Summary

This evaluation explores the extent to which the Basic Research Grants (BRG) Scheme fulfils its mission of supporting high-quality fundamental research in the third-level sector, as part of a process of industrial and economic development. It was commissioned by Forfás on behalf of the Office of Science and Technology in the Department of Enterprise and Employment.

Because the mission of the Scheme is not only scientific but also economic - namely, to play a part in the operation of the national innovation system - the evaluation lays special weight on understanding the relationship between the basic research funded by the Scheme and the use of science by industry in Ireland.

We used a range of methods during the course of the evaluation

- Exploratory interviews with scientists and policymakers
- A literature review
- A postal questionnaire to all the recipients of BRG grants since 1989
- Interviews with scientists involved
- Case studies of the way research-performing companies in Ireland related to third level research
- Some simple analysis of publications
- An administrative review with Scheme management
- Desk research

The traditional view that science generates information which can be used in industry is, of course, partly correct. But it provides much more than just this. It provides the instrumentation, methods, trained people and interpersonal networks needed to do high-quality R&D. Sometimes it helps create spin-off companies or activities.

Econometric studies abroad tend to confirm that there is a link not only between R&D in general and economic growth but that basic science plays a role in this link. What emerges from our report is a more detailed picture of the relationship between basic science and economic development than has been attempted in Ireland before. It confirms the importance of network relations within and between research communities and it confirms that these links work in practice in Ireland. It provides some evidence that the Scheme is producing good-quality science.

A good basic science research infrastructure is necessary if higher-level industrial research and development is to be a reasonable ambition in Ireland. The Basic Research Grants Scheme is a major source of the skilled people needed in this process of growth. The policy task is to pace the development of the scientific community so that it runs a little ahead of industrial need, without turning it into the kind of high-status white elephant so often found in less developed countries. Irish expenditure on basic science needs to rise, bringing it more into line with that of other developed countries. It is not possible to be a 'free rider' on the basic science performed in the rest of the world.

The Scheme is broadly well run. Operational improvements are possible in the area of appraisal.

Our main recommendations are

- The scale of the Scheme should rise to reach STIAC's GDP linked target of £7.6m per year
- During this period of rapid growth, the quality of proposals should be monitored for any evidence of decline in standards
- At the latest at the point where the Scheme reaches a budget of £7.6m, it should be subject to a new evaluation. Policy makers will need to know whether this much larger Scheme adequately fulfils its role or whether it is in need of further redefinition
- Once the Scheme exceeds £4m in annual funding, it should begin to prioritise groups of disciplines for investment based not only on their respective shares of total project applications but also based on industrial structure criteria
- The proportion of grant monies awarded to projects using post-doctoral fellows should rise over time
- The amount of funding provided to PhD students through the Scheme should be raised, in the context of a wider review of the adequacy of PhD funding
- The proposal appraisal process should be overhauled
- Since BRG research appears to be performed in laboratories which are less than well found, a review should should be undertaken of university research equipment levels, quality and vintages as a basis for setting a higher budge

Introduction

This evaluation of Forbairt's Basic Research Grants Scheme was commissioned in late 1996 by Forfás on behalf of the Office of Science and Technology in the Department of Employment and Enterprise.

The purpose of the evaluation is to explore the extent to which the Scheme fulfils its mission of supporting high-quality fundamental research in the third-level sector, as part of a process of industrial and economic development.

In consultation with Forfás, we considered and rejected early in the study the possibility of performing a large-scale quality audit using scientific peers. Peer review is the normal mechanism for quality control in basic science. However, since the Basic Research Grants (BRG) Scheme funds projects over a very wide range of disciplines, this would have involved an unmanageably large peer panel. Instead, we agreed that we would put particular effort into understanding the role of the Scheme in the Irish innovation system more broadly. In particular, this meant coming to terms with the relationship between the BRG Scheme and the economy. In addition, we needed to review the management processes involved in running the Scheme.

We adopted a mixture of tactics to tackle these issues

- **Exploratory interviews** with scientists and policymakers, to improve our qualitative understanding at the outset
- A **literature review** to capture what the innovation and science policy literature has to say about the relationship between basic science and the economy
- A **postal questionnaire** to all the recipients of BRG grants since 1989
- **Interviews with scientists** to understand how they perceived their own basic work, the way this related to other work they did and, especially, to industry
- **Case studies** of the way research-performing companies in Ireland related to third level research
- Some **simple analysis of publications** by a sample of scientists funded under the Scheme
- An **administrative review** with Scheme management, working step by step through the management processes involved
- **Desk research**

What emerges is a more detailed picture of the relationship between basic science and economic development than has been attempted in Ireland before. It confirms the importance of network relations within and between research communities. A good basic science research infrastructure is necessary if higher-level industrial research and development is to be a reasonable ambition in Ireland. Correspondingly, there needs to be an industrial R&D community in Ireland in order to exploit knowledge in wealth creation.

This does not mean that the traditional 'linear' view of invention and innovation namely, that science invents while industry translates inventions into wealth is correct. Quite the reverse. The linear model applies only in rather special circumstances and in a limited range of industries. Rather, for much of the time basic science and in-company research and development people live in rather separate 'worlds'. The interplay between them involves a web of interpersonal networks which must flourish if they are to play their respective roles well. It is a precondition for developing an industrial R&D community that there is a well-developed scientific infrastructure. The policy task is to pace the development of the scientific community so that it runs a little ahead of industrial need, without turning it into the kind of high-status white elephant so often found in less developed countries.

Our report has four chapters.

- **Chapter 1** is a review of the literature concerning the interplay of scientific research and the economy. It provides an intellectual framework for understanding the links between science and industry
- **Chapter 2** describes the Scheme in its context, explains how it is managed, offers a ‘spot check’ on the quality of research funded under the Scheme and sets Irish expenditure levels in their international context
- **Chapter 3** reports the results of our fieldwork: postal questionnaires; interviews; and case studies
- **Chapter 4** draws together our findings and conclusions, and uses these to make recommendations

1. The Role of Basic Science

Basic science is one of the building-blocks of innovation systems and - we shall argue - of a good innovation infrastructure. The direct economic returns to basic science appear, on the basis of the econometric evidence, to be attractive. At a less macro level, many of the benefits that flow from basic science are difficult to capture in economic statistics. Yet market failures mean that these returns are best captured through social investment by the state, rather than through private investment.

The nature of the relationship between basic science and the economy is changing, as applied scientific activity becomes increasingly interdisciplinary, and as the boundary between the university and other parts of the knowledge-producing system becomes increasingly fuzzy. There appear to be six major categories of linkage operating between science and the economy, each of which we explore in this chapter. These provide at least some of the micro-level mechanisms which explain the macroeconomic benefits identified by the econometricians.

Both companies' and scientists' actions are driven by their needs and the incentive-systems within which they operate. We discuss how these match and develop a short list of conclusions about successful linkage between basic science and the economy. These provide a basis for considering the specific aspects of the Irish situation. Some generally-held assumptions about the role of basic science may not necessarily hold in present-day Ireland, given the current scale and development of the research communities in academia and in industry.

1.1 Economic returns to basic science, and the role of the state

We invest in basic science for a broad range of reasons, including (roughly in increasing order of importance for the individual nation)

1. Cultural reasons, or pure curiosity
2. Improvement of human health
3. Improving the bases for social and political decisions
4. Enabling changes in defence technologies
5. Underpinning technological progress and therefore economic development

These are all arguably good reasons. In this report, we shall focus on the last one. While it may be possible to accept the first four reasons and still to rely largely on other countries to fund the science, we shall show that basic science contributes to economic development by being embedded within the innovation infrastructure. For the economy, basic science does much more than supply information which may eventually underpin inventions. It plays a vital role in maintaining the innovation infrastructure as a whole, and therefore industrial innovation.

A number of studies has now been undertaken which investigate the economic returns to science. Some have focused on basic science. More have taken 'science' as a broad category. Almost all have found large and statistically significant economic benefits from performing science. But almost all of the studies have been done in large, developed economies which include a significant number of big, research-performing firms. Agricultural research has been particularly well studied. Exhibit 1.1 summarises findings in the literature.

Exhibit 1.1 Return on Agricultural R&D and R&D Spillovers

Authors	Subject	% Rate of Return to Public R&D	Time Period
Griliches (1958)	Hybrid Corn Hybrid Sorghum	34-40 20	1949-59
Peterson (1967)	Poultry	21-25	1915-60
Schmitz-Seckler (1970)	Tomato Harvester	37-46	
Griliches (1968)	Aggregate	35-40	
Evenson (1968)	Aggregate	28-47	1949-59
Davis (1979)	Aggregate	37	1964-74
Evenson (1979)	Aggregate	45	1948-71
Davis & Peterson (1981)	Aggregate	37	1974
Huffman-Evenson (1993)	Crops Livestock Aggregate	45-62 11-83 43-67	

Source: Griliches (1995) and OTA (1986)

Mansfield's is one of the key recent studies[1] looking at the relation between academic research and industrial benefits. He claims a 28% social rate of return on investment in academic research.

