THE ROLE OF ECONOMIES OF SCALE IN AUSTRALIAN R&D*

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Australia does relatively little R&D. One possible explanation is that as a small country, Australia cannot take advantage of scale economies. A schema is provided for the role of economies of scale in R&D. Case studies from the automotive, mining, and pharmaceuticals industries show examples of successful R&D in Australia. These case studies illustrate that if Australian firms are internationally competitive, then economies of scale in production need not hamper R&D. Even when at a comparative disadvantage in producing a product, Australia may still be competitive in basic research or the initial development of ideas.

Keywords: R&D, economies of scale, spillovers, Australian industry policy

INTRODUCTION

The consensus among academics, the business community and the popular press is that Australia's aggregate level of R&D is too low in comparison with other OECD countries. Australia's expenditures are well below OECD averages, with gross and business expenditure on R&D quite low, as can be seen in table 1. Since Australia has a relatively large number of scientists, good infrastructure, and relatively low costs of doing business, it might be expected that Australia would be a better performer. Many explanations for this paradox have been offered, ranging from poor government policies towards R&D to bad attitudes on the part of managers. In this paper, we examine whether or not the small size of Australia's economy puts it at a disadvantage in conducting R&D. In other words, Australia may be too small to obtain economies of scale in R&D or in the products that result from R&D.

One way to interpret "smallness" is to say that firms will not engage in R&D because their discoveries will not be worthwhile at the low production levels necessary to supply the Australian market. This was noted in the Jessop Report of 1979.[1] Gregory described this link between the small size of the domestic market and R&D expenditure as follows:

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> [T]he small population and high wages led to small scale and simple manufacturing, which, as a result of high costs, found it difficult to export and compete against imports. The manufacturing sector was directed almost exclusively to the small home market, large segments were protected by tariffs, and most technologies were imported. As a result, there was a low level of private sector R&D.[2]

While this historical lack of export activity and reliance on imported technology may explain Australia's low levels of R&D expenditure in the past, small market size would not prevent Australian firms from currently doing R&D if they can export their products. It also would not apply if the inventions themselves could be sold abroad, as long as R&D need not be done in conjunction with large-scale output. Indeed, when Australian R&D has been successful, the innovations are often further developed and brought to market elsewhere. An example, discussed in detail below, is Sarich's technology for two-stroke engines, which was invented and developed in Australia but is now being marketed and produced in Detroit.

Another way in which Australia's small size may hinder R&D is if there are external economies of scale in the innovation process itself, due to positive spillovers between firms or research institutions. Technological advances in communications have made proximity perhaps less important than it used to be, but nonetheless, research institutions do still tend to locate near each other. Silicon Valley in California is the classic example, but others exist as well.[3] R&D could be less costly when there are lots of other firms or organisations doing similar R&D, due to sharing of information, or due to increased availability of well-trained researchers. If these sorts of spillovers are evident in the R&D process, Australia may be at a disadvantage compared to larger countries such as the US. Even though Australia has a relatively large population of well-trained research scientists, it does not have a large number of firms currently engaged in R&D. It may be caught in a "catch-22" situation: it can't be competitive in R&D because it doesn't do much R&D.

It is clear then that economies of scale will be a major issue in doing some types of R&D but not others. The aim of this paper is to help Australia identify the industries in which it could be successful in R&D and those in which it is disadvantaged. After a brief review of existing studies on Australian R&D, we present a simple model to illustrate the issues raised. We then examine three specific industries to show how economies of scale in R&D and in production can affect the ability of Australian firms to conduct R&D.

REVIEW OF THE LITERATURE

There has been a proliferation of papers on R&D and spillovers in the last decade. However, we know of none that examine the broader implications of economies of scale for R&D in a small economy. Grossman and Helpman suggested that economies of scale may play a role in determining the worldwide location of R&D activities, but they did not formally model this in the context of a small economy model.[4] Furthermore, there are no studies of the effects of economies of scale on Australian R&D. However, two recent Australian government reports discuss one type of economies of scale, namely, spillovers among R&D firms.

Table 1
International Comparisons

Country	*GERD/GDP (%)*[a] *1992*	*BERD/GDP (%)*[b] *1992*	*Researchers Per 10,000 labour force* *1991*
Sweden	3.11	2.14	56
United States	2.81	2.04	76[d]
Japan	2.80	2.06	75
Switzerland	2.68	1.88	40[d]
Germany	2.50	1.70	59[d]
France	2.40	1.51	52
Finland	2.18	1.24	55
United Kingdom	2.12	1.33	46[c]
South Korea	1.86[e]	1.38[e]	na
Netherlands	1.86	0.97	40[d]
Norway	1.76[h]	0.89[h]	63
Denmark	1.70[f]	1.00[f]	41
Chinese Taipei	1.69[e]	0.89[e]	na
Belgium	1.67[f]	1.11[f]	44[e]
Australia	**1.56**	**0.69**	**50[e]**
Canada	1.51	0.82	46[d]
Austria	1.53	0.80	25[d]
Italy	1.31	0.77	31
Ireland	1.07	0.67	58
Singapore	0.90[e]	0.49[e]	na
New Zealand	0.88[f]	0.28[f]	30[e]
Spain	0.85	0.47	25[e]
India	0.79[e]	0.18[e]	na
China	0.72[e]	0.19[e]	na
Average	1.76	1.06	36
OECD Average	1.91	1.18	46[i]

a gross expenditure on R&D as a percentage of GDP
b business expenditure on R&D as a percentage of GDP
c 1988
d 1989
e 1990
f 1991
g 1992
h 1993
i OECD median

