in contributing to greater economic dynamism in the economy and a more rapid change in the economic structure.

Thirdly, it is generally recognised among economists that the social rate of return from investment in research and development of a generic technology may substantially outweigh the private rate of return, as perceived by the firms or institutes undertaking the R&D. This is because private firms are often unable to capture all of the benefits that derive from the results of their pre-competitive R&D efforts. For example, there may be a leakage of information through the publication of articles in the scientific journals. More importantly, research and development personnel who have played a significant part in the development of an important innovation may take up positions in other firms or set up their own competitive businesses.

It is clearly very difficult to prevent valuable knowledge from leaking out in this way. In principle, the patent system helps to preserve the intellectual property rights of the original inventor and so helps to bring the private rate of return closer to the social rate. However, patent protection is much easier to achieve in respect of new manufactured products than it is at the pre-competitive stage, when broadly-based generic technologies are still in the process of development.

Apart from the problem of leakage of information to other firms (so-called 'externalities'),the private rate of return on investment in the development of a generic technology may also fall short of the social rate of return whenever very large lumpy investment outlays are required to achieve success. This seems to apply in the case of nuclear power and VLSI technology, for example. However, in computer software development and in many fields of biotechnology large-scale investments are relatively rare.

It is also often claimed that the high risks involved in research and development of a generic technology tend to dissuade private firms from participating, even though it may be possible for some firms to achieve a high rate of return. While this argument has some force it is nowadays widely recognised that risk can be diversified through the capital market. Even small firms may be able to attract funding for high risk projects provided the ultimate investors can build up a sufficiently diversified portfolio of high risk ventures. Moreover co-operative research ventures funded by a group of firms can significantly lower the risks for each particpant as well as reducing the magnitude of the required investment.

Taking all of these factors into account, it remains true that market forces may result in less investment being undertaken in pre-competitive R&D than would be socially desirable, because of the divergence between the prospective private and social rate of return on particular projects. In the next section of the paper I explore the circumstances in which government intervention is justified to correct this type of divergence.

Fourth, a potential problem may arise, if, as at present, many advanced countries are aiming to encourage the development of the same generic technologies. A country like Portugal for example, is focusing on biotechnology, computer software and new materials, just as Australia is. This concurrent world-wide development of the same generic technologies naturally raises the question as to whether the social rate of return for each nation will be adequate to justify the investment involved. A pessimistic view is that the major benefits will be captured by a few large international firms which first achieve the major technological breakthroughs. The also-rans, comprising the vast majority of firms and perhaps a majority of countries, will have largely wasted their R&D efforts. On this view, the average rate of return on investment in these new generic technologies will be quite low, reflecting over-investment rather than under-investment in this area.

However, one can take a more optimistic view of the outcome,looked at from the perspective of a small country like Australia. Information can often be readily obtained from other countries at low cost, and Australia can hope to capitalise on this leakage of technological information provided it has a reasonable technological competence in the field. It may not be necessary to achieve any dramatic technological break-throughs in order to justify a certain level of R&D expenditure aimed at exploiting the worldwide pool of knowledge. A further reason for optimism is that the increasing extent of co-operative research among firms across national boundaries helps to avoid the duplication of research effort and ensures that the returns from generic R&D accrue to a large number of countries.

However, whether one subscribes to the optimistic or pessimistic view it is evident that the social rate of return from investment in a particular new generic technology depends ultimately on the extent to which that technology leads to cost reductions in the processes of production and/or the introduction of a wide range of new products superior to those currently in use.