More recently, Griliches has modelled the effects of different types of R&D on the performance of 1,000 companies in the USA, using unpublished data on R&D expenditure from the US Census. His model recognises that it takes time for R&D expenditure to have an effect on business performance, so it relates the stock of R&D built up by companies to output. In effect, Griliches treats R&D as a cumulative investment - which he depreciates at 15% per year, much as if it were a capital good.

He finds that, first

... the implied average ... gross rate of return to R&D investments rises ... from 0.51 in 1967 to 0.62 in 1972, and a decline from 0.39 in 1972 to 0.32 in 1977 for comparable estimates. In either case, the estimated rate of return is quite high and there does not appear to be any dramatic fall in it over time. ...

The second major finding is the significant and rather large size of the basic research coefficient. It seems to be the case that firms that spend a larger fraction of their R&D on basic research are more productive, have a higher level of output relative to their other measured inputs, including R&D capital, and that this effect is relatively constant over time. If anything it has risen rather than fallen. The magnitude of this coefficient implies a very high premium, several hundred percent, on basic research.... A somewhat involved computation yields the implication of a 3 to 1 premium for basic research over the rest of R&D as far as its impact on productivity growth is concerned.

The third finding is the significant positive and rather high premium on company-financed R&D. For example, raising the stock of R&D by 20 per cent but shifting it all into the private component is estimated to double the effect of such dollars.[2]

However, even these recent studies are beset by difficulties of method and in attributing causation. There are no reliably accurate methods for estimating the value for money from publicly funded basic research. Nonetheless, the weight of evidence is that - at the aggregate level, and in large economies - the direct economic returns alone to science are much better than those available in more traditional investments, such as banking or the stock exchange.

Why, then, does private industry not tend to invest in basic research? Why should the state fund such an obviously attractive investment? Ken Arrow probably best captured the traditional argument for government intervention in science in his famous 1962 article.[3] He identified three major sources of market failure which make it useful for government to fund research

- **Indivisibility**, because of the existence of minimum efficient scale
- **Inappropriability** of the profit stream from research, leading to a divergence between public and private returns on investment
- **Uncertainty**, namely divergences in the riskiness of research respectively for private and public actors

Recently, Pavitt has restated the rationale for state funding in a simple way, though he omits uncertainty from his discussion, saying that the

economically useful output of basic research is codified information, which has the property of a 'public good' in being costly to produce, and virtually costless to transfer, use and re-use. It is therefore economically efficient to make the results of the research available to all potential users. But this reduces the incentive of private agents to fund it, since they cannot appropriate the economic benefits of its results: hence the need for public subsidy of basic research, the results of which are made public.[4]

The economics profession in general thinks about the results of research in this way as information, as if the results could costlessly be assimilated by any potential user. Callon has pointed out5 that for some important results of basic science this is not true. In many cases, only large and affluent companies have the complementary assets in terms of particular investments, capabilities and personnel needed to put specific scientific results to economic use.

It is therefore arguable that at least some of the public investment in basic science leads to private rather than public returns. However, this is a normal characteristic of public investment. Those making private returns also themselves make complementary investments. From the perspective of society, the interesting aspect is that the state investment leads to additional activity which would not have taken place without it; that it generates social returns which are bigger than the social investment; and that, in so doing, it does not lead to an unacceptable redistribution of resources.

1.2 Science in Modes 1 & 2: Implications for behaviour and linkage

Callon's point that the boundary between public and private may have moved is taken up more extensively by Gibbons et al.[6] They argue that science is splitting into two modes of knowledge production. Mode 1 is traditional disciplinary science, especially basic science. The important recent changes have happened in Mode 2, which includes not only the practice of applied science in universities and other research institutions but also the generation of knowledge elsewhere in society.

The boundary between the traditional, university-based applied sciences and the other parts of Mode 2 has been broken down by the massive output of qualified scientists and engineers (QSEs) from the universities into the economy since the post-War expansion of higher education, and by changes in research funding systems which deliberately promote research across institutional boundaries. The type of work funded by Forbairt's Basic Research Grants Scheme is largely Mode 1. However, the scientists who perform the work vary in the extent to which they stick to Mode 1 work or move between Modes

Mode 1 is discipline-based and carries a distinction between what is fundamental and what is applied; this implies an operational distinction between a theoretical core and other areas of knowledge such as the engineering sciences, where the theoretical insights are translated into applications. By contrast, Mode 2 knowledge production is transdisciplinary. It is characterised by a constant flow back and forth between the fundamental and the applied, between the theoretical and the practical. Typically, discovery occurs in contexts where knowledge is developed or put to use, while results - which would have been traditionally characterised as applied - fuel further theoretical advances.[7]

The authors summarise the distinctions between the two modes of production as in **Exhibit 1.2.** They go on to say that their analysis makes the traditional view of technology transfer - as a process where important ideas are passed down from the lofty heights of academia for the industrial mortals below to use - obsolete, because knowledge production is no longer a monopoly of the academics.

Exhibit 1.2 Distinctions Between Modes 1 and 2

Mode 1	Mode 2
Problems set out and solved in the context of the (academic) concerns of the research comminity.	Problems set out and solved in the context of application
Disciplinary	Transdisciplinary
Homogeneous	Heterogeneous
Hierarchial, tending to preserve existing forms of organisation	Heterarchical, involving more transient forms of organisation
Internal quality control	Quality control is more socially accountable

We believe the argument should be pushed even further. In this extended view of knowledge production, the traditional distinction between invention and imitation no longer matters very much. In effect, many of the same skills and tools are needed and many of the same processes are performed whether R&D workers are making knowledge new to the world (invention) or new to the user (imitation). The reduced importance of this distinction is already implicit in the modern 'innovation systems' way of thinking about technological change and economic development.[8]

The logic of Mode 1 comes from its internal organisation and control mechanisms, such as peer review. Its institutions tend to be centralised and stable. In terms of education, Mode 1 tends to provide ‘basic training’ and a disciplinary ‘entry ticket’ (such as a PhD) for people to qualify as credible researchers in either Mode.

In contrast, Mode 2 work tends to be transient. It forms and re-forms around applications problems. Calling on different disciplines and locations at different times, it is hard to centralise. Since Mode 2 work is performed in an applied, social context, it is normally subject to social and economic evaluation, and not solely to traditional quality reviews by scientific peers. To the occasional irritation of those used to the Mode 1 tradition, this means that relatively frequent evaluation - in part by non-scientists - is normal in Mode 2 work, and has become part of a ‘new social contract’ between science and society.

Mode 2 does not simply **apply** results obtained in Mode 1. Distinct types of knowledge are also created in the process of doing Mode 2 work. This is familiar in engineering where, for example, for many years propeller design has been done by reference to experimentally-derived tables about the aerodynamic efficiency of alternative profiles. These tables, put together over a long period by NASA, represented the best available knowledge exactly because basic science was unable to provide adequate predictive theory.[9]

One of the reasons why the Mode 1/Mode 2 distinction is interesting is that it focuses on **how** knowledge is produced, rather than on **why**. The Basic Science Research Grants Scheme uses the more traditional distinction between basic and applied science which was set out in the Frascati manual - the book which defines how the OECD collects national statistics on research and development (R&D)

Basic research is experimental or theoretical work undertaken primarily in order to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view....

Applied research is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.[10]

A key difficulty with the Frascati approach is that the same piece of research may be classified as basic or applied depending on the supposed intentions of the people doing it. Correspondingly, of course, a research project can often be dressed up as basic or applied, depending on the preferences of research-funding agencies.

1.3 Six types of link: How do they work?

Case studies and surveys provide an interesting - but essentially unquantified - list of economic benefits which result from basic research[11]

- New, useful information
- New instrumentation and methodologies
- Skills, especially skilled graduates
- Access to networks of experts and information
- Solving complex technological problems
- 'Spin-off' companies

The actual benefits seem to vary considerably by sector. In the UK, they appear bigger, for example, in chemistry and biology than in physics and engineering. Company attitudes are important in realising the potential benefits.

Nelson and Levin's survey[12] of 600 US R&D managers found that three quarters of the most important contributions of academic research to technological development were in the form of uncodified knowledge and skill transfers, and only one quarter in the form of codified knowledge (that is, knowledge which has been systematised and written down sufficiently that it can be communicated and re-used, as distinct from uncodified or tacit knowledge which cannot be communicated, but has to be acquired through experience). Overall, our findings in this Chapter support Pavitt's claim that "Contrary to common belief, the main economic benefits of basic research are not knowledge directly applicable in a narrow range of sectors, but background knowledge, research skills, instruments and methods that yield economic benefits over a much broader range of sectors."[13]

New, useful information is the most obvious output of basic research. This leads to an expectation that any economic impacts of basic science are very long term - an expectation which tends to be confirmed by studies such as Project Hindsight[14] , which looked for these kinds of longer-term links. Hindsight was a deliberate reaction by the US National Science Foundation to the Department of Defense's TRACES study. TRACES showed via detailed case study how US defence technologies were built on specific pieces of applied research, funded explicitly for this purpose. Hindsight showed how certain commercial products were linked back to basic scientific knowledge over a longer period. Both views can, of course, be correct, and are consistent with the common-sense view that research done with a specific, useful end in mind is more likely quickly to match the needs of those who defined it than work defined by someone else for some other purpose. This is now widely recognised in the innovation and technology transfer literatures, which see user-orientation of projects as a key success-factor.