Source: Industry Commission, *Research and Development,* Report No. 44, Australian Government Publishing Service, Canberra, May 1995, pp. 105, 111.

One of these studies was undertaken by the Bureau of Industry Economics.[5] Its aim was to clarify the spillover benefits of Australian R&D so as to make it easier to evaluate government R&D policies. It used case studies of sixteen Australian innovations. One interesting policy question was whether government R&D subsidies ought to be linked to domestic production of the resulting invention so that spillovers from production could be captured by domestic firms. The study did not find evidence that such a policy was warranted.

In 1993, the Industry Commission launched a study into R&D to understand the roles different sectors of the economy play in determining the level and composition of investment in R&D in Australia. The report, released in 1995, mentions the importance of market size and spillovers, but does not define precisely how an economy's size could influence the R&D decision. They suggest that the effect of spillovers may be conflicting — external economies of scale in R&D may allow each firm to benefit from the efforts of others and thus produce innovations more cheaply, but this may also imply an inability by the innovating firm to appropriate the full returns from an innovation and thus discourage R&D.

Much of the academic literature tries to identify the determinants of R&D in Australian industries. Gannicott finds that foreign ownership spurs R&D for high-tech firms, while government subsidies to R&D do not affect R&D.[6] He tests for economies of scale at the firm level, but does not find a significant relationship.

In a comparative study of R&D rates, Castles disaggregates R&D expenditure (as a percentage of GDP) into government effort, higher education and defence effort, and industry effort.[7] He finds that Australian government expenditures are relatively high, higher education expenditure only slightly below the OECD average, but that industry expenditures are "extraordinarily low by international standards". However, when he adjusts for Australia's population, wealth and percentage of exports in primary industries, he finds that Australia's R&D performance is to be expected for an economy of its size and structure. After adjusting R&D expenditures for population size and export emphasis, Castles suggests that market size and the level of manufacturing are important determinants of R&D, but his study does not explicitly consider economies of scale.

Lewis and Mangan discuss several possible reasons for Australia's low R&D, beginning with a lack of venture capital and a lack of innovative managers.[8] While there may be some truth in this, we are reluctant to accept the backwardness of Australian bankers and managers as the prime explanation for low R&D without also investigating market-based explanations. The other institutional factor suggested by Lewis and Mangan is that trade unions are reluctant to accept technological advances, discouraging R&D. Finally, they note that technology can be purchased abroad as a substitute for domestic R&D and that foreign multinationals producing in Australia do their R&D in their "home" countries, while there are few Australian multinationals to do R&D in Australia.

Lattimore provides a detailed comparison of Australia's R&D to that of other countries.[9] He makes two main points. The first is that Australian government policy towards R&D has been haphazard, and therefore unsuccessful. The second is that low levels of R&D need not imply technological inferiority, since new inventions and methods of production can be imported from other countries.

Most studies of Australian R&D examine the effects of government policy on the levels of R&D expenditure. However, few consider the feasibility of Australian R&D *per se*. Since there is so little previous work on how economies of scale impact R&D in small countries such as Australia, we present a systematic approach to the topic in the next section.

THE MODEL

This is a partial equilibrium model of industries. It provides a general framework for thinking about how economies of scale affect R&D in many different sorts of industries.

This model divides the world into two markets for every good: Australia and the Rest of the World (ROW). Each market has an exogenously-determined demand for every good. The key way in which Australia's size plays a role is by assuming that demand for each good is significantly lower in Australia than in the ROW.

Each industry can do two types of activities. First, an industry may engage in R&D. Second, an industry produces final goods. R&D and final goods production may be done in the same or different firms within the industry. Some firms may do R&D only, selling the results to other firms which produce only the final goods.

R&D

The nature of R&D may be to invent new products, known as *product innovation*, or to improve a production process, known as *process innovation*, and either can be accommodated in our framework. We do not attempt to model the creative process *per se*. In order to keep the model general enough to describe different kinds of R&D in different industries, the R&D process is described by a simple production function. We call the output from R&D activities a *blueprint.*

Firms undertaking R&D always run the risk that their efforts will be unsuccessful. However, we will not be formally modelling uncertainty in the R&D process, since it is tangential to our main focus. Instead, simply think of greater uncertainty in the R&D process as increasing the costs of producing a blueprint.

