EMERGING BIOTECHNOLOGIES: SOME ECONOMIC IMPLICATIONS FOR AGRICULTURE AND TECHNOLOGY POLICY

B. G. Johnston, B. S. Wonder and W. Gerardi

Biotechnology is one of a number of technologies that may improve productivity and competitiveness in the rural and non-rural industries. As in other areas of research in Australia, the biotechnology research program will be undertaken by both the private and public sectors. Determination of an economically efficient balance between private and public research activities has often been made by reference to the market failure model. The principal characteristics of that model (namely indivisibility, inappropriability and uncertainty) suggest several reasons why governments may wish to consider supplementing the research effort undertaken by the private sector. To establish socially optimal levels of public expenditure on biotechnology research and development, and the priorities for such expenditure, it is necessary to go beyond the market failure model and use an explicit cost-benefit framework. Such a framework is developed and the main economic variables likely to affect net social returns to investment in biotechnology research and development are identified. These variables are compared with the funding criteria employed by the National Biotechnology Program Research Grants Advisory Committee and it is concluded that considerable scope exists for injecting additional economic analysis into the assessment procedures currently used by that Committee.

Keywords: biotechnology, technology policy, research funding, market failure, research priorities

INTRODUCTION

Biotechnology has been defined by the Australian Science and Technology Council as "the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services".[1] Within this definition, there is a range of industrial techniques, many of which are not new (for example, brewing, wine making and baking) that could be classified as biotechnology. A more specific definition of biotechnology is provided by CSIRO:

> Industrial processes based on biological systems involving naturally occurring micro-organisms, micro-organisms that have been modified by

> genetic engineering, or isolated cells of plants or animals, and the genetic manipulation of cells to produce new strains of plants or animals.[2]

Regardless of the definition chosen, there is, from an economic perspective, one common point of interest: the fact that the undertaking and results of biotechnology research are oriented toward the market provision of goods and services. Consequently, an evaluation of the alternative opportunities for biotechnology research can be conducted within an economic framework which is concerned with maximising the net social returns from the production of biotechnology goods and services.

From an agricultural economic perspective, biotechnology research and development is of interest because of the potential scope it offers for productivity improvements in the rural sector. With the historic downward trend in farmers' terms of trade expected to continue in the longer term, new sources of productivity improvements will be required to maintain the profitability of the farm sector.[3] An examination of current local and overseas research work in the biotechnical field (as listed in Appendices A and B) would suggest that biotechnological innovations could be a major source of such productivity improvements. Biotechnological innovations could improve productivity either by reducing on-farm costs (for example, defleecing by biotechnological methods) or by directly raising output at the farm level (for example, growth hormones for improved animal production).

It should be understood, however, that biotechnology research and development in agriculture and other fields is being undertaken in many countries and, for this reason, Australia's efforts in this area must be selective. A key issue, therefore, is the determination of Australian expenditure on biotechnology research and development and priorities for that expenditure. The focus in this paper is the usefulness of economic models for the purpose of addressing such issues. Attention is focused initially on the market failure model and its compatibility with biotechnology policies in place in Australia and overseas. It is suggested that, while the model provides useful insights into the role for governments in research and development markets, it is inadequate as a basis for assessing the suitability of alternative policy strategies. It is subsequently suggested that a cost-benefit framework is a necessary adjunct to the market failure model if research and development policies and priorities are to be addressed in economic terms. The committee responsible for allocating funds made available under the recently introduced National Biotechnology Grants Scheme has developed a research priority framework for guiding decisions on the allocation of research grants. Its research priority framework is compared with an explicit cost-benefit alternative.

THE MARKET FAILURE MODEL AND BIOTECHNOLOGY RESEARCH AND DEVELOPMENT

Research is the process of discovering new knowledge. This process of discovery can occur at a number of levels, depending on the purpose for which the research is being undertaken. Basic research is undertaken to acquire new knowledge, without any particular application in view. Strategic research is undertaken to acquire new knowledge in broad, specified areas, to provide the basis for solving particular problems. Applied research is undertaken to acquire new knowledge with a particular application in view. Developmental research is undertaken to transform an invention (the creation of a new idea) into an innovation (a commercially viable new product or process based on the new idea).

The case for market failure in relation to basic research was first made by Nelson, who argued that governments must subsidise such research because private firms are unable to retain the commercial benefits of investment in its production.[4] The case for market failure in research and development was subsequently extended by Arrow, who argued that new knowledge possesses three characteristics, namely, indivisibility, inappropriability and uncertainty.[5] When taken together in the absence of public intervention, these preclude the market from providing socially optimal levels of research and development. Indivisibilities arise in research because of the scale of investment needed to produce viable new technologies. The level of resources required, so the argument goes, may simply be beyond the resources of any individual firm. Inappropriability refers to the inability of any individual firm to capture a sufficient proportion of the commercial benefits of its research to justify investment in that research. The leakage of benefits to other firms or to the wider community through externalities provides less incentive for the firm to invest in new knowledge than may be warranted from the viewpoint of society. Uncertainty refers to the risky nature of perceived research and development benefits and may be another factor responsible, Arrow suggests, for less than socially desirable levels of investment in this field.