Narin's analysis of the citation of publicly-funded research in US patents suggests that, at times, the movement of information from science to technology can be a lot faster than Hindsight would suggest. The lag between the publication of new science and its citation in the patent literature was in many cases almost as short as the time before citation in the scientific literature itself. This, and the fact that national science was 2 - 3 times as likely to be cited in a patent as foreign science, suggests that many companies filing patents are well networked to the scientific community, especially to the local scientific community. Publicly-funded science also provided the knowledge-base for patenting in the USA by US companies: 85% of the science they cited was publicly funded.

However, if information were the only result of basic science, then there would be no incentive for individual governments to fund it. Instead, they could act as 'free riders': using the information published as a result of other countries' investments in science, rather than themselves contributing to the costs of science. This free-rider behaviour would be contained if the time from scientific discovery to market exploitation were an important factor in competition. This seems to be the case in parts of molecular biology and pharmaceuticals.

But there need to be other benefits from funding science if individual states are to be dissuaded from free-riding.

Japan's investment in basic science rose sharply during the 1980s, notably following the acceptance of new policy guidelines for research in 1986. This followed a period of industry pressure and numerous public statements by the large Japanese companies that they were themselves funding more 'basic' research internally. Increasing the amount of basic research was seen both as a way to evade foreign (especially US) claims that Japan was 'free-riding' on others' investment in science and, more importantly, to underpin Japan's transition from technological follower to leader in a number of industries.**15**

In the 1990s, large Japanese firms have increasingly been collaborating with national universities in relatively basic research.

New instrumentation and methodologies represent the 'capital goods' of the scientific research industry.16 Their transfer to the commercial sector can create the basis for production as well as for industrial research activity.

Huge amounts of effort and expertise may be expended on developing instrumentation and the equipment needed to do basic research. The European Centre for Nuclear Research (CERN) is an extreme example, where major engineering feats have been required in order to provide the particle accelerators, sensors and control equipment needed for leading-edge experimentation in particle physics.

However, it seems hard to predict when new instrumentation will be crucial to scientific research and when that research can safely be done using small-scale or commercially obsolete instruments. Equally, it is not always clear when instrumentation devised for research purposes will make the transition to industry. Almost all the major production equipment used in semiconductor manufacture originated in this way, while the bulk of the advances made in medical instrumentation in this century have originated in medical schools and research hospitals, not in the instruments companies.[17] But, as with the information that emerges from basic science, there are often very long lags in adoption, and by no means all research instruments find their way into commercial use.

In contrast, there is often a very lively 'trade' in instrumentation, methods and the associated knowledge among research scientists both in academia and in industry. As a result, quite big research communities can quickly adopt technological changes, creating the basis for movement to industry **-** not least through the movement of students, especially postgraduate research students.

De Solla Price has proposed a wider interpretation of the role of instrumentation and methods, coining the word "**instrumentality** to carry the general connotation of a laboratory method for doing something to nature or to the data in hand." [18] He argues that "a great deal of the actual work that goes on in all sorts of experimental laboratories consists in the discovery of new techniques for doing something or producing some new effect, then perfecting and extending the technique and using it on everything in sight." Science and technology, he argues, live in rather separate worlds. It is the use of common instrumentalities, the associated tacit knowledge and the training of people in the use of such instrumentalities that creates the link between science and technology. He overstates his case, omitting other links which are important. Nonetheless, this idea of common tools and a common **craft** of experiment captures rather well the nature of many of the interactions within and between scientific and technological communities.

Skills, especially skilled graduates, may well form **the** key short-term link between basic science and industry. Those firms needing graduates for R&D or in some other technical functions, actively seek research-trained people. "As far as companies are concerned, formal qualifications are ... evidence of researchers' tacit ability to acquire and use knowledge in a meaningful way. This attitude of mind ... is a most important contribution to new product development."[19] Graduates of taught courses, such as typical first degrees, cannot offer this evidence.

Graduates and post-graduates do not simply transfer from universities to companies the state of learning at the time when they passed their exams. Studies of basic-science roots of knowledge used in innovations show that industrial R&D workers use their education to keep up with the state of knowledge.[20] So an important aspect of basic science education is to implant a capability for continuous learning in graduates and, therefore, among their employers.

Even those parts of basic science which seem most remote from industry generate industrially significant skills. For example, Irvine and Martin have shown that MSc and PhD graduates in radio astronomy brought important skills with them when they migrated to other occupations. Irvine and Martin's survey of these former students showed that their training in such tasks as the construction of receiver equipment, the development of computer programmes and the development of analytical data-handling techniques were extremely useful in their subsequent careers. Some 30% of those surveyed went on to work in industrial R&D departments, especially in telecommunications, radar, computing and related areas.[21] Both anecdotal and systematic evidence point to the broad industrial usefulness of physics graduates and postgraduates.[22]

Access to networks of experts and information is important for company R&D departments. It would be impossibly uneconomic for them to generate themselves most of the knowledge and information they use, so they need a strong 'search' function to identify and absorb external knowledge. Formal and informal participation in scientific networks is therefore important.

Derek de Solla Price pointed out[23] that research scientists tend to organise themselves in global "invisible colleges," made up of people who are advancing the frontiers of knowledge. Within these colleges, discussions, draft papers, conferences and bilateral exchanges of various sorts provide members with privileged and **early** access to new knowledge. Members of these invisible colleges engage in what has recently been dubbed 'copetition': a mixture of cooperative and competitive behaviour. Invisible colleges are therefore rather exclusive affairs. Those who can bring nothing new to the party are not invited. Like everyone else, they can read the journals, but they struggle to keep up with the field because they are not part of the discussions that set research directions and the controversies that fuel competition. They are largely excluded from the informal interchanges of techniques, methods and clues about failed approaches that are enjoyed by invisible college members.

Companies employ a number of means to be involved in such invisible colleges or networks, where this is important. For example, Pilkington's last head of research was a part-time professor of chemistry at Liverpool University. Hicks[24] has shown that corporate R&D departments increasingly publish relatively basic research results in order to create an 'entry ticket' to international scientific networks. This allows them to access technical opportunities in the science base, including the recruitment of skilled graduates who also carry with them bodies of tacit knowledge. The PACE Study[25] emphasised the importance to firms of monitoring developments in public research, and the widespread use of informal, networking mechanisms to access these developments. The evidence is therefore that many R&D-performing companies consider links to basic science as important and are prepared to back up this perception of importance with resources devoted to monitoring.

The importance of this type of monitoring and learning is also reflected in how companies participate in Mode 2 'pre-competitive, collaborative' R&D programmes. **Exhibit 1.3** indicates that - as a typical example - the Swedish national programme in precompetitive, collaborative IT R&D (IT4) provided a way for industrial participants to access external knowledge and capabilities rather than to do near-to-market development work.[26]

Exhibit 1.3 What IT4 enabled industrial R&D teams to do

Activity	% of Teams Stating IT4 Was Very Important[1]	Achievement Score[2]
Upgrade skills	53.1	3.7
Accelerate R&D	49.0	3.5
Use new tools and techniques	44.9	3.5
Establish new links with other firms	40.8	3.5
Establish new links with other academics[3]	40.8	3.3
Access academic know-how	36.7	3.3
Build on R&D base	36.7	3.5
Enhance image and reputation	34.7	3.4
Spread costs	34.7	3.5
Enter new R&D areas	32.7	3.4
Access other industry know-how	30.6	3.0
Deepen understanding	28.6	3.5
Maintain R&D presence	26.5	3.4
Keep track of R&D	26.5	3.3
Get used to new IT standards	26.5	3.4
Achieve critical mass	12.2	2.8
Develop new tools and techniques	26.5	3.3
Develop prototypes	26.5	3.2
Enter international R&D programmes	20.4	3.1
Enter private sector R&D ventures	16.3	3.2
Develop products	14.3	2.9
Enter new non-R&D collaborations	14.3	2.8
Influence new IT standards	12.2	2.6
Enter national R&D programmes	12.2	2.8
Spread risks	4.1	2.9

1 - Percentage scoring > 3 on a 1-5 **Importance** scale, where 5 is high

2 - Mean scores on a 1-5 **Achievements compared to Expectations** scale

3 - The term **academics** is used to denote universities and research institutes

This suggests that companies' participation in scientific 'invisible colleges' is a special case of their wider 'search' behaviour, looking for new and useful kills and knowledge.

Basic science also contributes to the economy by **solving complex technological problems** - in the sense of enabling the application of the stock of (basic) knowledge to industrial needs. It is not normally the basic scientists but others who put the stock of knowledge to use, both directly and indirectly.

The relative importance of direct and indirect transfers differs a great deal between industrial sectors. Direct linkages visible through patent and citation data are clearest between basic chemistry and the chemicals industry. Half the links identified by Pavitt for the USA were in this field, with another 20 - 30 percent linking basic science with electrical and electronic products. In contrast, less than 10 percent of the measured linkages were with non-electrical machinery, automobiles and aerospace - which together employ almost half the QSEs in the

USA.[27] This latter group is more engineering-oriented, and links with basic science are more indirect.