THE ECONOMIC RATIONALE FOR GOVERNMENT SUPPORT FOR GENERIC TECHNOLOGIES

In the light of the discussion in the previous section I should like now to focus on the reasons why governments may be justified in providing support for the development of generic technologies. First, if there are significant externalities of the kind mentioned earlier, government action may be needed to prevent under-investment in R&D in these technologies by the private sector. It may be possible to correct this potential under-investment without the provision of government subsidies. For example, if the danger of under-investment in private R&D arises from the *Generic* likelihood of spillovers to firms in other countries, measures to strengthen Australian firms' foreign patent rights may be sufficient to achieve the desired end. The government can also play a role in encouraging co-operative research amongst domestic firms. The risk that free riders will obtain the benefits of the research results without making a contribution to the co-operative research effort can sometimes be eliminated by raising a compulsory research levy on all competing firms in the domestic industry.

If action of this kind does not eliminate the problem there may be a case for the provision of grants or subsidies to encourage private R&D to reach the socially optimal level. The aim of such a subsidy would be to remedy the divergence between the prospective private and social rates of return from the investment in research and development. Yet a subsidy is still not economically defensible unless two other conditions are met:

- the specific R&D projects in question would not proceed without government support
- the social rate of return obtained would be at least equal to the minimum social rate of return achievable from any alternative investment in the economy.

While the formal logic of these conditions seems unassailable, in practice it is very difficult for governments or private firms to work out the prospective rates of return achievable from many investments in pre-competitive generic technology. In view of this uncertainty a precise mathematical calculation of returns may be impossible and careful judgement is needed instead. However the presence of uncertainty does not necessarily diminish nor does it strengthen the case for government assistance.

A second argument for government intervention in support of generic technology is that the government may be able to play a catalytic role in achieving better communication and co-operation between scientists and engineers employed in competing firms. This appears to have been the rationale for government intervention in some major R&D projects in Japan. Much of the training of scientists and engineers in Japan takes place within individual firms rather than in universities. Hence informal contacts between scientists and engineers tend to be quite limited in comparison with those in the United States. By arranging co-operative research programs among firms, the Ministry for International Trade and Industry (MITI) seems to have improved the communication channels between its scientists and engineers in industry with a consequent improvement in the overall efficiency with which the R&D is conducted.

A third reason for government involvement is evident whenever technical education is largely funded through the public purse, as is the case in Australia. If a particular generic technology is to be developed successfully there must be a sufficient supply of scientific and engineering personnel to develop the technology and ensure its application in industry. However, success in high technology industries requires more than the matching of demands for specific types of skilled personnel with the supply. As Richard Nelson of Yale University has pointed out:

> . . . . the most important lesson . . . is that nations aspiring to strengthen high technology industries had better attend to their general strength in technical education and establish and maintain a set of policies and institutions supporting general economic growth. A possible danger of the recent rhetoric about the importance of high technology industries is that it may take attention away from these broader policy areas.[3]

In summary, governments can have a legitimate role in supporting generic technologies by helping to correct externalities; achieving a better flow of information between scientists and engineers and between different firms; and facilitating an adequate supply of skilled manpower. This role arises essentially because private markets are sometimes non-existent or function ineffectively. In the case of research and development and generic technologies, market failure is likely to be more common than in many other parts of the economic system.

While there is evidently a rationale for government support for generic technologies it would be foolish to deny the dangers. In particular, government officials are not well equipped to 'pick the winners'. It is usually claimed that the private sector is likely to do better in this respect, particularly as its own funds are at risk. To some extent, however, this argument misses the point. If there are significant externalities and hence some degree of market failure, private firms will fail to invest in some potential winners. This may be just as serious as government encouragement of certain projects which yield less than satisfactory returns. Yet the main problems seems to be that the governments of many countries have demonstrated a reluctance to cut their losses and withdraw from high technology projects which have little chance of commercial success. In the case of pre-competitive generic technologies, there is no immediate yardstick for judging the eventual commercial viability of the myriad of potential applications of the technology. Therefore governments can easily find themselves locked into long-term support when an earlier withdrawal from the project would be more appropriate.