Since Nelson and Arrow first formulated their ideas on market failure associated with research, there has been a continuing debate on the usefulness of the model for the purpose of devising policies consistent with the goal of a socially optimal level of research and development. Demsetz made a significant contribution to the debate, arguing that Arrow was guilty of a 'Nirvana' approach to the public intervention.[6] That is, Demsetz suggested, Arrow had focused on the benefits of intervention but had failed to consider the costs. More recent debate has developed Demsetz's thoughts on the costs of

intervention, particularly the ease with which Nelson's and Arrow's arguments can be employed as a basis for a governmental role in research and development.

The indivisibility criterion put forward by Arrow is particularly relevant to biotechnology research in agriculture. The rural sector is characterised by a large number of family farms which lack the substantial resources required for such research. This is not to suggest, of course, that governments should therefore provide the resources necessary to undertake such research. It does, however, raise the question of whether intervention, in the form of taxes and/or levies on production, may be appropriate for the purpose of funding large-scale biotechnology projects. Such a response is unlikely to be worthwhile, given the presence in Australia and overseas of research firms sufficiently large to undertake and market a range of research projects of interest to the farming community. Furthermore, there are other institutional facilities, such as the share market, which provide the opportunity to spread the costs of biotechnology research and development over a large number of farmers.

The uncertainty criterion for government intervention in agriculture has been raised in several contexts, including the effects of output and price variability on investment and input demand, and the use of price support mechanisms (such as underwriting) to encourage supply of rural products in risky environments where producers may be risk averse. The uncertainty argument for government intervention in research is similar to the following agricultural example. A risk averse firm will value a portfolio of research projects (where commercial payoffs are uncertain and highly variable) at less than its expected profitability. Consequently, it underinvests in such research. Since society as a whole is presumed to be neutral to risk, proponents of the uncertainty argument for intervention conclude that governments should supplement the market's contribution to research activity.

The strength of the risk and uncertainty argument for government support of research and other risky activities has been challenged by a number of authors, including Demsetz, who concluded that risk reduction is an economic good, which must be incorporated into the notion of efficiency. More recently, the Industries Assistance Commission has suggested that the decision by participants in the market not to undertake a particular research project reflects their lack of confidence in the likely success of that project, and a preference for investment of scarce resources in more certain and more productive alternative research and competing activities.[7] Moreover, society as a whole may not be significantly less risk averse than its individual members, who have several options available for coping with the risks they face.[8] Nevertheless, the IAC has suggested that intervention to assist producers to undertake risk management

more effectively may be justified, and has identified several policy instruments, including the development of additional options in the capital, insurance and futures markets, as possible responses.[9]

Of the market failure criteria, it is the inappropriability criterion that seems to have gained widest acceptance as a basis for government involvement in research and development. Indeed, Gannicott has argued that one reason why so few Australian economists have taken an interest in CSIRO and other public laboratories is that such organisations seem an entirely appropriate means of overcoming the supposed reluctance of private firms to invest in basic research, because of the freely available nature of their research results to those who have not shared in the cost of production.[10]

In the case of policies relating to biotechnology research and development, many of the Government's measures can be rationalised on the basis of the inappropriability criterion. In fact, the Australian Scientific and Technology Council has noted that biotechnology research relevant to the rural sector (the sector in ASTEC's opinion most likely to benefit from biotechnology) is unlikely to be undertaken by Australian companies, who cannot appropriate sufficient commercial benefit from their research.[11] As a result, the Council recommended a program of substantial biotechnology grants, which the government has since introduced in the form of the National Biotechnology Program Research Grants Scheme. The objective of the scheme is to support programs undertaken in universities and commercial organisations (particularly in areas where there is scope for collaboration between research institutions and industry) which have relevance to a wide range of primary and secondary industries. For 1983-84, the Government allocated $0.75m for the scheme. This has been increased to $2.17m for 1984-85.

In addition to the National Biotechnology Program Research Grants Scheme, several other government initiatives intended to stimulate the level of biotechnology research are consistent with the inappropriability criterion. The measures (and their respective 1983-84 budget appropriations) include:

- $7.8m for biotechnology-related projects in CSIRO;
- $2.5m to extend the Australian Industrial Research and Development Incentives Scheme to encompass biotechnology projects. This scheme will be able to commit additional sums to biotechnology industrial projects as appropriate;
- $400,000 for biotechnology research at the Howard Florey Institute of Experimental Physiology and Medicine at the University of Melbourne.

Altogether, the 1983-84 budget appropriations for biotechnology programs amounted to some $11.45m.