The 'PACE' study explored the way individual scientific disciplines relate to branches of industry. In **Exhibit 1.4**, we have classified the disciplines and industrial sectors and shown the intensity of the links found in the PACE survey of large firms.

Exhibit 1.4 Importance of publicly funded research in last 10 years to companies' technology base

		Engineering-Based								Other		Science-Based			
	Overall	Aerospace	Basic Metals	Electricals	Telecoms	Automotive	Utilities	Computers	Plastics	ECG	Food	Pharma	Petroleum	Chemicals	Instruments
Transfer / Applied Science															
• Materials	**42**	**77**	**76**	**72**						**63**					
• Computer	**34**	**60**		47	**56**	47		47							
• Mechanical Eng	**34**	**64**				47		**64**	**53**	47					
• Electrical Eng	**33**	**73**		**56**	**70**			**78**							
• Chemical Eng	**29**								46			**55**	**60**	**46**	
Basic Science															
• Chemistry	**29**							33				**78**	**52**	46	
• Physics	**19**		33					**64**	25	25					
• Biology	**18**										33	**71**	18	17	
• Medicine	**15**							27			15	**85**			29
• Mathematics	**9**	20				20		25		13					

Source: Arundel et al, 1995: Technopolis analysis

The 'Overall' column in the **Exhibit** shows the proportion of the companies sampled which indicated that publicly funded research in the science shown during the past ten years was 'very important' to their technology base (scoring 5 or more on a 7-point scale where 1= not important and 7=very important). As might be expected from the 10-year horizon chosen, the applied and transfer sciences were generally more important to them than the basic sciences.

The remaining columns show the top-four scoring industries when the same responses are analysed at the individual sector level. The numbers in the columns show the percent of firms saying the relevant science was 'very important'. This confirms Pavitt's analysis that the engineering-based industries tend to lean heavily on the applied and transfer sciences. Chemical engineering has a markedly different pattern of links with industry from the other transfer disciplines because it is effectively provides 'engineering to the science-based industries'. Three of the basic sciences (chemistry, biology and medicine) have strong links are with the corresponding science-based industries. Physics and mathematics are different: they provide underpinnings to engineering rather than supporting their own unique industries.

Among the industries, computing is unusual in using a good deal of both transfer and basic sciences, presumably in part because it has a high electronics content. Industries which make use of basic science necessarily tend to have a distinct pattern of sources of knowledge and technology. Companies tend to be larger and to have formal R&D departments. **Exhibit 1.5** shows the use made of different sources of technical knowledge by the largest manufacturing and industrial firms in Europe, surveyed in the PACE study.28 It contrasts this with the findings of the Community Innovation Survey, where the response is dominated by small firms. The use of the public research base by the smaller firms is much lower than by those in the PACE sample.

Exhibit 1.5 Importance of different sources of technical knowledge

Source	PACE Respondents	CIS Ireland
	Percentage of respondents rating source as important	
Competitors' products	46.9%	45%
Independent suppliers	37.1%	38-41%
Affiliated firms	37.0%	N/A
Independent customers	36.6%	67%
Joint ventures	32.7%	N/A
Public research institutes	31.5%	9%

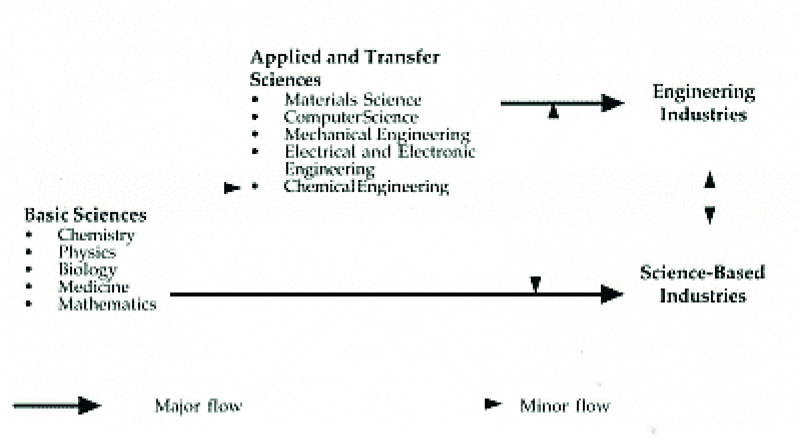
Geography is also important. As the PACE report notes,

Domestic public research is substantially more important to respondents than foreign sources, suggesting that the public research infrastructure is one of the most important national assets for supporting innovation.[29]

PACE respondents stressed the importance of basic research over more applied areas of research.

Existing research shows, then, that the **mechanisms** through which basic science contributes to technological problem-solving are not always direct. We cannot simply think of basic science as putting new information into a bucket, into which applied scientists and engineers dip for ideas. Rather, the flows look more like those shown in **Exhibit 1.6** - which should be regarded as broadly illustrative rather than as being definitive. Equally, these flows are only possible when appropriately qualified and experienced people are available to translate and develop the tacit knowledge needed to exploit the codified flows shown in the **Exhibit**.

Exhibit 1.6 Knowledge flows in technological problem-solving



At present, the Irish industrial structure is biased away from science-using firms, although some of the multinationals present in Ireland are science-using in their home countries. Correspondingly, the maintenance of a viable science base is a precondition for linking these potentially 'footloose' foreign multinationals more permanently into the Irish innovation system, as well as for supporting indigenously-owned industry.

Spin-off companies are often thought of as a major benefit of research in academia and research institutes, yet the empirical evidence for this is at best mixed.

A great part of the science park movement has been founded on the idea that there is a substantial pool of untapped ideas in the research sector which can be nurtured into commercial reality through new firm creation. Reality does not always live up to these expectations.[30] In some cases, science parks come to be populated by those who find it attractive to be near a university rather than those who are genuinely exporting and commercialising scientific capabilities from it.[31] Growth rates of such firms tend to be low.[32] US research suggests a positive correlation between university research and firm growth in the electronic equipment sector, but - surprisingly - finds no significant relation in instruments.[33]

However, while the survey evidence for a link from science to company creation may be weak, there are prominent examples of companies which have in practice spun off from science departments at universities, not least in instrumentation and in biotechnology. Examples such as Varian Techtron (spectrophotometers) in Australia, and Genentech (biotechnology) or Evans and Sutherland (Computer-Aided Design and graphics) in the USA are easy to find.

We strongly suspect that the reason for this paradox is the extremely skewed nature of success and the correspondingly high death rates of spin-off firms. Government and other programmes to promote invention typically involve filtering out the overwhelming majority of ideas in order to find a handful of commercially feasible ones. Only a small minority of the feasible ideas go on to become profitable. Yet the occasional 'hit' can make significant amounts of money.[34] We found a similar 'skewed' pattern in the Irish Technology Transfer and Partnership Programme, where the overall economic success of the programme depended on large returns to a very small proportion of the technology transfer projects.[35]

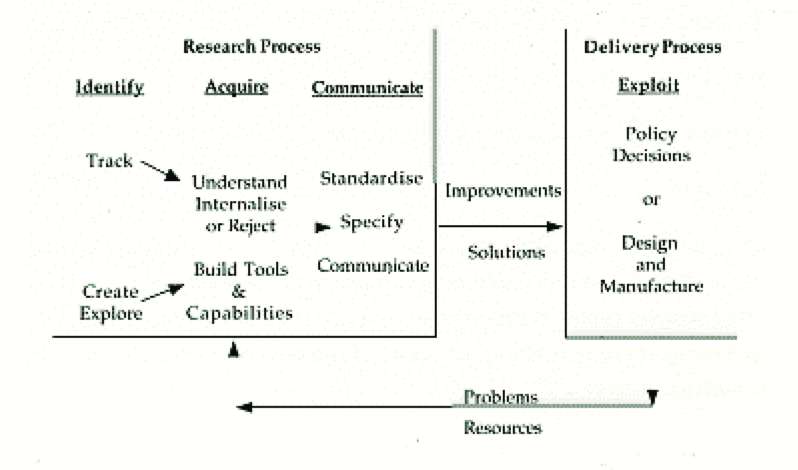
Our conclusion is that there is indeed a link between science funding - including basic science - and the creation of new firms. While it can be very hard to force the pace in this link, success in doing so can produce significant rewards.

1.4 What companies need and what they do

Evidence from a range of studies shows that companies' ability to access the external science base depends on their internal technological capabilities and, in particular, on the extent to which they employ Qualified Scientists and Engineers (QSEs).[36] In general, therefore, it is only companies which perform R&D that can to make use of the science base.

Exhibit 1.7 sketches the role played by the research function in a large company. It both searches for and creates new knowledge, which it explores, evaluates and communicates to the design, manufacturing and decision-making functions. This is fully consistent with the current view in evolutionary economics seeing the firm as a searching, learning mechanism which survives and improves by continually reinventing itself.