In this simplified approach, we will describe economies of scale in R&D in terms of how scale affects the average cost of producing a blueprint.[10] Let r_i denote this average cost, with $i = A$ or ROW representing the country. There are several levels at which economies of scale might be relevant. First, economies of scale may be important at the firm level. Larger firms may be better able to do R&D, because progress may be easier if there are many people working together. In considering the effect of Australia's size on its ability to do R&D, there are probably few industries for which Australia isn't large enough to support even one firm doing R&D. In this sense, economies of scale at the firm level are probably not a constraint on Australian R&D.

Second, there may be external economies of scale. This is when it is less costly for a firm to do R&D because there are lots of other firms also doing R&D in similar areas. This may be due to spillovers of information across firms, or due to having cheaper specialised labor. These spillovers may be hard to identify and detect, and yet may be significant. It is assumed that spillovers occur primarily within an industry rather than across different industries. External economies of scale could relate to domestic and/or world levels of R&D, depending on the industry and the type of research being done. We concentrate on the domestic case, since Australian policy is unlikely to be influential enough to affect worldwide levels of R&D, and so we write $r_i\,(B_i, f_i)$, where B_i is the rate of blueprint production, and f_i represents average factor prices.[11] The average cost of producing a blueprint is assumed to fall as the level of R&D being done in the domestic industry rises. The model assumes that there is a limit to the cost-reducing benefits of spillovers, however. Once the domestic industry reaches a threshold size, denoted $\overline{B}_i$, the average cost of producing a blueprint no longer declines.[12]

It will be helpful to think about the costs of producing a blueprint in two parts. The first part represents the costs of producing a blueprint if industry output exceeds $\overline{B}_i$, and it is defined as:

$$\overline{r}_i(f_i) \equiv r_i(\overline{B}_i, f_i).$$

We can think of $\overline{r}_i$ as a *base cost* of doing R&D when economies of scale have been completely exhausted. The second part is a *cost premium* due to producing less than $\overline{B}_i$, and it is defined:

$$\delta_i \equiv r_i\,(B_i, f_i) - \overline{r}_i \geq 0\,.$$

While Australia's level of R&D in this industry may or may not reach $\overline{B}_i$, it is assumed that the scale of R&D in the ROW is always large enough to exploit all of the spillover benefits in R&D. In other words we assume $\delta_{ROW} = 0$. Australia will be able to do R&D in a particular industry only if its costs are no higher than in the ROW, as in:

$$\overline{r}_A\,(f_A) + \delta_A \leq \overline{r_{ROW}}\,(f_{ROW}).$$

If Australia's R&D reaches the threshold level, then Australia's ability to do R&D in this industry will depend solely on its R&D factor prices relative to those in the ROW. However, if the level of Australian R&D in this industry is low, then Australian firms will be handicapped by higher costs that stem from having fewer spillover benefits. So it is possible that an Australian firm could have cheap R&D facilities and cheap scientists compared to world levels, and yet not be competitive at R&D because its researchers do not have enough contact with others working on similar problems.

Figure 1 provides a flow-chart which shows how to determine whether economies of scale prohibit Australian R&D in a particular industry. If Australian costs of doing R&D are higher than world costs, then Australia cannot be successful at R&D in this industry. Notice, however, that having cheaper R&D costs does not guarantee R&D success. In some cases it may be difficult to do R&D, especially process R&D, without access to a production facility. For example, it may be impossible at the later stages of development for a new process to be tested adequately in the laboratory.

The possibility that production is necessary for research means that economies of scale in production of final goods may limit Australia's ability to do R&D. For example, some technologies must be closely tailored to match the needs of a specific plant or group of consumers, and therefore the new technology cannot simply be sold — it must be developed in place. In addition to creative reasons for R&D to be done at a production facility, there may be other market conditions which make it difficult to simply "sell a blueprint". Also, there may be transactions costs involved in trading blueprints. If these are large enough then production firms must do their own R&D. We have chosen to simplify these problems by assuming either it is necessary to do R&D with an associated production facility or it is not. This link will be explored more below.

Consider the case when Australian R&D costs are competitive and R&D need *not* be done in conjunction with production. Then Australian R&D can be successful, but what does this mean? The blueprints produced in Australia may be used by the innovating firm or by the firms which purchase or license it. Note that the blueprint may be sold and used abroad. In fact, economies of scale in production of the final good may, in some cases, result in the blueprint being most valuable when used in the ROW. Selling the blueprint overseas does not mean that the R&D is wasted, since the innovating firm is compensated for its efforts.