Apart from these government initiatives, based on the inappropriability criterion, there are other measures, such as the recently-introduced venture capital arrangements for management and investment companies, which can be related to the market failure model. This measure enables licensed companies to claim full tax deductions on investments in approved high technology businesses and could be classified as a response to the risk and uncertainty arguments discussed earlier. The investment companies will now provide funds for high technology research projects (including biotechnological projects) that might not previously have received funds because of their riskiness. Similar policies are in place overseas, though, as in Australia, the dominant form of government support for biotechnology research and development is a system of subsidies, comprising grants and taxation concessions on capital expenditure in research and development.

Although the market failure model provides significant insight into the economic reasons why governments may be justified in supporting research and development, it says little about socially appropriate levels of public expenditure and priorities for basic, strategic and applied research activities. This point is well illustrated by Gannicott, who has argued that the importance given, in the market failure model, to basic research, due to its non-appropriable public good characteristics, turns out to be insufficient to conclude that such research should be supported by public funding.[12] Rather, any evaluation of public funding of basic research will have to include the fact that basic research results become international collective property and acknowledge the substantial evidence that basic research is frequently not the precursor of innovation.[13] Of course, Gannicott's property right argument stems from the global nature of the market failure model (i.e. it does not consider leakage of benefits in the context of information flows between countries) and the inapplicability of patents to new basic knowledge documented in the scientific literature. Even for research results from the strategic and applied end of the research spectrum (for example, a new wheat variety or a new method for controlling sheep diseases), there is some evidence to suggest that patents may not significantly stimulate research activity.[14] The problem with patents is that they are costly to administer, can be legally challenged (resulting in substantial litigation costs) and can be used as a weapon for anti-competitive behaviour. By conferring on a firm a monopoly on the use of information embodied in the patent specification, social costs are automatically generated through the restricted use of the information by other firms or individuals. In the case of biotechnology research and development, there is already considerable evidence to suggest that patents may not be a very effective method of allocating legal rights to inventions. The

process of registering a patent involves full disclosure of the invention to be patented; in a rapidly changing area like biotechnology, such disclosure can be a disincentive to patent since it provides an opportunity for a close competitor to use the disclosed information to develop a slightly modified organism or process that can also be patented or, at least, used to circumvent the patent protection afforded the original development. It has been suggested that the fortunes of the leading overseas biotechnology companies will be determined in the courtrooms and hearing rooms of United States and European patent offices.[15] Many expect patent disputes in biotechnology to take years to resolve and to cost millions of dollars in legal fees. It is concluded, therefore, the patents may not be an effective mechanism for allowing firms to appropriate sufficient commercial benefits from their inventions. Hence, the appropriability problem may remain.

While the market failure model provides useful insights into the reasons why governments intervene to support research and development, it provides little guidance on which projects to support. To achieve the latter objective, it is necessary to go beyond the market failure model and develop a framework which can provide an assessment of the social benefits and costs which stem from intervention. To evaluate support by Australian governments of biotechnology research, such an assessment must capture the significance of the traded goods sector and the range of variables which will affect social returns to alternative policy strategies (for example, grants, taxation concessions and loans).

BEYOND THE MARKET FAILURE MODEL

It is likely that the Australian government will continue to rely on a mixture of instruments to stimulate research activity — direct grants to public research organisations, general industrial research incentives through the Australian Industrial Research and Development Incentives Scheme, specific grants to high priority fields such as biotechnology, and selective financial market instruments, such as the venture capital scheme. For all these measures, the same criterion of economic efficiency applies — the maximisation of net social benefit to Australia. This requires the balancing of the social benefits generated by intervention for research and development against the social costs of the intervention. For direct granting schemes, such as the National Biotechnology Program Research Grants Scheme, funds are being directed into 'high priority' biotechnology research and development in an attempt to encourage joint programs between public and private researchers, with a view to encouraging the commercialisation of biotechnology applications here in Australia.

Thus, the emphasis is clearly on picking those biotechnology inventions with good prospects for becoming Australian innovations.

To maximise economic gains from research and development effort, this strategy makes good sense. If research stimulated by the Biotechnology Research Grants Scheme leads to new inventions with potential application for Australian industry, then the chances of the invention becoming an innovation in Australia are that much greater. Where inventions have their greatest potential in international markets, Australian companies are less likely to have the financial resources or marketing skills to exploit these markets successfully. Licensing of the invention to overseas companies will be necessary and the technology will be transferred overseas. Where the technology is of direct benefit to our competitors, Australia can actually lose from inventions generated by indigenous research and development.