Exhibit 1.7 A systems view of the role of research



Senker and Faulkner have shown that firms in certain high-tech industries (pharmaceutical biotechnology, advanced engineering ceramics and parallel computing) actively seek relations with the science base in two ways

- As a source of new knowledge in specialist fields of science and engineering - it is vital that companies engaged in innovative R&D keep up with developments at the leading edge of research and gain the necessary underpinning knowledge
- As a source of practical help and assistance, often in response to specific problems, and frequently in the area of experimental methodologies and research instrumentation, for example in interpreting results from test equipment

These companies do not expect or use a meaningful flow of inventions from basic science. Rather, the contribution of publicly-funded research is made up of small, 'invisible' flows, the cumulative effect of which is very significant.[37]

There is a geographical element to these flows. Because the major multinationals continue to do most of their research at or close to headquarters, there is no systematic relationship observable through the proxy of patenting in the USA between the locations in which they do R&D and the scientific strengths of host countries.[38]

Nonetheless, studies which address themselves to individual multinationals indicate that the science infrastructure is important in helping to explain the decisions of those companies which do choose to locate R&D away from headquarters. Stoneman's study, for example, led him to conclude that the three main factors attracting R&D facilities to the UK are the supply of highly-skilled manpower, a strong university system and the relatively low cost of UK

QSEs.[39] Taggart found five reasons why US and European pharmaceuticals companies set up R&D laboratories in the UK

- High present stock of scientists, engineers and technologists
- High level of competitors' R&D activities
- Excellence of tertiary education system
- Strategic importance of firm's presence in the market
- Efficient patent laws.[40]

Based on a combination of examples of inward R&D investment to the UK and on other studies, SPRU has concluded that individual multinationals' decisions to locate R&D - especially when this involves research rather than more routine development or applications engineering - involve seeking out some of the best academic science needed by the firm in an individual field.

The literature suggests, then, that the location of R&D is affected both by agglomeration effects, where companies seek to be in a place where there is a critical mass of research going on - and by the availability of a strong science infrastructure.

1.5 Conclusions for Policy

If we put basic science into its context in the overall innovation system, it is clear that this system has many components. Exhibit 1.8 shows the major processes in the innovation system, indicating by whom and why each function is typically undertaken.

Strikingly, the forces that motivate each of the functions are different. This helps explain why it is in practice so difficult to get the innovation process to work as a single system and why those (in both industry and government) who work with it spend so much of their time looking for ways to link its different parts together.

While the order of the functions shown in Exhibit 1.8 is the one conventionally used in discussing the innovation system, there are in fact multiple interrelationships between them. For example, unexpected problems in design engineering or even technology adoption may lead a firm to reach back into basic science for clues to an alternative approach. Findings in applied research can identify the need for more applied research. Experimental development sometimes results in production-ready products or processes, and so on.

This means that the traditional 'linear' model of science technology and innovation is wrong[41]. Science does not 'cause' innovation is such a direct way that increasing the amount of science will automatically increase the amount of innovation: funding more science will result mostly in more science. Nor (except in a trivial sense) can the amount of economically productive technology adoption readily be increased without the availability of skills and knowledge from the other functions. The innovation system is a complex one and needs to be handled as a whole. Its growth is an important element in national economic development. While not all the parts have to grow at the same rate, policymakers need to ensure sufficiently balanced growth to ensure that the system as a whole performs well.

We can therefore view the role of government in managing the innovation system as: ensuring that both the technology-providing and the technology-using parts of the system are healthy as well as being in balance, and ensuring that the socioeconomic environment and infrastructures are supportive of innovation.

Exhibit 1.8 Main functions performed in the Innovation System

Function	Characteristics	Typical Performers	Activity Drivers
Basic Research	'Blue Sky' exploration. Curiosity-led, based on clues from theory or data. Includes pure science	Universities or research institutes, based on state or charity funds. Certain very large compang Research labs eg. Bell, IBM	Curiosity, Cultural concerns. Academic career requirements, including publication. Search for very long-term technological opportunities
Applied Research	Generates new knowledge with a pratical aim. Includes know-how generation as well as formal applied science.	Universities and research institutions. Some corporate R&D labs.	Academic and industrial career requirements. Exploration of technological opportunities with medium-longterm payoffs.
Experimental Development	Systematic work drawing on theory and experience to demonstrate technical viability of a class of product. Identifies and eliminates technical uncertainties.	Company R&D labs. Research institutes or associations. Occasionally, universities	Need to eliminate uncertainties from design engineering process.
Design Enginneering	Translates known and demonstrated principles into new products or models. No significant unknowns should be on the critical path.	Company R&D labs. Technology-based SMEs	Develop products to serve market needs. Generates short-medium term profits.
Standards & Certification	Technology is codified into standards. Norms are negotiated. A limited set of ways to use technology get a 'seal of approval	Makers and users of technology, organised by state agencies, including international standards agencies.	Technology suppliers seeking market dominance. Technology users seeking to stabilise technology, maximise its usefulness and preveny monopolisation by suppliers.
Diffusion Adoption & Adaptation	Technologies embodied in processes and products are bought, adapted and used. Incremental innaivations are made, both by technology suppliers and technology users. Product characteristics and reverse engineering eventually cause design knowledge to 'leak' to competitors.	In-house production and plant engineering departments. R&D departments also become involved in firefighting and incremental improvements.	Competitive pressures to use adequate or best practice technologies.

While the relationship between basic science and other functions in the innovation system is complex, the econometric evidence is clear in showing that the economic returns to the state's investment in science are large in large countries, even if the available estimates of returns are individually unreliable.

The econometricians cannot tell us much about the mechanisms which connect basic science to the economy. To understand these, we have had to look elsewhere. Contrary to popular expectations, it appears that the major contributions of basic science are not inventions and spin-off firms, though these can be important in particular cases. Rather, they are research skills, methods and instruments ("instrumentalities") and professional contacts, all of which help technologists define and solve problems. These contributions are vectored through people, so networks are important and - above all - the relationship between basic science and research training (at postgraduate level) is central.

This being the case, 'free-riding' on the rest of the world's science is not a feasible strategy. Since the links both among basic scientists and between them and industrial researchers are personal and based on informal trading in ideas, techniques, instrumentalities (and sometimes other scarce resources such as experimental materials or money), there is no room for passengers. To make use of basic science, you have to be a contributor and an insider.

Companies which make use of basic science need a high degree of internal capability. In particular they need to employ a good number of the people produced by the basic science education system. In order to exploit the personal nature of links with the basic science community, they need generally to be geographically close. Sometimes, if the academic science is really good, companies will locate a laboratory nearby in order to join in the research and get early access to results. More generally, a good local science infrastructure is attractive because it provides the scientific, technical and personal support networks needed to provide manpower for R&D and to keep this manpower both up-to-date and connected with scientific and technological change.

There are important sectoral differences in the type and intensity between the basic sciences and industry. The 'science-based' industries depend quite directly on basic research. Others relate more directly to the applied disciplines or 'transfer sciences'. Both sets of sciences need to be strong in order to enable the presence of R&D in strong, knowledge-based companies.

The international literature therefore suggests that adequate basic science infrastructure and funding are essential if Ireland is to move beyond its so-far very successful policy of attracting technology-based inward investment. The infrastructure is needed, first, in order to enable footloose multinationals to put down stronger roots in Ireland. (Of course, basic science is not the only requirement here.) But the success of Ireland's inward investment policy has not just been in attracting foreign companies but in beginning to grow technologically capable, indigenously-owned firms in the same sectors. Supporting this new growth is the second task of the basic science infrastructure.

2. The Basic Science Research Grants Scheme

Introduction

In this Chapter, we describe the location of the Basic Research Grants Scheme in the Irish funding system and explain how it is managed. Finally, we consider some broad indicators that suggest current Irish levels of funding for Basic Research are low by international standards.

2.1 The Irish research funding system

The University-based R&D funding system in Ireland essentially has four components

1. Recurrent University funding
2. National Research Support Fund
3. EU programmes
4. Programmes in Advanced Technologies (PATs)

A significant part (25%) of the recurrent funding provided to the Universities from the education and science budget is normally imputed to their research role. In reality, the Universities have no way to manage the boundary between education and research - a boundary which is, in any case, fuzzy at the postgraduate level. Recurrent funding effectively means that the Universities exist, that they have some level of laboratory provision and that academics have some part of their time available to do or to supervise research. It provides no project-specific resources. It therefore guarantees academic freedom to do any kind of research, provided it does not cost any money. This is a fairly normal characteristic of a modern University system.

In most countries, the state sets the direction of University research through a national science foundation which provides marginal, project-specific resources for University research. The National Research Support Fund Board plays this role in Ireland, through six funding schemes (Exhibit 2.1), of which the Basic Research Grants Scheme - the Scheme considered in this report - is the largest. It represents a continuation of the former Scientific Research Grants Scheme administered by EOLAS and, before that, by the National Board for Science and Technology. Its stated objective is To support high quality fundamental research in the third-level sector.