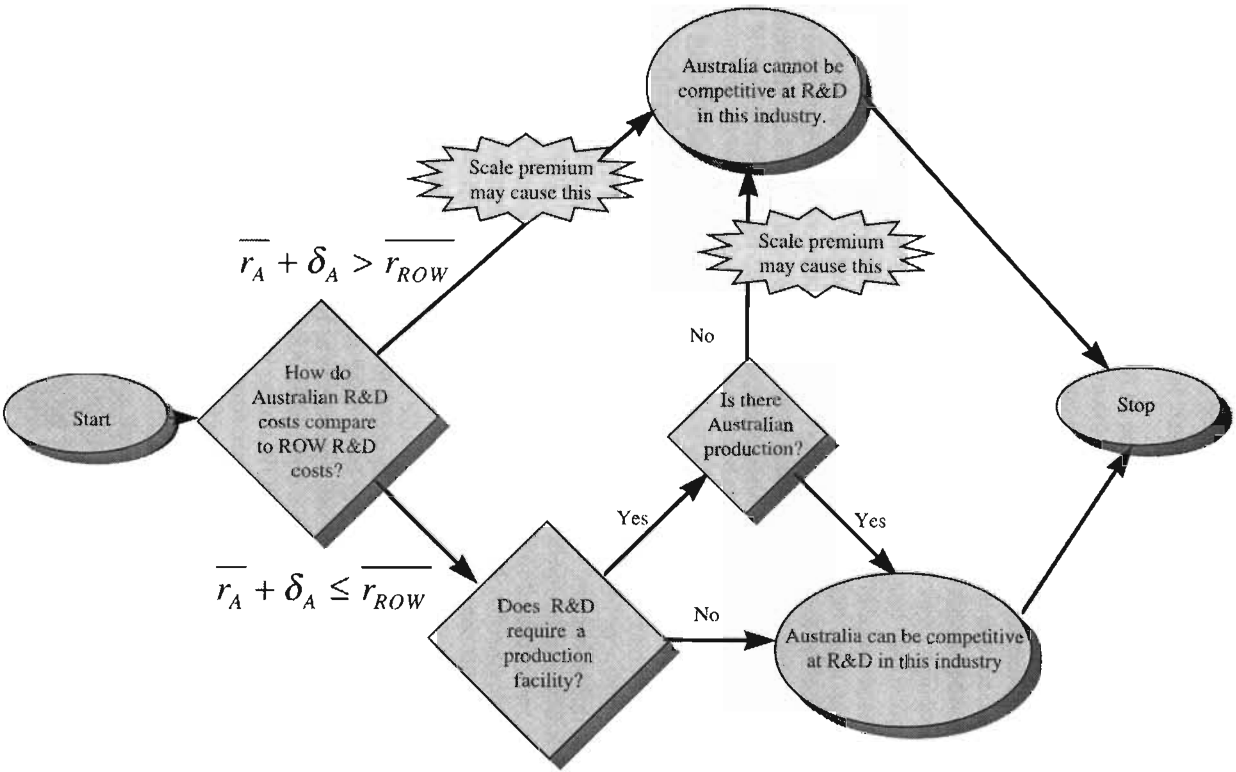
PRODUCTION OF THE FINAL GOOD

In addition to economies of scale for the R&D process, economies of scale in production of the final good might also be a factor in the ability to do R&D. As stated earlier, process R&D, especially, may be difficult to do without access to production facility. If that is the case, then Australia will be able to do this sort of R&D only if it can be competitive producing the final good.

Many factors determine whether or not Australia is competitive in a particular industry. First, average production costs for final goods, c_i, may be different in Australia than the ROW because of (a) different production functions, (b) different factor prices or (c) different scales of production. As with R&D, there may be economies of scale in the firm, industry, or world levels of production. We focus, however, on economies of scale at the firm level.[13] We assume that a firm's average cost of production falls with firm output, q_i, until some critical level of output, $\overline{q_i}$, is reached. Beyond this level, average production costs are constant.[14]

As with the costs of doing R&D, it is helpful to think about a firm's average cost of producing the final good as having two components: a *base cost*, $\overline{c_i}$, which is the average cost a firm would have if it could achieve economies of scale, and a *scale premium*, γ_i, which is added to base costs when the firm produces too little. These are defined as follows:

Figure 1
Australian R&D Competitiveness



$$\bar{c}_i \equiv c_i\,(\bar{q}_i\,, f_i)$$

$$\gamma_i \equiv c_i\,(q_i\,, f_i) - \bar{c}_i \geq 0$$

It is assumed that demand in the ROW is always large enough to have only base costs with no scale premium. However, Australian producers may face a scale premium in some industries. International trade in final goods may be affected by transportation costs or import barriers. The average cost of shipping a final good between Australia and the ROW is denoted by s. We summarise the effects of trade barriers, such as tariffs, by t_i, which is the average price premium on this industry's goods when imported into country i. An Australian firm will have lower costs as long as:

$$\bar{c}_A\,(f_A) + \gamma_A \leq \overline{c_{ROW}}\,(f_{ROW}) + s + t_A\,.$$

In the absence of barriers to imports and large transportation costs, an Australian producer must either be able to achieve economies of scale or have lower base costs than the ROW if it is going to be competitive with foreign imports. Import barriers or transportation costs drive a wedge between world and Australian prices, and so they might enable Australian producers to be successful even if they produce at a low scale.