The Edwards-Freebairn framework for setting priorities

Edwards and Freebairn, in a paper prepared for the now disbanded Commonwealth Council for Rural Research and Extension, outlined an economic framework for quantifying the market benefits flowing from investment in research and development.[16] In their model, Edwards and Freebairn conceptualised the gains from research in terms of effects on commodity supply curves. Subsequently, Edwards included the effects of research on the demand curve.[17] The resultant change in supply or demand of the commodity, arising from the adoption of the findings of research and development, led to changes in producer and consumer surplus, both in Australia and overseas. The net gain in economic surplus accruing to Australians from these changes in supply or demand is identified as the social benefit of the research program. The model has been applied to evaluating the social gains from serated tussock control in New South Wales.[18]

Edwards and Freebairn were able to put forward a quantitative framework for evaluating these benefits and thus to identify the important variables affecting the economic payoff. This framework has subsequently been extended by Johnston to include externalities and the social costs of undertaking the research.[19] McLeish and Wonder have applied this extended framework to a set of plant pathology research projects in CSIRO.[20]

In the Edwards-Freebairn model, it is important to distinguish between traded and non-traded goods. Traded goods (exports or imports) enter international trade (for example, wheat), while non-traded goods do not (for example, fresh vegetables). For non-traded goods that are produced and consumed locally, the important determinants of research gains are the size of the industry, its growth prospects and the extent of the reduction in costs induced by the research when implemented. In contrast to what might be expected,

the slopes of the supply and demand curves do not have a large impact on the gross gains from research.

For goods that are traded (the vast bulk of agricultural products), it is necessary to obtain further information to estimate research gains. The reasons for this are twofold. First, for traded goods, the outward movement of the Australian supply curve induced by research can have price effects, which in turn affect the proportion of benefits captured by Australian producers and consumers, compared with overseas producers and consumers. Second, research undertaken in Australia may be adopted by overseas producers, thereby affecting the extent to which Australia retains the benefits of its research efforts. For traded goods, the most important factors affecting the gross gains from research are the size of the industry, its growth prospects, the extent of the reduction in costs (as with non-traded goods) and also the export elasticity of demand and the transferability of the research results overseas.

When research into an export industry has no applicability overseas, Australians will gain more the greater the responsiveness of foreign demand for Australian exports to price changes. The responsiveness to price variations of foreign demand for Australia's exports increases as Australia's share of the world trade decreases, world demand becomes more responsive to changes in price, and supply in the rest of the world becomes less responsive to changes in price.

The question of technology transfer between countries is a difficult and complex issue. In general, however, Australia benefits most from research designed to overcome problems specific to Australia's export industries and which transfers and adapts results from overseas to Australian problems. For research relevant to import-competing industries, the reverse situation applies. Australia benefits most from research which is successful in reducing costs overseas as well as domestically. This may be the case in certain fields of biotechnology research and development.

Other factors affecting research gains

So far, the discussion has highlighted the following variables as being important in determining the gains from Australian research and development: the size of the industry and its growth prospects, the effect of the research on reducing costs (or stimulating output), research transferability, and export demand conditions. In order to put research into a framework that allows the net social benefits of that research to be fully identified, there is a need to account for research, development and implementation costs, as well as the rate of adoption of the research findings. Also, any benefits (or costs) not

captured by the market place (externalities) need to be accounted for. These external effects are often less easily defined than market benefits (or costs) and are more difficult to quantify. Research that generates unpriced production or consumption effects may not be uncommon. For example, research aimed at breeding plants with resistance to insect attacks may also result in the need for fewer chemical sprays, providing external benefits to human health and the environment. The problem is quantifying the magnitude of those external benefits and costs. At the very least, they should be taken qualitatively into account when assessing research benefits and costs.

Some limitations to applying the model

Central to the use of the Edwards-Freebairn framework is the assumption of a free and perfectly competitive market. When using the Edwards-Freebairn framework for markets which are aided by government assistance measures (such as price subsidies), it is desirable to use free trade rather than assisted prices. Edwards and Freebairn found that, when distorted market prices were employed in their model, the estimated net social benefits of research could be biased significantly. While, for many activities, free market shadow prices may not be difficult to obtain (for example, by using the export parity price), there are some cases, such as the wool industry, where those prices are difficult to estimate.

Of greater concern is the case where the research innovation will be used in an industry which has an imperfect market structure (for example, where the market is characterised by only a few sellers who band together to support prices at non-free trade levels, or where there is a monopoly seller in the market). In the case of the monopolist, the Edwards-Freebairn model can still be used to evaluate the social benefits and costs of research by reference to the appropriate price determining mechanism for a monopoly industry, instead of the price determining mechanism for a perfectly competitive market. It is more difficult, however, to use the Edwards-Freebairn framework for research which will be used in an industry characterised by a few large sellers because many price setting mechanisms are possible for this type of market structure and there would be uncertainty as to what price setting mechanisms existed in a particular oligopoly industry. However, the results obtained using the Edwards-Freebairn framework with the perfect market assumption may be a reasonable approximation of the long term benefits and costs of research applicable to such industries.[21] Furthermore, much of the biotechnology research currently being proposed or undertaken is applicable to industries which are characterised by highly competitive market structures (such as the agricultural and food processing industries).