Exhibit 2.1 National research support fund schemes

Scheme £m	1995 £m	1996 £m	1997 £m
Basic Research Grants Scheme	1.5	2.0	2.3
Strategic Research Grants Scheme	1.0	1.2	1.5
Applied Research Grants Schemec - RTCs + DIT	0.8	0.8	1.0
Applied Research Grants Schemec - Universities*	0.8	1.3	1.7
Research Scholarships (PhDs)	0.5	0.97	0.90
Industry Scholarships	0.3	0.29	0.26
International Collaboration		0.24	0.25
Post Doctoral Fellowships		0.20	0.28
Total	**5.0**	**7.5**	**8.5**

Source: Forbairt * Formerly HEIC

While the Basic Research, Research Scholarships and Post Doctoral Fellowships schemes are oriented to maintaining scientific capabilities in Ireland, the other schemes are industry-oriented. Strategic Research Grants have historically been available for the technologies which have been prioritised in policy: namely, those for which PATs also exist. Historically, the object of the Strategic grants was to support the research 'base' from which the PATs draw. The PATs themselves may not receive Strategic grants. Rather, the associated academics should receive them, in order that they may create industrially-exploitable results over the medium term. (An unfortunate side effect of this rule is that academics feel they need to distance themselves from the PATs in order to obtain Strategic Research money.) The PATs are, however, eligible to receive Applied Research (formerly known as HEIC) grants, which are jointly funded by the state and industry.

The most striking characteristic of the National Research Support Fund is its small size. Irish basic researchers are therefore strongly driven to orient their work towards the European Union's science and technology funding programmes in order to secure research funds. These tend to be applied, oriented to developing and exploiting existing scientific capabilities in member states.

Between 1989 and 1996 - the period considered in this report - the scheme allocated £8,695,000 to various research projects. Based on the data provided to us by Forbairt, **Exhibit 2.2** shows the scheme's commitment in terms of funds awarded and number of grants from 1989 to 1996.[42]

Exhibit 2.2 Basic research grants scheme funding, 1989-1996

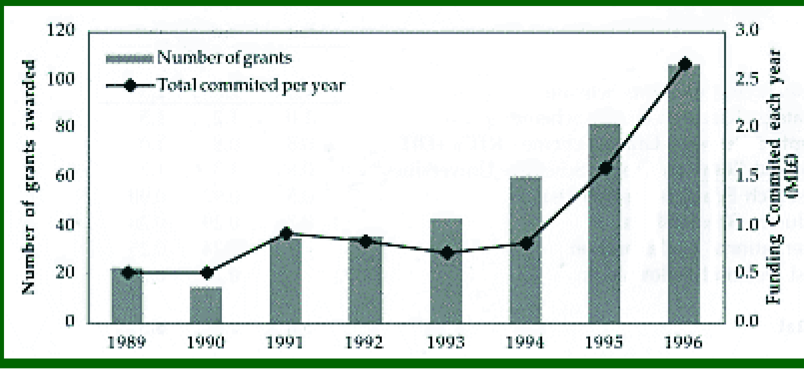
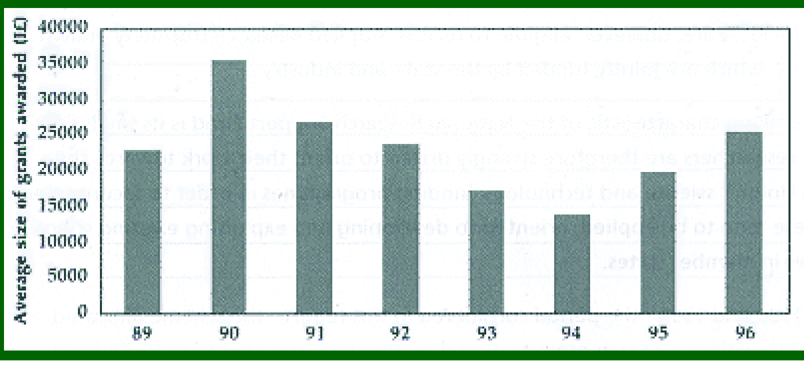


Exhibit 2.3 shows the average value of grants awarded over the same period. The increase in grant value in 1996 is largely driven by an increase in permitted project duration from 2 to 3 years, as a result of which the average length of project approved in 1996 was 31.5 months.

Exhibit 2.3 Mean value of basic research grants, 1989-1996



Since the reports of the STIAC and Travers Committees, there has been a growing consensus that science funding in Ireland needs to be increased. This has partly been reflected in the funding committed by the Basic Research Grants Scheme, which has grown from £0.45m in 1992 to £2.5m in 1996, though this growth has to be compared with STIAC's 1995 recommendation that the amount should rise to £6m.

As a result of this increasing funding, the scheme has been able to accept a growing proportion of the proposals it receives, and to make funding offers which approximate more closely than before to the sums requested by researchers (Exhibit 2.4). The raw application:acceptance ratio is now quite low, compared with that from other funders such as the EU, thought it must be remembered that the grants involved are small. Nonetheless, the number of applications has not yet risen in line with the funding increases and the increasingly attractive odds involved in making an application. While the general message from this report will be that it makes sense to continue to increase funding through the scheme and to increase available grant sizes, programme management should at the same time be monitoring the quality of applications year on year, in order to identify the point at which increased funds are being awarded at the price of inadequate quality.

Exhibit 2.4 Application and funding statistics

	1994	1995	1996	1997*
No of Proposals	338	237	327	341
No Proposals Accepted	60	71	103	110
Application: Acceptance Ratio	5.6	3.8	3.2	3.1
Total Funds Requested (millions)	£9.5	£7.9	£12.2	£16.0
Overall Funding Rate	13%	24%	22%	23%
% of requested funds awarded to successful proposals	40%	65%	67%	68%

* Initial outturn. 16 additional grants were subsequently funded

2.2 Programme Management

The Scheme is managed by two people in Forbairt, with additional clerical support at the peak of the proposal appraisal process. We estimate the overall cost of administration to be between £60,000 and 80,000 or approximately 3% of the current research budget.

Proposals are assessed by seven Assessment Panels, each dealing with a cluster of disciplines. Funds are allocated to the Panels pro rata the share of the value of relevant incoming proposals within the total amount of funding sought. The Panels each comprise about half a dozen Irish academics. Each Panel is supported by two foreign (generally UK) academics or ‘externs’. Members do not see proposals from their own institution.

Proposals are first rated A to D by three Irish members of the panel. Proposals are allocated to referees according to their area of expertise. Projects not considered to be basic science are eliminated, and Forbairt then determines a cut-off grade above which projects will be considered for funding. (Normally this is set to generate a short list which accounts for roughly twice the available money.) The externs see all the proposals and may add to this short list. At a subsequent meeting of the panel, short-listed proposals are ranked and funded down to the point in the ranking at which the Panel budget runs out.

Formally, no scientist may submit more than two proposals per year.[43] Informally, the panels tend to ‘spread it around’ so that - irrespective of quality - individual scientists do not receive more than one grant per year from the Scheme. The Panels have a general practice of reducing the funds allocated to projects, compared with the proposals. An effect of this, according to those who filled in our questionnaire, is that as many as 28% of projects may therefore become too small to be viable.

The Scheme operates on a cycle driven by the annual budgeting process in Irish government. The key steps are

- **October**. Approval and distribution of programme descriptions and application forms to central distribution points in the Colleges
- **Mid-December**, closing date for applications for funding from the following October
- **January**. Proposals are sent to Panel members for assessment. Scores are collected centrally and fed back to the Panels. The externs see all the proposals
- A total budget decision for the Scheme is handed down in March. Until this point, the total size of the Scheme is formally unknown

- Panel meetings in **March** and **April** allow offer letters to be sent out to successful proposers. Unsuccessful proposers are notified a few weeks later, and are offered the opportunity to talk through the referees' comments and grades on the telephone
- Grant holders are asked to name the PhD students they intend to use during **July**, so that these can be eliminated from the Research Student Grants Scheme
- Projects then typically start in **October**, at the beginning of the new academic year

Monitoring has been relatively 'hands-off'. While there is an intention to increase the proportion of projects which receive site visits from Forbairt to some 20%, it is not entirely clear to us how this will add value above and beyond the existing, simple, paper-based monitoring system. A more useful step might be to post-audit project performance, compare it with assessors' original gradings and use this 'track record' as an advisory input to the appraisal process. The Scheme currently does not employ any output indicators.

2.3 Grant-related publications and citations

In order to confirm that the grants are funding research projects which allow researchers to perform worthwhile projects, we performed some very simple tests for publications related to projects. These should be regarded more as a 'spot check' on the quality of work funded under the Scheme than as conclusive and systematic bibliometric evidence. (A full-scale bibliometric exercise is beyond the scope of this study.)

We asked project leaders to list peer-reviewed publications arising from their BRG (either on the questionnaire or on the CV they attached with their responses) and to indicate whether these were fully or partly attributable to the grant.

There is a time delay between performing research and so we restricted our exercise to respondents who had received BRG funding between 1989 and 1992. This allows us to check on the publications arising from these grants between 1989 and 1997 and on the citations that these publications received in the same period.