Australia's small demand may lead to an industry having only a small number of firms, and this introduces the possibility that firms will be able to price over their economic costs. We have not attempted to model Australian industries as being monopolistic or oligopolistic, because to the extent that transport costs and barriers to import are low, Australian firms are forced to compete with firms from around the world, and so they will not be able to earn economic profits. Also, if Australian firms *are* insulated from foreign competition by transport costs or barriers to import, then this simply makes it more likely that they are able to produce, which is our foremost concern with respect to the ability of Australian firms to do R&D.

As long as there are low transport costs and no barriers to export, Australian firms need not be limited by the size of Australian demand, since they can achieve economies of scale through exporting to the ROW, provided they have competitive base costs. If Australia has lower base costs than the ROW, then low domestic demand will not disadvantage producers as long as there are no barriers to export. If Australia has higher base costs, then Australian producers will not be competitive with imports from the ROW unless import barriers and/or transportation costs are high enough to offset higher Australian base costs plus any scale premium. Australia will be able to export its final goods as long as:

$$\bar{c}_A\,(f_A) + s + t_{ROW} \leq \overline{c_{ROW}}\,(f_{ROW})\,.$$

Note that economies of scale in production of the final good will not stand in the way of R&D in many cases. First, it may not be necessary to do R&D in conjunction with production of the final good. Second, even if Australian demand for a product is insufficient to achieve economies of scale, Australia may be able to export the good in order to reach them. Third, even if Australia does not have a comparative advantage in producing the final good, it may still be able to do R&D

and export blueprints to the ROW, where production will occur. The following section presents case studies which illustrate some of these possibilities.

CASE STUDIES

AUTOMOTIVE AND SMALL ENGINES

Since car manufacturing is characterised by economies of scale, and Australia is a small country which doesn't export many cars, it might seem unlikely that R&D on car engines would be successful in Australia. History has shown that it is possible, however.

In 1970 Ralph Sarich began work in Perth on inventing a new type of automotive engine. By 1972 he had succeeded in designing a radically different engine, which he called "the orbital engine". BHP became a financial backer, and with additional assistance from the Federal and Western Australian governments, he began marketing his invention to the world's largest car manufacturers. Sarich faced resistance from the car makers, in large part owing to the massive costs of entirely retooling factories to produce his engines. Recognising that the new engine design would never be mass-produced, the company decided to focus on developing the novel combustion system which had been developed originally for the first orbital engine. It was able to adapt a two-stream fuel-injection system for use on a two-cycle engine, which is commonly used on smaller equipment such as motorboats, lawn mowers, and motorcycles. Sarich's innovation made two-cycles practical for use on automobiles. Outboard Marine and Brunswick Corporation, both major manufacturers of marine engines, signed license agreements in 1986 and 1987. Eventually Detroit was willing to listen. Ford signed its license agreement with Orbital Engine Company (OEC) in 1988, with GM following in 1989.

Today, Sarich is no longer associated with the company. OEC has not yet seen its technology mass produced for cars, but Mercury Marine has announced plans to manufacture engines using Orbital technology. The firm maintains a research and production facility in Perth, continuing R&D on fuel-injection systems, emissions control systems, and other automotive technology. It also has production facilities in Michigan, which will be supplying some of the parts for the Mercury Marine engines. It has already earned $US160 million from licensing agreements.[15] The largest part of the payoff from research is expected to come from future royalties as mass production begins.

One might be tempted to predict that automotive R&D cannot be done in Australia, since Australia has a small domestic market and does not export much, and since Australian production does not achieve economies of scale. In fact, in the absence of protectionist barriers to trade and transportation costs, the Australian car industry would probably be even smaller than it is today.[16] What made the difference in this case is (1) the R&D could be done separately from a production line, and (2) it wasn't necessary to share ideas in order to be successful. Indeed, with hindsight it seems that isolation from other researchers may have resulted in increased ingenuity. Even though economies of scale were binding in terms of production of the engines, economies of scale or spillovers were not necessary to do the research. This case illustrates that having a relatively small market need not be a barrier to Australian R&D in manufacturing.

MINING

Consider features of the mining industry in terms of our model. Initial research into mining and processing minerals need not be done near a mine, although later development and testing must be. In addition, mining and refining minerals are characterised by economies of scale. In terms of these features, the mining industry resembles the automotive industry. One key difference, however, is that geology dictates comparative advantage in mining. Australia is lucky in this respect, and is currently mining copper, zinc, iron, and other minerals for export. The model then predicts that while Australia will export minerals, it may import or export mining blueprints, depending on the cost of doing R&D in Australia versus the ROW. Furthermore, we would predict that Australia will be more competitive in R&D near the final stages of production of the blueprint, when access to mines and refineries is more important.

In several cases, Australia has been successful at mining R&D. One example is Intec Pty Ltd., which has developed a new low-temperature method of refining copper. The advantage of this method is that construction of this type of smelter costs significantly less than existing technology and the smelting itself does not produce air-polluting sulphur dioxide emissions. A consortium of mostly foreign-owned, international mining companies has formed Intec Copper to fund a pilot plant for ongoing research, which is now in operation in Chatswood, New South Wales. The formation of the consortium is evidence that there are economies of scale in this kind of R&D, since otherwise there would be no incentive to cooperate. This cooperative arrangement has enabled Australia to achieve economies of scale and, in effect, export the blueprint for the new smelting process.