The Edwards-Freebairn framework provides little guidance for the optimal allocation of funds to basic research. By definition, the results of basic research have no immediate commercial application and it is not possible, therefore, to obtain values for many of the variables considered important in the extended Edwards-Freebairn framework. Further, there are problems in using the Edwards-Freebairn framework for evaluating non-commodity research because it is hard to define and measure non-commodity output.[22] Again, these deficiencies are not acute when evaluating biotechnological research because much of the research is of an applied or strategic nature, and many of the innovations will be used in commodity markets.

Criteria for selecting grants recipients

All applicants for grants under the National Biotechnology Program Research Grants Scheme are assessed in terms of their ability to contribute to the objectives of the scheme. This task is undertaken by the National Biotechnology Program Research Grants Advisory Committee, which bases its recommendations on an assessment of the relative commercial viability and scientific and technological merit of individual proposals in accordance with criteria approved by the Minister and the relevance of proposals to applications in the priority areas approved by the Minister.[23] Outside assessors are used where necessary. Priority areas in relation to agriculture, identified at the Second Biotechnology Workshop organised in 1982 by the Department of Science and Technology,[24] were:

plant agriculture, comprising
- genetic engineering to modify important microbes
- tissue culture to improve plant species;

veterinary science, comprising
- diagnostic probes
- vaccines;

animal husbandry, comprising
- advanced breeding techniques
- animal hormones.

The reason for identifying these priority areas was to ensure that funds for biotechnology research were directed into areas which offered the greatest chance of successful development in Australia and which offered the highest rewards for Australia.[25] Nine criteria are used to evaluate projects falling within these priority areas:

1. Evidence of industry interest or commitment to the research program.
2. Whether the research proposed is likely to lead to a commercially exploitable process or product.

3. Whether such commercialisation can take place in a reasonable time scale.
4. Whether potential markets have been identified.
5. Whether it has any potential for export growth.
6. Whether there are likely to be beneficial 'spin-offs' to other Australian industries, both established and possible new industries.
7. What prospects there are for creating new jobs, either directly in areas of high skill or indirectly in associated support industries.
8. Whether the new processes or products are likely to be competitive compared with substitutable processes or products, either being developed elsewhere or currently on the market.
9. The quality of the research to be undertaken, with the probability that it will lead to important new discoveries, the solution of important technical problems, or the introduction of innovative techniques in Australian industry.

While the criteria developed by the Advisory Committee can be expected to differentiate between applications for funds, they do not, in general, coincide with the economic criteria that can be distilled from an explicit benefit-cost approach, based on the extended Edwards-Freebairn framework. The latter criteria and the extent to which they overlap with the criteria applied by the Advisory Committee are set out below:

- The current size of the industry(ies) to which the research results are directed.
- The industry's growth prospects (partially addressed in criteria 2, 4 and 5).
- The expected impact of the innovation on reducing costs, stimulating output or improving product demand of Australian industries (partly addressed in criterion 8).
- Whether the technology developed is likely to be internationally mobile and quickly transferred overseas to our competitors.
- Research, development and marketing costs to launch the new product or process.
- How quickly the innovation is likely to be adopted (partly addressed in criterion 3).
- Whether there are significant externalities associated with the research and development (partly addressed in criterion 9).

The criteria adopted by the Advisory Committee differ, in several respects, from those we have extracted from the extended Edwards-Freebairn framework. Most importantly, the Advisory Committee

places considerable emphasis on commercial potential or viability, a requirement which, if satisfied, suggests that private firms would undertake the research without support. In contrast, our framework focuses on social benefits and costs. In particular, it includes as important criteria the current size of the industry, the international mobility of the technology and the costs of research and development (R & D) none of which are addressed by the Advisory Committee's criteria. How important can we expect these criteria to be in determining the priorities of competing biotechnology R & D projects?

Current size of the industry

Edwards and Freebairn found the current size of the industry to be a most important factor affecting the magnitude of the potential gross social benefits generated from successful Australian R & D in the rural sector. For example, a successful R & D project in the wheat industry which reduces the unit costs of production by 10 per cent has the potential to generate $1,501m gross social benefit (in 1980-81 dollars), whereas the same innovation applied to the sunflower industry has only the potential to generate $35m.[26]

International mobility of the technology

As discussed, the Edwards-Freebairn framework explicitly focusses on the traded/non-traded good aspects of the economy. Within this framework the transferability of a new technology to overseas countries was found to be of crucial importance to the magnitude of the gross social benefits generated from successful Australian R & D into traded goods. For example, consider the implications of biotechnology cost-reducing research undertaken in Australia but applied by both domestic and overseas producers. Using the Edwards-Freebairn framework, it can be demonstrated that such research may result in Australian producers being worse off, due to reduced costs of production in the rest of the world and subsequent reductions in world prices. The overall effect of such research may be that Australian and overseas consumers are better off (because of reduced world prices); overseas producers are better off (because of increased world demand and cost of production declines which exceed any reduction in world prices), and Australian producers are worse off (because of cost of production declines which are insufficient to offset any increase in world demand and reduction in world prices).