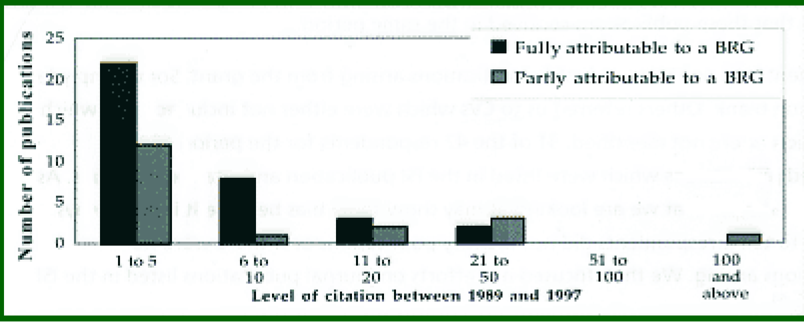
Respondents did not always identify publications arising from the grant. Some simply left this section blank. Others referred us to CVs which were either not included or in which publications were not identified. 31 of the 42 respondents for the period 1989-92 identified publications which were listed in the ISI publication and citation database. As a result, the sample that we are looking at may show some bias because it is not always possible to tell if respondents did not identify publications or if there were no publications arising. We then focused our efforts on journal publications listed in the ISI database.[44]

Although we did not have information on all publications related to the grants, we were able to identify the level of journal publications of all scientists who had received grants between 1989-1992. We used the ISI database to identify these scientists by name and institution and then recorded all their publications between 1989 and the latest available data from the ISI. On average, each project leader had published 25.7 papers in the seven years covered. This leads to an average publication rate of 3.65 journal articles per year for each scientist. However, a few scientists within this sample have published over 50 articles in the seven years covered which will have increased this average. The median number of publications over the period is 15 publications or 2.15 publications a year.

The latest available figure for average number of publication per head per annum for of full time academic staff in Ireland is 0.90 publications.[45] Both the average and median number of publications are significantly higher than the average publication rate of other Irish academics.

We looked at the different levels of citations achieved by publications that were fully or partly attributable to the grant. Exhibit 2.5 shows how often the publications identified were cited in the period 1989-97.[46] Proportionately, partially attributable publication tend to be cited more often than fully attributable publications. A significant number of the partially attributable publications also link to large international research projects.[47] The high level of partly attributable citations indicates that the scheme is helping scientists to participate in international science.

Exhibit 2.5 Frequency of citations to sample of BRG papers

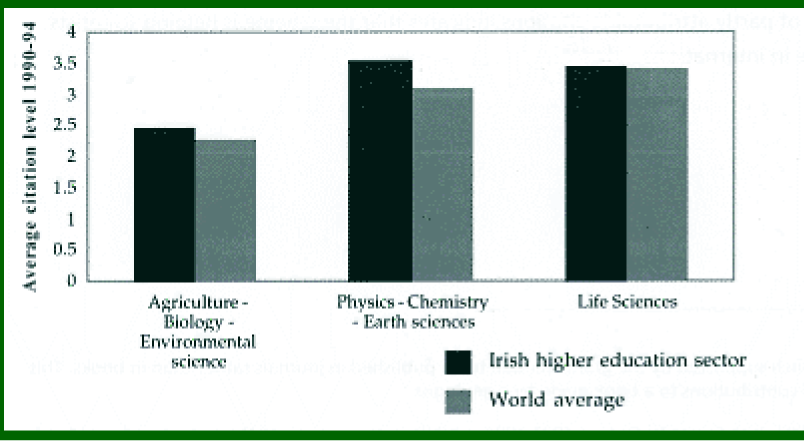


Excluding partly attributable publications we find that, on average, in the period 1989-1997 publications arising from BRG support were cited 5.4 times in the ISI database.

It is difficult to use this average as a strong indication of performance because citation levels tend to vary by field of research. In addition, our sample was too small to restrict citations to 5 year cohorts, which is the usual basis for international comparisons. However, with the exception of seminal publications, or less active fields of research, most citations occur shortly after publication. The vast majority of articles within our sample were cited within 5 years of publication and most of the publications occurred after 1991. We believe that it is reasonable to use this as a simple check on the performance of articles arising from the BRG scheme.

The latest available figures[48] for average world and Irish citations for Physics, Chemistry and Earth sciences; the Life Sciences, and; Agricultural and Biological sciences are presented in Exhibit 2.6.

Exhibit 2.6 Irish and World Average Citation Frequencies by Field



Based on our limited sample, we tentatively conclude that the grant recipients:

- Publish more articles in journals covered by the ISI than other researchers in the Higher Education Sector in Ireland
- Achieve higher citation rates for the publications they identified compared to other Irish scientists in the Higher Education Sector

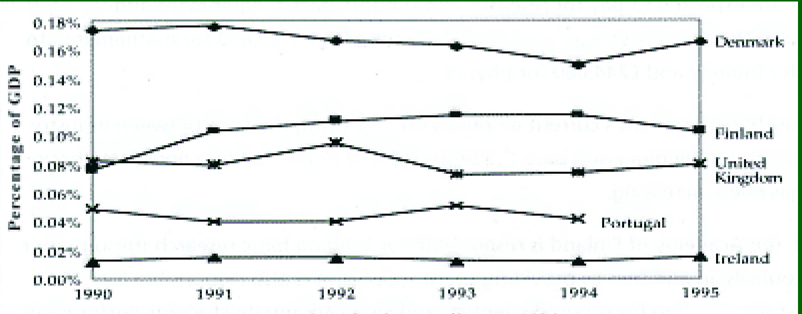
The above-average performance of BRG research grant holders in this respect tends to confirm that the Scheme is selectively funding good quality science.

2.4 Some Broad International Comparisons

Raising the proportion of GDP devoted to R&D is already an objective of Irish policy. Within the public allocation for R&D, Ireland directs a smaller proportion to basic research (defined as non-orientated programmes) than other countries. The proportion of GDP directed towards basic research is less than half of that of any of the other countries examined **(Exhibit 2.7)**.

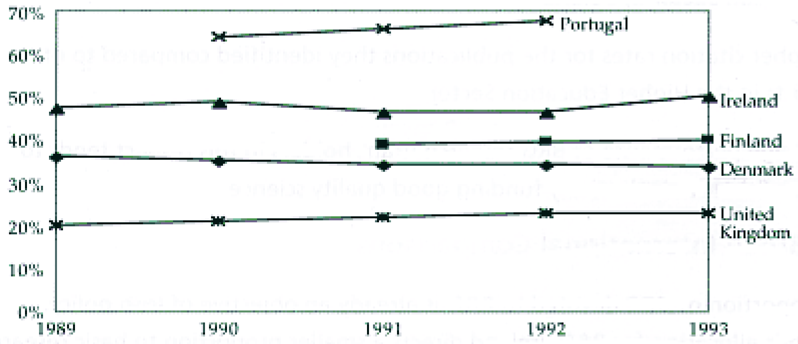
Exhibit 2.8 shows that Irish researchers in universities make up a disproportionate share of the total number of researchers in the country. This is a problem in that university-based researchers provide little direct contribution to wealth creation, even if their indirect role is significant. Over time, with increasing industrial development, we should expect the university-based share to fall and the proportion of researchers working for industry to rise - within the context of an overall growth in numbers. The BRG Scheme should be a significant provider of people in both categories.

Exhibit 2.7 Non-oriented research programmes as a percentage of GDP



Source: OECD, *Main Science and Technology Indicators*, 1996

Exhibit 2.8 Higher education researchers as a percentage of national total



Source: OECD, *Main Science and Technology Indicators*, 1996

Our international review shows that there is usually a variety of sources for funding research projects. However in the countries examined (Portugal, Finland, Denmark, Singapore and the UK) the source of funding for basic research tend to be allocated through dedicated agencies or bodies.

In the UK research councils are responsible (amongst other things) for allocating funds through 'response mode' programmes (i.e. in response to a call for proposals). This accounts for the majority of funds awarded in any given year.**49**

Grants are peer reviewed by national and international experts (of which at least one is nominated by the proposer) and any grant that receives strong support from at least two reviewers goes on to be assessed by a larger panel of peers.

Grants are usually awarded to cover research activities over a three year period.

All awards are expected to pay for research and support staff[50], equipment and consumables. The average size of grants varies by field from £ 80,000 for mathematics to £160,000 for biology and £244,000 for physics.

Despite the UK government's current emphasis on improving the links between industry and the science and engineering base the proportion of public funding going into basic research has been increasing.

In Finland, the Academy of Finland is responsible for funding basic research through four research councils. In addition to providing grant support, it is also responsible for awarding direct funding for tenured scientists and to postgraduate students performing fundamental research.

Proposals are peer reviewed (usually by Nordic experts) and allocated funds based on scientific quality and the researchers' track records. The level of funding available for university based research depends on whether the project forms part of a wider targeted research programme. If it does, funding levels tend to be set at between £60,000 and 120,000 for a three year project.[51] Projects which do not naturally fall under a targeted research programme receive grants of between £25,000 and 60,000 for a 12 month project.[52] In both cases, postgraduate students are treated as members of staff and their salaries will be included in the grant awarded.

In Denmark, funding for university research is available either directly from the ministry of education which provides core funding and from the Danish Research Foundation which awards large discretionary grants to research centres undertaking fundamental work.