CRA has also had success with mining R&D, some being done in Australia and some elsewhere. It is currently running a pilot zinc processing plant near the Century Zinc deposit in north-west Queensland to test its zinc flowsheet technology, which reduces mined zinc to unusually small particles before using flotation to separate impurities from zinc. The research for this new technology has been done entirely in Australia.

In a separate project, CRA has been developing a new iron smelting technology in Western Australia called HIsmelt. The process uses fine iron ore and coal as an alternative to the blast furnace which requires lump ore, sinter and coke. Research for this technology was originally undertaken in a joint venture with Klöckner Werke in Germany, then continued in Australia as a joint venture with MIDREX of USA and now wholly developed by RTZ CRA. CSRIO has played a key role in the leading edge research behind the HIsmelt process. This is a case of importing the early stages of the R&D while doing the later stages in Australia. Given successful development, the HIsmelt technology has potential applications world wide. This case resembles the Orbital Engine Company with the direction of trade reversed — Australia imported the blueprint and exported the final good.

In the case of mining, nature has cooperated by giving Australia a comparative advantage. In the case of CRA's HIsmelt iron smelting process, Australia has pursued the development of a technology which makes good use of its natural resources. But many types of mining R&D could be done anywhere in the world. In the case of Intec Copper and CRA's zinc flowsheet technology, the research has been done completely in Australia, suggesting that Australia can be competitive at all stages of R&D in this industry.

PHARMACEUTICALS

Innovation in the pharmaceutical industry requires substantial investment in R&D. Furthermore, there are some special characteristics of the industry that set it apart from other industries that rely on ongoing innovation. The development phase is likely to be much longer than, say, electronics or software design, due to the lengthy testing required before a new product is allowed to be put on the market.[17] This testing process has also increased over time as governments have increased their safety standards and required greater evidence of effectiveness, which makes the development stage quite expensive.[18]

Given the large expenditures required and the uncertainty associated with the success of each venture, firms engaged in pharmaceutical R&D would therefore like to spread their fixed costs of R&D over as large a market as possible. The small size of the Australian market means that it is unlikely that a company would be able to recover development costs if they were to rely on sales in the domestic market alone. If a firm could export its product, though, the small market would not prohibit local development of new drugs. However, most domestic pharmaceutical or biotechnology firms do not have the extensive marketing, distribution and retailing networks that the large multinationals have. In order for a local firm to take advantage of the global market, it may have to form some sort of association with a multinational which has well-established networks in place.

Australia does have a natural advantage in the early stages of the R&D process, however, because of the relatively large number of highly trained researchers in the field of biotechnology and chemistry. Furthermore, Australian universities and research institutions have a strong foundation in basic research and clinical trials, there is an internationally recognised medical infrastructure here and government support for R&D in the pharmaceutical industry is well-established. There is also a high degree of cooperation amongst researchers in this area via collaborative research projects between companies, CSIRO and the universities.[19] These arrangements give the (often small) companies access to research facilities and staff that would otherwise be beyond their capabilities and allows them to share in the knowledge base of these institutions. This level of cooperation suggests that knowledge spillovers or external economies of scale could be quite significant in the Australian pharmaceutical industry.

Given that economies of scale seem to be important in both the R&D process and in the downstream activities of marketing and distribution in pharmaceuticals (but not necessarily in the *production* of pharmaceuticals), it might be expected that products such as new base compounds, drugs or treatment delivery systems might be developed by local firms within Australia, but produced and distributed with the aid of larger multinationals that are not necessarily based in Australia. The following two cases fit this pattern.

The development of an anti-influenza vaccine (code-named GG167) is a classic example of the sort of collaborative research described above. Its development began in 1978 when a CSIRO scientist, Peter Colman, and Graeme Laver of the Australian National University began investigating the structure of the flu virus. This research led to the identification of a common structure contained within an enzyme in all flu viruses. On the basis of this work, Biota Holdings, a medical research group, funded a group at the Victorian College of Pharmacy to develop a compound that would block the enzyme containing the common structure and thus prevent the spread of new virus particles. Biota initially received support from the Industry Research & Development Board which allowed it to test the compound in Australia, the UK and the US, but then licensed the international rights to GG167 to Glaxo Wellcome Plc., a large British multinational, in order to proceed to the stage of clinical trials. Glaxo's international distribution network can be used when the product is brought to market. Biota owns all intellectual property from the research, but Glaxo owns the rights to develop the drug globally.

External economies or spillovers in the R&D process were clearly significant in this case. Several different organisations were involved in the development of the anti-flu compound. Government funding enabled Biota to do the initial testing to see if it was effective at blocking the spread of the flu virus. (Support from the IR&D Board helped Biota get started on its project.) However, since Biota is a research firm without manufacturing, marketing, distribution or retailing capabilities, it had to rely on the expertise of a multinational for the final stages of product development and sale.