Finally, there is a danger that government support of generic technologies may lead eventually to widespread subsidisation of high technology industries seeking to sell on world markets. If this does occur, and already there are some signs of it happening, international trade frictions may result. Such subsidisation can also lead to an unduly fast rate of growth of international trade in high technology products with taxpayers in each country bearing the burden of the consequent misallocation of resources.

HOW DO WE IDENTIFY THE GENERIC TECHNOLOGIES IN WHICH AUSTRALIA MAY HAVE A COMPARATIVE ADVANTAGE?

It would be generally accepted that Australia should only be involved in those generic technologies in which it is likely to have a comparative advantage — that is, where the resultant products and processes will be internationally competitive in the long run. The problem confronting firms (as well as the government) is how to identify such technologies. Two routes might be considered. One route involves an examination of the nation's resource base, to discover the types of technology that might be developed most cheaply and efficiently in this country. The second route is to work with past data on technology flows or trade flows to ascertain the 'revealed' comparative advantages.

Let me say something about these two routes. First, comparative advantage in a technology is likely to derive partly from accumulated knowledge and skills built up over a period of years. Sometimes that skill and knowledge will reflect the particular characteristics of Australia's natural resource base and its past patterns of production, e.g., experience in dry-land farming. In considering future comparative advantage it is also important to take into account the prospective market growth both in Australia and overseas for the products derived from the technology. Investment in a specfic technology cannot be justified on the basis of relative costs alone but must also allow for the magnitude and likely growth of demand.

However, empirical studies which have tested the hypothesis that the pattern of a country's net exports is related to its relative abundance of particular resources and factors of production have often proved unrewarding. Most of these studies have been unable to confirm that net exports are largest in those products which make intensive use of the country's most abundant resources. Hence some doubt must exist whether the future pattern of high-technology exports can be identified by focusing on those areas where accumlated knowledge, skills and experience are evident.

The second route, which can be complementary to the first, is to examine the actual past patterns of international trade or patenting in the hope of inferring the particular product or technology areas in which the country may have a comparative advantage. An interesting recent paper[4] by Keith Pavitt of the Science Policy Research Unit at the University of Sussex has followed this approach, using data on foreign patents in the United States. Table 2 taken from Pavitt provides details of the industry pattern of foreign patents in the United States for nine advanced countries.

The second row of the table shows each country's national share of total foreign patents issued by the United States in the periods 1963-68 and 1976-81. In the latter period, Canada for example, was responsible for 4.6 per cent of all foreign patents in the United States. In the body

TABLE 2

US PATENTING AS AN INDICATOR OF NATIONAL PATTERNS OF SECTORAL TECHNOLOGICAL ADVANTAGE [a]