To illustrate this effect, consider the wheat industry example cited earlier. Should a new technology provide reductions in unit costs for Australian and overseas procedures of 10 and 15 per cent respectively, it can be shown that Australia actually loses from the international

adoption of the innovation. In particular, gross benefits are reduced from $1,501m (in the case where the technology reduces costs in Australia by 10 per cent and does not affect costs in the rest of the world) to -$235m (in the case where the technology reduces costs in Australia and the rest of the world by 10 and 15 per cent respectively). While the example cited may be an extreme one, it does serve to illustrate the point that technology transfer is crucial to the magnitude of the gains accruing to Australia from the development of new technology.

Costs of research and development

In an explicit social benefit-cost framework, it is just as important to consider the social costs of a proposed intervention (such as support for a biotechnology project) as it is to consider the potential social benefits. In the criteria currently used by the Advisory Committee, minimal attention is given to the magnitude of the social costs likely to be needed to carry the proposed biotechnology R & D to successful fruition — that is, research, develop and apply the biotechnology innovation commercially. Other things being equal, the lower the social costs of a biotechnology innovation, the higher the priority the proposed biotechnology R & D grant should receive for funding. In practice, of course, a project requiring substantial R & D funding may have prospects for success and higher potential social benefits than one requiring only limited R & D resources and having limited application. This emphasises the need to consider the tradeoffs explicitly when deciding on funding priorities. An explicit benefit-cost framework facilitates such comparisons.[27]

For illustrative purposes, we have examined the projects supported by the Advisory Committee in 1983-84, using the benefit-cost criteria suggested by our earlier analysis (see Table 1). To do this, we have made two simplifying assumptions. First, we have given each criterion equal weight in terms of its expected contribution to net social benefits. This simplification is used for discussion purposes only and could be modified accordingly if a computer-based version of the Edwards-Freebairn model were to be used to estimate cost-benefit ratios. In fact, the latter model permits sensitivity testing of the cost-benefit estimates to specific assumptions about the values of key variables. Second, information was not available to the authors on the expected research, development or marketing costs associated with launching the new biotechnology projects. Further, information on the expected probability of a project's success was not available to the authors. The results presented in Table 1 provide some interesting insights into the projects chosen for funding under the National Biotechnology Program Research Grants Scheme. Only one project, that relating to the development of an anti-malarial vaccine for

TABLE 1

Subjective Ranking of Biotechnology Projects using Benefit-Cost Criteria

Project	Current size of the Australian industry	Growth prospects	Effect of the innovation on reducing costs or improving productivity	Rate of adoption of the innovations	Likelihood of transfer of the technology to overseas competitors	Significance of externalities
No. 1 Vaccine for the control of gastro-intestinal nematodes in sheep	+ +	+	+	+ +	--	0
No. 2 Anti-malarial vaccine for humans	0	0	0	+ +	0	+ + +
No. 3 Virus detection for crop plants	+ +	+ +	+	+	--	0
No. 4 Insecticidal compounds for livestock	+ +	+	+ +	+	---	0
No. 5 Vaccine for control of diarrhoeal diseases in humans and animals	+	+	+	+ +	---	+ + +
No. 6 Gels for electrophoretic analysis of proteins and nucleic acids	+ +	+ +	+	+ +	---	+
No. 7 Diagnostic probes for human and animal applications	+ +	+	+	+	---	+ +

Key: +, + +, + + + small, medium or large positive effects on the potential benefit-cost ratio.
-,--,--- small, medium or large negative effects on the potential benefit-cost ratio.
0 no effect on the potential benefit-cost ratio.

humans, would appear to have no agricultural implications. Two other projects (Nos. 5 and 7) have implications for human health, in addition to obvious potential agricultural applications. We would expect all three projects with implications for human health to generate significant externalities.

In the case of the anti-malarial vaccine, most of the benefits could be external to the market and the Australian community since it is not clear that the vaccine, if successful, would be solely produced in Australia. Because malaria continues to be a significant problem overseas, the external benefits generated would be captured largely by overseas countries. Nevertheless, since improving human health is a universal objective, Australia could be expected to benefit on humanitarian grounds. The transfer of the technology overseas, if it occurred, would not adversely affect our competitive position, and for that reason is not discounted *vis-a-vis* other projects. All remaining projects are likely, if successful, to generate technologies that are internationally transferable. The extent and speed of such transferability requires closer investigation before it would be possible to discriminate further. As noted earlier, the extent and speed of transferability is likely to be determined largely by the uniqueness of the problem to Australia.