Was this R&D successful? When it announced the success of the initial (northern hemisphere) trials, its shares climbed 10% in one day. It had cash reserves of $19 million and was looking for new medical research projects.[20] Biota will continue to receive royalties once the drug is on the market. By any measure, this would have to be judged a success, even if the drug is ultimately not manufactured here.

Another recent drug development that shows a similar pattern of collaborative research and reliance on a multinational firm for marketing and distribution is the oral slow-release morphine capsule, Kapanol, for use by terminal cancer patients and for severe arthritis. The innovation here was not in the discovery of the compound, morphine, which has been around for thousands of years, but in the treatment-delivery system. Doctors at the Pain Management Unit of Flinders Medical Centre wanted a more effective pain control system for their patients. They knew that morphine was one of the strongest pain-killers available, but it breaks down in the body too quickly. The only way to maintain the level of pain relief was to have round-the-clock administering of the drug, either in oral form or through self-administered drips. This was possible in hospital, but it was too expensive for home care patients. F.H. Faulding & Co. Ltd. had developed an expertise at slow-release drug delivery systems. It already had a sustained-release asthma drug on the market. The innovation was in the use of a polymer coating over tiny pellets that allowed precise control over when the drug is released into the bloodstream. The coating used for the asthma drug had to be adapted for use with morphine because morphine dissolves more quickly. After some time in the lab, prototypes were developed and trials were held.

Like Biota, Faulding lacked an international marketing or distribution system. Faulding needed a partner with such a network already in place. It chose Glaxo Wellcome, because it was willing to allow the product to be produced within Australia. So, unlike Biota, Faulding will manufacture the drug in Australia for all export markets except Japan and the US. Australian-grown poppies will be used for the production of the morphine.

The *Sydney Morning Herald* summed up the process of bringing Kapanol to the market thus:

> The story of Kapanol's successful development suggests that business and university science are, at last, beginning to network for their mutual benefit. The historic gulf in Australia between the white-coated scientist and the grey-suited businessman is being bridged, despite the different motives and work cultures of each party. As well, it seems local business has learnt how to do deals with the big multinationals without losing control over the product and the money it makes.[21]

The collaborative effort between an Australian pharmaceutical company with an established expertise in a drug delivery system and an Australian university-based research team with a worldwide reputation for research into pain control was crucial in the development of Kapanol. Neither group on its own had the knowledge necessary to solve this particular problem, but the spillovers evident in the joint work indicate that Australia does have a sufficient research base to be successful in the right arena. Again, partnership with a large multinational pharmaceutical company provided the access to the economies of scale necessary for successful distribution and marketing.

Three lessons emerge from the pharmaceutical cases examined. Australia does have a network of private sector and university or government scientists and researchers large enough to take advantage of economies of scale in the R&D process in the area of biotechnology. Secondly, one way for local firms to be successful is through the formation of joint ventures or partnerships with each other or with multinationals in order to spread the costs of development (and the risks) and to access the distribution and marketing networks of the multinationals. The third lesson is that the government can play a role in encouraging R&D effort. Without it, Glaxo might not have become involved in either project.

CONCLUSION

Much has been made of the comparatively low levels of industrial R&D being done in Australia. This paper asked whether Australia might be limited in its R&D opportunities because of its small size.

First, we considered external economies of scale in the R&D process itself. Having a small economy might limit R&D for this reason, and yet we saw that the pharmaceuticals industry, characterised by such spillovers, nonetheless has been able to do R&D. So it seems that there is enough R&D being done in the pharmaceuticals industry to be competitive. Other sectors may not be so lucky. In particular, it may be difficult to initiate R&D in industries in which there is currently little being done domestically. Australia will be better able to exploit R&D spillovers if its resources are not spread too thinly across many industries. Because of this, there may be a role for the government to facilitate cooperation among firms, ensuring that no opportunities for beneficial spillovers are lost. The research being done through CSIRO is an example of how the government can coordinate R&D activities.

We also predicted that Australia may be precluded from doing some R&D if there are economies of scale in the production process and if R&D must be done in conjunction with production. Australian firms can partially overcome this difficulty by doing those early stages of R&D that can be done independently from production, and then exporting the blueprints needed to continue with final development of the product. The Orbital Engine Company is an example of this case. Even though Australian car makers do not achieve economies of scale, it is still possible to do basic automotive research in Australia. In an interesting reversal, Australia is able to achieve economies of scale in mining and is therefore able to complete mining R&D begun elsewhere, in addition to conducting start-to-finish projects.

Some Australian industries may be small enough that doing R&D is uneconomical even with full cooperation among firms, especially if competing foreign firms enjoy large positive R&D spillovers from their nearer neighbours. It is tempting to use government policy to correct this disadvantage, on the grounds of fairness. However, it must be remembered that the opportunity costs of doing the R&D in Australia cannot be lessened through government intervention in this case. It would be less costly to obtain the new technology by either buying a blueprint to use in Australian production, or by importing the final good.