		CANADA		FRANCE		F.R. GERMANY	
PERIOD BY DATE OF PATENT GRANT		1963-8	1976-81	1963-8	1976-81	1963-8	1976-81
NATIONAL SHARE OF FOREIGN PATENTING IN USA [a]		6.9	4.6	10.7	8.7	26.9	23.6
I	Chemicals and Petrochemicals [b]	0.61	0.65	0.76	0.90	1.17	1.15
II	Pharmaceuticals	0.39	0.55	1.69	1.46	0.95	1.06
III	Bioengineering	1.07	0.44	1.34	0.80	0.66	0.74
IV	Plastic and Rubber Products	0.78	0.71	1.13	1.17	0.91	0.96
V	Non-Metallic Materials	1.59	1.35	1.07	0.96	0.84	0.90
VI	Food and Tobacco	1.20	1.34	0.52	0.98	0.79	0.69
VIII	Metallurgical & Other Processes	0.98	0.99	0.92	0.95	0.98	0.81
IX	Process Equipment	1.18	1.30	0.86	0.76	1.06	1.18
X	General Industrial Equipment (Non-Elect)	0.82	0.98	1.30	1.06	0.98	1.13
XI	General Industrial Equipment (Elect)	0.77	0.88	1.21	1.09	0.90	0.88
XII	Specialised Ind. Equipment (Non-Elect)	1.09	1.29	0.80	0.79	0.98	1.08
XIII	Metal Working Machinery & Equipment	0.98	0.88	0.92	1.02	1.29	1.19
XIV	Assembling & Handling Equipment	1.25	1.17	1.01	0.88	0.98	1.17
XV	Nuclear Reactors	0.71	0.34	2.11	2.70	0.34	1.63
XVI	Power Plants	0.52	0.59	1.36	1.01	0.68	0.79
XVII	Motor Vehicles and Engines	1.07	0.62	1.49	0.80	1.13	1.14
XVIII	Other Transport (Exc. Aircraft)	2.14	1.64	1.50	1.41	0.66	1.03
XIX	Aircraft	0.65	1.75	1.37	2.70	0.73	1.17
XX	Agricultural & Construction Machinery	3.61	2.49	0.55	1.25	0.58	0.59
XXI	Mining & Wells Equipment	2.00	3.55	0.99	0.84	1.01	1.08
XXII	Telecommunications	0.80	1.46	1.33	1.66	0.75	0.61
XXIII	Electrical Components - Devices	0.85	0.95	1.09	1.11	0.84	0.85
XXIV	Calculators, Computers, Office Equipment	0.47	0.34	0.83	0.99	0.98	0.64
XXVI	Image and Sound Equipment	0.88	0.61	1.21	0.80	0.86	0.53
XXVII	Instruments, Controls, Photo	0.78	0.76	0.99	0.83	1.24	0.94
XXVIII	Metal Products	1.90	2.22	1.01	1.03	0.83	0.87
XXIX	Textile, Clothing, Leather, Wood	2.23	2.05	0.79	1.22	0.99	0.95

SOURCE: Pavitt (1986), who used information supplied to the Science Policy Research Unit, University of Sussex, by the Office of Technology Assessment and Forecast, US Department of Commerce.

a For all countries except the USA, sectoral technological advantage is the ratio of a country's share of foreign patenting in the USA in the sector, to its share in all sectors. For the USA, the ratio is for the share of total patenting in the USA that is of US origin.

b Sectors are based on the US Patent Classes and have been aggregated at the Science Policy Research Unit by G. Dosi.