The information base on which we have scored the seven projects supported by the National Biotechnology Program is, admittedly, weak. Some additional information of relevance to the Edwards-Freebairn framework would most likely have been available to the Advisory Committee, though it is not clear that it would have been sufficient to allow a confident selection of projects on the basis of their expected contribution to Australia's net social welfare. While the task of obtaining such information may prove to be difficult in the short term, it is likely that, in the longer term, much of the information required to estimate social rates of return to research could be obtained from the funding applicants themselves. This information could be supplemented by the judgment of the Advisory Committee regarding the quality of the proposed research and its probability of success, thereby providing an explicit *ex ante* benefit-cost ratio ranking of projects. This process could be assisted by the use of a computerised version of the Edwards-Freebairn model available in the Bureau of Agricultural Economics.

DISCUSSION AND CONCLUSIONS

We have attempted to address the problem of allocating scarce public resources to biotechnology research and development objectives in an economic framework. Our interest in the problem was twofold. First, biotechnology research and development is likely to lead to

innovations of benefits to the rural sector. Because of the economic pressures that face Australian agriculture, there is a need to adopt new technologies and continually to adjust the resource base of farms to maintain incomes. Biotechnology, as a field of research and development, offers much promise of new productivity growth. Second, Australia is a small country and cannot expect to generate all its new technologies from indigenous research effort. Importation of new technology will continue to dominate the total technology field in Australia for the foreseeable future. There is, therefore, a need to be very selective in the fields of research and development approved for support from scarce public funds. The choice of appropriate policy instruments for intervention in research, and the selection of priority areas for research funding, are essentially economic problems. Thus, the market failure model of government intervention and the extended Edwards-Freebairn framework for quantifying the social gains from research and development are both considered relevant to the problem.

As for the market failure model, it was suggested that the inappropriability, uncertainty and indivisibility arguments, set out by Nelson and Arrow, are of limited use in guiding policy makers toward a socially optimal set of research and development policies and priorities. Of the three arguments, inappropriability seems to have gained the widest acceptance as a basis for government intervention. Inspection of the policies in place for biotechnology research and development in Australia and overseas suggests that, with the emphasis on subsidies, they can be rationalised to a significant extent on the appropriability argument. However, rationalising current biotechnology policies on market failure grounds contributes little to the estimation of socially appropriate levels of funding and research priority determinations. For those objectives it has been suggested that the benefits and costs of intervention in research and development markets need to be evaluated carefully. Clearly, an evaluative model which captures the key variables affecting the costs and benefits of research will be useful.

While the extended Edwards-Freebairn model has general applicability to the estimation of costs and benefits of research, we chose to compare the criteria for project priority determination under the National Biotechnology Scheme with a set of criteria distilled from the extended Edwards-Freebairn framework. Our motivation for this exercise stemmed from the desire by policy makers and administrators to put research and development funding of biotechnology in an economic framework, as suggested by the Australian Science and Technology Council's interest in the market failure model and the definitions of biotechnology referred to initially. A central conclusion of that analysis is that the criteria applied by the National

Biotechnology Program Research Grants Advisory Committee differ from those suggested by an economic model of the gains from research. An assessment of the projects selected for the first year of the National Biotechnology Program Research Scheme, in terms of benefit-cost criteria, indicated that the sources of benefits likely to accrue to Australia from successful biotechnology research are quite diverse. Some projects had specific industry benefits with no obvious externalities, others had little or no Australian industry benefit and large externalities.

While the assessment undertaken focused on some economic variables likely to be important to estimates of net social benefits, there was insufficient information available to utilise the computer-mounted version of the extended Edwards-Freebairn model. In particular, information on research costs, the probability of success and the likely transferability of new technology to overseas competitors was unavailable. Nevertheless, it is clear that, in the long term, these data could be obtained and the cost-benefit assessment could be extended from the simple analysis conducted in this paper to a computer-based evaluation of applications for biotechnology funding. The next step, therefore, must be to ensure that applicants for grants in future years provide information that allows a more thorough assessment of the perceived net social benefits to be derived from allocating scarce public resources to investment in biotechnology research and development.

Appendix A CURRENT BIOTECHNOLOGY RESEARCH PROGRAMS UNDERTAKEN IN AUSTRALIA OF RELEVANCE TO AUSTRALIAN AGRICULTURE

Defleecing Using Biotechnology Techniques

- Biology of EGF (University of Sydney)
- Genetic engineering on defleecing of sheep (Adelaide University)
- Isolation of the coding and non-coding DNA sequences which comprise the wool keratin genes in sheep (CSIRO)
- Production of EGF using biotechnology techniques (CSIRO)

Synthesis and Transfer of Desirable Traits into Existing Plant Species

- Genes for nitrogen fixation and symbiosis in rhizobrium (ANU, University of Queensland)
- Wheat strains which produce their own nitrogen (Ager Pty. Ltd.)