Turning the tables around, some Australian innovations will naturally end up being produced elsewhere, either because of economies of scale or a comparative disadvantage in production of the good. Selling blueprints abroad does not mean that the R&D is a failure—it merely means that the final good can be produced more cheaply overseas than at home. Government efforts to ensure that a good is produced in Australia only because it was invented here are as wasteful as refusing to allow a good to be produced in Australia only because it was not invented here. Why produce technology domestically when it could be imported more at a lower opportunity cost?

In sum, Adam Smith's advice on international trade in goods and services can be applied equally well to blueprints:

> It is the maxim of every prudent master of a family never to attempt to make at home what it will cost him more to make than to buy. . . . What is prudence in the conduct of every private family can scarce be folly in that of a great kingdom.[22]

NOTES AND REFERENCES:

1 Among other issues, the Jessop Report suggested that firms could recapture their R&D expenditures through export or licensing. (See pp. 106-107.) They provide examples of Australian technologies that were developed into products overseas. (See p. 228.) Senate Standing Committee on Science and the Environment, *Industrial Research and Development in Australia*, Australian Government Publishing Service, Canberra, 1979.

2 Robert Gregory, 'The Australian Innovation System' in R.R. Nelson (ed.), *National Innovation Systems: A Comparative Analysis*, Oxford University Press, New York, 1993.

3 The fact that governments think these spillovers exist and are significant is evidenced by the attempt to establish the Multifunction Polis near Adelaide. The basic idea was that the State and Federal governments would contribute to funding to build a "technology city" which would include various research organisations as well as manufacturing facilities. It was thought that this would give Australia a leading edge in innovation and production in the high technology area.

4 Gene Grossman and Elhanan Helpman, *Innovation and Growth in the Global Economy*, MIT Press, Cambridge, Massachusetts and London, England, 1991.

5 Bureau of Industry Economics, *Beyond the Innovator: Spillovers from Australian Industrial R&D*, Australian Government Publishing Service, Canberra, 1994.

6 Kenneth Gannicott, 'The determinants of industrial R&D in Australia', *Economic Record, 60(170)*, 1984, pp. 231-35.

7 Francis Castles, 'An ABC of R&D: Is Australia's record as black as it has been painted?', *Australian Quarterly*, Autumn, 1989.

8 Donald Lewis and John Mangan. 'Research and development in Australia: The role of multinational corporations', *Prometheus, 5(2)*, 1987, pp. 368-85.

9 Ralph Lattimore, 'Research and Development: Hidden investment in Australian industry', in C. Hamilton (ed.), *The Economic Dynamics of Australian Industry*, Allen & Unwin, Sydney, 1991.

10 By "average cost" we mean the opportunity cost of undertaking R&D, that is, the alternative uses for the resources that must be expended on R&D.

11 More formally, f_i can be thought of as a vector of the relevant factor prices.

12 In mathematical terms, $\partial r_i / \partial B_i < 0, 0 \leq B_i < \bar{B}_i$ and $\partial r_i / \partial B_i = 0, \bar{B}_i \leq B_i$.

13 This is not crucial to the analysis that follows. As will be clear later, the cost premium for operating at a low scale could be interpreted as coming from a low scale of firm or industry output.

14 So $\partial c_i / \partial q_i < 0, 0 \leq q_i < \bar{q}_i$ and $\partial c_i / \partial q_i = 0, \bar{q}_i \leq q_i$.

15 *Australian Financial Review*, 'Patience Wears Thin for Investors', September 14, 1995, p. 27.

16 Industry Commission, *The Automotive Industry*, Report No. 5, Australian Government Publication Service, Canberra, December 1990.

17 S.W.F. Omta *et al.* state that from the 1960s to the 1990s, the period between finding the lead compound (a chemical compound with assumed therapeutic effectiveness) to the introduction of the product onto the market lengthened from 5 years on average to more than ten. S.W.F. Omta, 'Managing industrial pharmaceutical R&D: A comparative study of management control and innovation effective in European and Anglo-American companies', *R&D Management Journal, 24(4)*, 1994, pp. 303-315.

18 Estimates of expenditure required to bring a new product from discovery of a new compound through to marketing is in the range of US$150-300 million in 1990, compared with US$10-24 million in the early 1960s. Bureau of Industry Economics, *The Pharmaceutical Industry: Impediments and Opportunities*, Australian Government Publication Service, Canberra, 1991.

19 The Federal Government has recognised the importance of encouraging cooperative research efforts. There are specific provisions in the Competitive Grants for Research and Development scheme aimed at encouraging joint work.

20 *The Australian*, 17 June, 1995, p. 39.

21 *Sydney Morning Herald*, 26 July, 1995, p. 15.

22 Adam Smith, *An Inquiry Into the Nature and Causes of The Wealth of Nations*, Clarendon Press, Oxford, 1776, [edition published 1847], pp. 424-426.