ITALY		JAPAN		NETHERLANDS		SWEDEN		SWITZERLAND		UK		USA	
1963-8	1976-81	1963-8	1976-81	1963-8	1976-81	1963-8	1976-81	1963-8	1976-81	1963-8	1976-81	1963-8	1976-81
3.4	3.1	8.2	28.0	3.7	2.7	4.2	3.3	6.9	5.3	19.6	10.5	79.5[a]	61.8[a]
1.44	1.06	1.21	1.02	1.27	1.00	0.31	0.37	1.55	1.36	0.83	0.98	0.94	0.96
1.09	1.49	1.30	0.89	1.21	0.59	0.67	0.60	1.54	1.53	0.70	1.65	0.89	0.80
1.15	1.26	7.28	1.45	0.94	0.74	1.03	1.10	0.82	0.87	0.55	0.68	0.75	0.89
1.42	1.47	1.49	1.01	0.92	0.64	0.73	0.73	0.65	0.38	1.06	1.39	0.94	0.90
0.84	0.70	0.65	1.02	1.21	0.94	1.17	0.91	0.62	0.71	1.04	1.16	1.04	1.03
1.45	0.82	1.24	0.83	1.91	2.00	1.05	0.96	0.79	1.73	0.96	1.35	1.01	1.04
0.52	0.77	1.68	1.21	1.28	0.69	0.86	1.46	0.55	0.67	1.03	0.88	0.98	0.98
1.02	1.08	0.67	0.69	1.17	1.02	1.84	1.78	0.74	0.90	0.84	0.83	0.99	0.96
0.73	0.55	0.71	0.77	0.47	0.74	1.35	1.55	0.78	0.80	1.27	1.23	0.97	1.03
0.76	0.74	1.24	1.11	0.79	0.73	1.08	1.10	1.11	0.92	1.07	0.93	1.01	0.96
1.56	1.90	0.99	0.73	0.75	0.73.	0.91	1.31	1.31	1.23	0.89	0.98	0.98	0.96
0.75	1.01	0.59	0.63	0.31	0.50	1.27	1.43	1.05	1.14	0.95	0.77	0.95	0.85
0.86	1.15	0.68	0.72	0.82	1.12	1.51	2.11	0.92	1.08	1.06	0.92	1.00	1.03
0.96	0.19	0.17	0.36	0.48	0.43	1.52	0.76	0.67	0.30	2.10	1.06	0.66	0.83
0.63	0.82	0.48	1.23	0.64	0.78	0.77	1.65	0.76	0.75	2.13	1.34.	0.93	0.96
0.81	0.65	0.56	1.60	0.12	0.22	0.72	0.43	0.37	0.32	1.32	0.73	0.93	0.78
1.19	0.72	0.50	0.64	0.37	0.71	1.13	1.38	0.66	0.78	0.94	0.83	1.01	1.03
0.36	0.11	0.40	0.15	0.05	0.13	1.11	1.25	0.30	0.07	2.31	2.14	0.98	1.25
0.79	0.94	0.23	0.23	1.75	5.29	0.65	1.35	2.16	3.87	0.62	0.72	1.09	1.15
0.43	0.04	0.18	0.21	2.06	1.18	1.60	1.90	0.17	0.29	0.75	1.55	1.16	1.26
0.51	1.19	1.21	1.23	1.74	1.64	1.68	0.92	0.34	0.48	1.30	1.07	1.02	1.07
0.57	0.74	1.49	1.31	1.92	2.20	1.05	0.71	0.79	0.65	1.15	0.92	1.05	1.04
0.95	1.46	1.66	1.69	2.03	1.99	0.79	0.58	0.59	0.46	1.11	0.76	1.03	1.02
0.80	0.34	1.70	1.92	1.48	2.03	0.46	0.47	0.45	0.46	1.17	0.96	1.04	0.04
0.81	0.65	1.07	1.34	0.76	0.64	0.76	0.87	0.96	0.93	0.91	0.86	1.01	0.96
0.94	1.01	0.663	0.66	0.82	0.91	1.50	1.58	0.78	0.87	0.97	1.11	1.11	1.19
1.38	2.09	0.53	0.56	0.19	0.46	0.95	1.47	0.50	0.81	0.93	0.89	1.10	1.18

of the table the ratio of a country's share of foreign patents in the United States in each industry to its overall share in all industries is shown. Thus, for Canada, the ratio of 0.65 for chemicals and petro-chemicals indicates that this industry has a share below the country's average share in all US foreign patents — the actual share for this particular Canadian industry being 0.65 x 4.6 = 3.0 per cent.

According to Pavitt, three broad conclusions emerge from an analysis of the data in this table

- small countries are more technologically specialised than large countries — this is indicated by the fact that for a small country the ratios in the table are generally more widely scattered around the mean of 1 than is the case with larger countries like Japan, Federal Republic of Germany and the UK.
- The patterns of technological advantage are very different among the various countries.
- Each country's pattern of technological advantage seems to remain quite stable over time — as indicated by the fact that the ratios for any industry are generally quite similar for both the periods examined.

This type of calculation could be extended to include Australia. It could be useful in identifying, on the basis of past performance, particular product areas in which Australia may have a comparative technological advantage.

However, some potential difficulties with this approach to identifying revealed comparative advantage should be noted. First, the relative technological advantage of a particular sector (revealed by a ratio greater than 1.0) may not reflect the country's long run international competitiveness in that field as much as the effect of (temporary) government support for a specific technology. A noteworthy example may be seen in the case of France, where nuclear reactors and aircraft, both strongly supported by the French Government, have by far the highest comparative advantage ratios for that country in the period 1976-82 (2.70 in both cases).