Veterinary Applications

- Monoclonal antibody research into the production of diagnostic probes and kits (Hybridoma Research and Development Lab.)
- Molecular biology of equine herpivirus (Macquarie University)
- Antigenic determinants from liver fluke (ANU)
- Vaccines against gastro-intestinal nematodes which infect sheep (CSIRO and Biotechnology Aust. Pty. Ltd.)
- Development of insecticidal compounds of bacterial origin for controlling insects affecting livestock (University of Adelaide)

Plant Diseases

- Genetic engineering research on diagnostic probes for plant diseases (CSIRO)
- Recombinant DNA techniques used to investigate the biological control of crown gall (a plant disease) (Waite Institute)
- Gene probes for plant viruses and viroids (Adelaide University)

Food Processing

- Cheese starter cultures (University of NSW)
- Production of amino acids and protein using biotechnology techniques (various organisations)
- Bioconversion of hemicellulose and cellulose into sugar (University of NSW)
- Amino acids for stock feeds (various organisations)

Synthesis and Transfer of Desirable Traits in Existing Plant Species

- Tissue culture to improve grapevines and avocados (CSIRO)
- Molecular basis of plant improvement (developing methods for transfer of important genes between plants) (CSIRO)
- Introduction of genes for disease resistance in plants (Waite Institute)
- Regulation of ripening in tomato fruits (Macquarie University)
- Regulation of synthesis of fraction-protein in wheat (Macquarie University)
- Manipulation of genes for photosynthesis using *in vivo* methods (University of Queensland)
- Recombinant DNA and somaclonal variation techniques to improve plant breeding (CSIRO)

Animal Husbandary

- Elucidate the structure and regulatory mechanisms of animal genes and derive a method to transfer them as functional units to foreign cells, where they may provide the information for the

synthesis of potentially valuable proteins or be used to alter the genetic component of whole organisms (CSIRO)

Note: Some projects (for example, breeding disease-resistance in plants and production of vaccines) have both an effect on inputs used in agriculture and an output effect.

Sources: Department of Science and Technology, *Genetic Engineering: Commercial Opportunities in Australia, Canberra, 1982; South Australian Council on Technological Change, Technology Appraisal: Biotechnology, an Introductory Summary,* Adelaide, 1983; New South Wales Department of Industrial Development and Decentralisation, *Business Opportunities in Advanced Technologies: Biotechnology,* Sydney, 1983; CSIRO, *Directory of CSIRO Research Projects — 1983;* B. Jones, 'Grants for biotechnology research', press release from the Minister for Science and Technology, 23 December 1983.

Appendix B SOME CURRENT OVERSEAS BIOTECHNOLOGY PROJECTS WHICH MAY HAVE AN IMPACT ON AUSTRALIAN AGRICULTURE

Plant Improvements Using Biotechnology

- Nitrogen fixation in cereals
- Disease-resistant potatoes
- Herbicide-resistant cereals
- Biopesticides
- Improved nutrient efficiency in plants

Animal Vaccines

- Foot-and-mouth disease vaccine
- Various viral vaccines
- Bovine interferon (against shipping fever in cattle)
- Vaccine to prevent scours

Animal Husbandry

- Feed additives (amino acids from microbial fermentation)

Plant Improvements Using Biotechnologies

- Genetics of protein storage in soybean
- Development of hybrid tomatoes and cabbages
- Improved nutrient efficiency in plants
- Enhanced photosynthesis
- Early maturing hybrid corn, cereals and vegetables
- Salinity tolerance in maize, tomatoes and wheat
- Cereals with improved protein content
- Hybrid wheat
- Improved assimilation in forage crops
- Drought-resistant plants

Animal Husbandry

- Production of bovine and porcine growth hormones
- Hormones to increase milk production

Food Processing

- New sweeteners which can substitute for sugar

Note: Some of these output-enhancing developments may have adverse effects on Australian agriculture (by decreasing the competitiveness of certain agricultural products in world trade).

Sources: *Business Week,* various issues; *Biotechnology,* various issues; *New Scientist,* various issues; *Nature,* various issues; New South Wales Department of Industrial Development and Decentralisation, *Business Opportunities in Advanced Technologies: Biotechnology,* Sydney, 1983.

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see P. Thomas, 'Patents for genetic engineering inventions' in *Genetic Engineering: Commercial Opportunities in Australia,* AGPS, Canberra, 1982. In this context, there has been considerable discussion about the desirability of introduction into Australia of plant variety rights, a type of patent for new plant varieties. A discussion of the key issues surrounding plant variety rights is contained in A. P. Ockwell, *Plant Variety Rights — A Review of Issues,* Bureau of Agricultural Economics Occasional Paper No. 64, AGPS, Canberra, 1982. It is not certain that introduction of plant variety rights would confer net benefits to Australia because they suffer from similar problems (e.g., monopoly rights) to patents in general.

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