Secondly, given the inevitable time lag in obtaining the requisite data it is clear that the pattern of revealed comparative advantage may be more of historical interest than of value in identifying future areas of comparative technology advantage. This point is of particular importance for Australia, since the recent devaluation of the $A is likely to bring about a shift in the industrial structure towards manufacturing and away from the more traditional exports of primary products. Because of this shift, past patterns of R&D effort and foreign patenting may be a poor guide to the future patterns that are required.

In summary, studies of revealed comparative advantage and the relative abundance of different resources may be useful in identifying broad generic technologies in which Australia might specialise. But the evidence shows the results of these studies should be approached with caution. They can provide a broad indication of the directions in which

R&D effort might be concentrated. In the end, however, there is no substitute for an attempt to evaluate the prospective profitability of specific individual R&D projects.

We have so far not considered a choice which must often be made by a small country like Australia — whether to develop a specific generic technology domestically or rely instead on imported technological know-how. Even for a large country it can be economical to capitalise on the availability of technological know-how from abroad. As Saxonhouse[5] notes the Japanese have shown themselves adept at making extensive use of the results of United States government research, which are usually published or are available free on request. Australia also can probably take greater advantage of the spillover benefits of research and development conducted abroad.

Indeed, an important question is what proportion of the available R&D manpower in Australia should be directed to the development of new generic technologies, which may result in substantial spillover benefits to other countries, compared with the alternative of ensuring the effective utilisation of generic or specific technologies obtained from abroad.

Since Australia only has the resources to specialise in a small number of generic technologies this choice will depend, among other things, on

- the relative cost of gaining access to the different technologies developed overseas (taking account of licence fees and transfer costs, etc.);
- the relative scarcity in Australia of the scientific and technological skills needed to develop each technology at home;
- the relative size of the Australian industry which would utilise each technology; and
- the extent to which Australian firms and institutions are able to protect their intellectual property rights and appropriate the major benefits of the various technologies developed here.

It is sometimes claimed that unless local firms undertake development in a particular generic technology it will be very difficult to obtain on reasonable terms the later-stage specific technologies which would be of direct value to Australian industry. In other words, in view of the close interconnection between the successive stages in a complex fast-moving technology, a small country is likely to be at a disadvantage unless it is involved in each of the stages. However this danger may be exaggerated. There is increasing evidence of co-operative R&D effort by firms in different countries, with firms in one country specialising in a slightly different stage or aspect of the technology from those of another. Such co-operative R&D efforts may help to 'unbundle the technological package' and enable Australian firms to specialise in those stages of the technology in which they have a comparative advantage, and which would be relatively costly to obtain from elsewhere.

WHY ARE THE LINKS WITH DOWNSTREAM INDUSTRIES IMPORTANT IN THE CHOICE OF GENERIC TECHNOLOGIES?

When business firms and governments make a choice of which generic technologies to support they are usually concerned with the ultimate private and social economic benefits (respectively). It is not economically sensible to pursue a particular line of research or development in the vague hope that a market will ultimately be found for any resultant products or processes. The direction of research will normally have to be dictated by established market opportunities rather than by scientific interest and opportunity alone.

One factor that may strongly influence the magnitude of the economic benefits that can be obtained from the local development of a generic technology, is the ease with which that technology can be exploited by downstream Australian industries. This raises the question of whether it is preferable to select technologies that are likely to be taken up by domestic manufacturers, or those where the income will be mainly derived from licensing or selling the resultant know-how to overseas manufacturers.

There is no simple answer to this question. However, two factors are clearly important — the appropriability of the benefits from the technology and the relative costs of manufacturing at home and abroad.[6] Consider first the case where an Australian firm undertaking research on a specific generic technology can obtain strong patents[7] for a resultant product or process with world-wide applications and where the cost of manufacturing abroad is likely to be lower than at home.[8] In this case, the balance of advantage will usually lie in exporting the technological know-how, either through sale to a foreign firm, licensing abroad, or direct foreign investment. The economic benefits to Australia from selecting this particular technology and exploiting the results in this way may well be as large as if the technology chosen had been one that could be utilised by Australian manufacturers.

However, suppose instead that there is already a sizeable internationally competitive local industry, with unit costs no higher than those of overseas producers and able to make effective use of the results of a local generic technology program. Further suppose that the know-how arising from that program is only 'weakly' appropriable in the sense that if it was licensed to overseas manufacturers it might quickly leak out to non-licensed foreign firms. In this case, it will probably be more advantageous not to license or sell to overseas manufacturers[9] but instead to capture the benefits of the technological advance through greater manufactured exports from Australia.

The economic benefits that can be derived from a new process technology also depend critically upon the rate at which the technology is adopted by domestic firms. The more quickly a cost-reducing innovation is adopted by the majority of firms in an Australian industry the more likely it is that the industry will be able to capture an increased share of domestic and international markets. Thus, prior to selecting a generic technology for development it is important that mechanisms are in place to ensure that any cost-reducing benefits arising from the technology can be diffused promptly and effectively among local user firms. Industry associations, private consultants and government institutions like the Technology Transfer Council and the National Industry Extension Service all have a role to play in this process.

In short, research and development and technological innovation should be seen as an integral element in the overall strategy for industrial development. The aim is to achieve an internationally competitive manufacturing sector which is both responsive to changing patterns of demand and dynamic in introducing technological advances as they become available.

NOTES AND REFERENCES

1. In particular, see M. Abramovitz, 'Resource and output trends in the United States since 1870', *American Economic Review*, 46, 2, May 1956, pp. 5-23; R.M. Solow, 'Technical change and the aggregate production function', *Review of Economics and Statistics*, 39, 3, August 1957, pp. 312-320; J.. Kendrick, *Productivity Trends in the United States*, Princeton University Press, New York, 1961; E.F. Denison, *The Sources of Economic Growth in the United States and the Alternatives before Us*, Committee for Economic Development, Supplementary Paper No. 13, New York, 1962; and for Australia, H.R. Edwards and N.T. Drane, 'The Australian economy, July 1963', *Economic Record*, 39, 87, September 1963, pp. 259-282.
2. See, for example, F.M. Scherer, 'Demand-pull and technological invention: Schmookler revisited', *Journal of Industrial Economics*, 30, 3, March 1982, pp. 225-238 and Michael Gort and Richard A. Wall, 'The evolution of technologies and investment in innovation', *Economic Journal*, 96, 383, September 1986, pp. 741-757.
3. R. Nelson, *High Technology Policies: a Five-nation Comparison*, American Enterprise Institute for Public Policy Research, Washington, D.C., 1984.
4. K. Pavitt, 'International patterns of technological accumulation' in N. Hood and J.E. Vahlne (eds), *Strategies in Global Competition*, Wiley, London, 1986.
5. G.R. Saxonhouse, 'Biotechnology in Japan: industrial policy and factor market distortions', *Prometheus*, 3, 2, December 1985, pp. 277-314.
6. For a similar view see D.J. Teece, 'Profiting from technological innovation: implications for integration, collaboration, licensing and public policy', *Research Policy*, 15, 1986, pp. 285-305.
7. In a more general sense, the key question is whether the Australian firm can appropriate most of the benefits of the technology through negotiation with overseas licensees or through direct investment abroad. Success in negotiation may sometimes depend on the strength of the patents held while on other occasions it may depend on the ability to keep the nature of the innovation secret from non-licensees.
8. The Sarich orbital engine may be a case in point.
9. An alternative approach might be for the Australian firm responsible for the innovation to establish its own manufacturing facilities overseas but in the circumstances described this appears to have no net *social* advantage compared with manufacturing the product at home.