The Danish Research Academy is responsible for coordinating postgraduate work in university and academic colleges. It advises the government on the distribution of postgraduate scholarships to higher education institutions.

Portugal funds basic research through the National Board for Scientific and Technological Research (JNICT). JNICT manages both its own funds and a proportion of funds allocated under the PRAXIS XXI project. Funding for fundamental research projects is administered through a national peer review exercise. Spending on fundamental research in Higher Education has increased from £15 million in 1988 to just under £60 million in 1995.[53] Funding for basic research now represents roughly a quarter of total research activity.

Grants are intended to cover the cost of research staff, materials and equipment. Postgraduate students are awarded separate grants to cover living expenses and laboratory costs.[54]

Singapore has adopted a different strategy. The National Technology Board is responsible for coordinating R&D activities. It funds basic research through grants to public research institutes (60% of Basic Research Budget) and Higher Education (25% of Basic Research Budget).

These countries fund basic research through a variety of mechanisms with some having an agency or board dedicated to funding basic research and others channelling funds through research councils responsible for allocating funds to support both applied and basic research projects. In most cases the funds for basic (response mode) projects are larger than the funds for applied projects, mainly because these are funded by different bodies.

Portugal and Denmark fund PhDs directly with post graduate grant funding.[55] Other countries operate through mixed funding strategies (i.e. through research grants and studentship awards). In all cases, however, funding for postgraduate students is provided from a single source which is stable for three or more years.

2.5 Conclusions

The BRG Scheme is a well-established mechanism for funding basic research in Ireland. It has been growing at a fast rate in recent years, though from a very low base. As a result, it is able to make more, larger awards than before.

The Scheme appears broadly well managed, although the dominance by Irish peers in the assessment mechanism leaves the BRG open to criticism. Significant publications are being made in respected international journals, based on BRG funds. Publication and citation rates are both higher for BRG-funded projects than for the generality of Irish science.

The major concern arising from the analyses in this Chapter is the small size of the Scheme, in the context of a national spend on basic science (and on R&D in general) which is low by international standards.

3. The Scheme and the Economic Role of Basic Science

Introduction

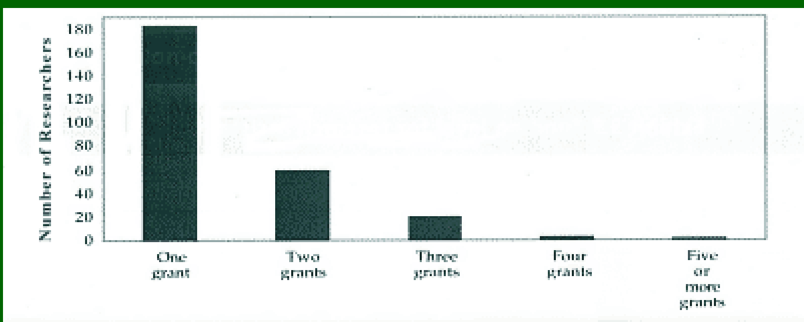
In this Chapter, we describe the results of our survey of Scheme participants. This survey maps important aspects of the way the Scheme is used and perceived. We then move on to look at the economic role of the type of basic research funded by the Scheme. We do this through reporting a series of interviews with scientists which were structured around the types of science-industry links discussed in Chapter 1. Finally, we look at the relationship from the perspective of industry, reporting the results of structured interviews with a sample of the leading research-performing companies in Ireland in order to understand the role and importance of the science base in Ireland to their operations.

3.1 Mapping the Scheme: Participants' Views

3.1.1 Questionnaire responses

We obtained information from Forbairt on the grants awarded between 1989 and 1996. After standardising the different formats the data were recorded in, we obtained information on 400 different grants awarded to 272 distinct project leaders. **Exhibit 3.1** shows the distribution of grants to researchers by total number of grants received.

Exhibit 3.1 Distribution of grants to project leaders 1989-96



In order to maximise response, we limited the number of questionnaires sent out to no more than two per project leader. We asked recipients with 3 or more grants to fill in questionnaires relating to their oldest projects as this would allow us to look at the impact of research projects. In all, 361 questionnaires were sent out to the 272 project leaders.

There were delays in obtaining questionnaire returns and after the initial deadline we chased the majority of non respondents. In the end, we received 172 questionnaires from 122 different researchers, or a response rate of 48%[56], covering 45% of grant recipients.

3.1.2 Project timing and resources

Project duration was fairly stable in the period 1989-95 with an average project length of around 24 months.[57] In 1996, however, as a result of the decision to extend the funding period to up to 3 years the average estimated project length increased dramatically to 31.5 months.

Exhibit 3.2 shows the allocation of funds to different categories of expense. Although the proportion of the funds granted which paid for staff is high as a percentage of total grant funding the real level of funding for staff is surprisingly low. **Exhibit 3.3** shows how the amount of funds allocated to research assistants varied between 1989-96.

Exhibit 3.2 Distribution of grant resources

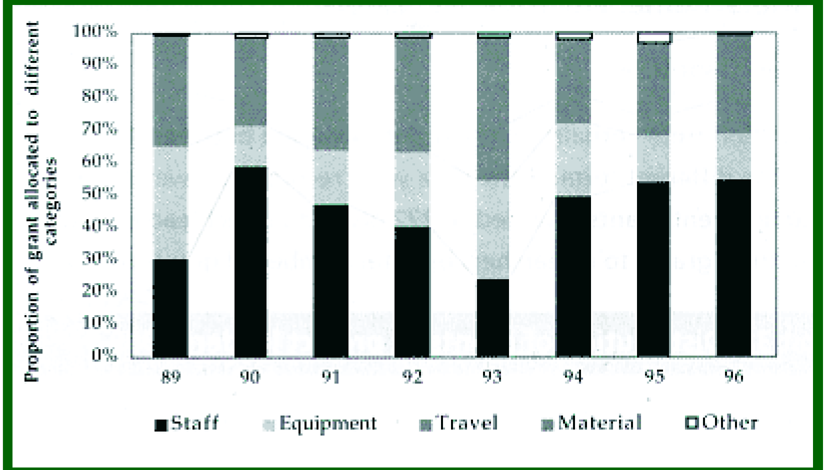
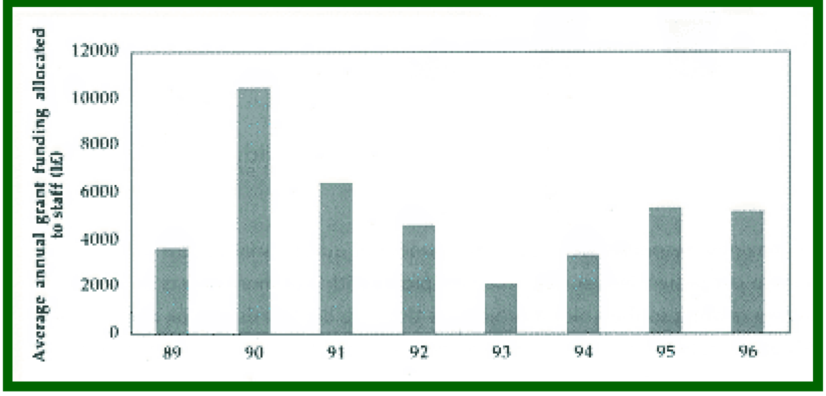


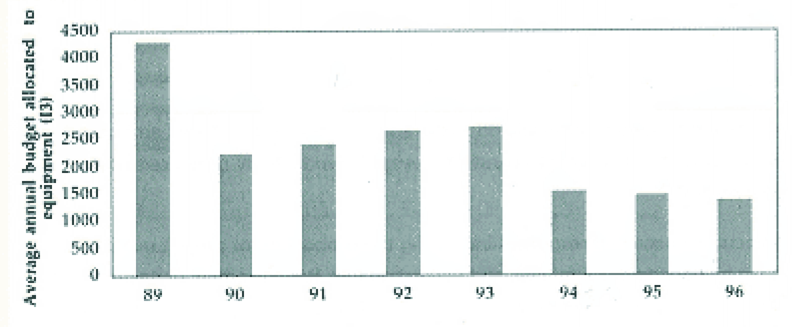
Exhibit 3.3 Funding level for research assistants



The peak in staff funding in 1990 is caused mainly by the high average value of grants awarded in that year.[58] Research assistants tend to be PhD students although there are now a few post-doctoral fellows also supported by the grants. However, on average there is not enough funding to fully fund the full cost of even one post-graduate research assistant per project.

A similar graph for project resources allocated to equipment shows that between 1993 and 1994 there was a sharp decrease in project-associated equipment funds. The level of equipment funding has now stabilised at just under £1,500 a year. This has to be understood in the context of the low level of equipment funding provided to Irish Universities which has fallen to £0.5 million in the most recent year.

Exhibit 3.4 Equipment funding from grants



3.1.3 Participation of postgraduate students

One of the main functions of the scheme is to support the training of postgraduate students.

Out of the 172 questionnaires returned, 156 provided some information on the project staff. We received information on 42 post doctoral fellows and 202 postgraduate students (of whom 154 were PhD students).

- 44% of all post-doctoral fellows, 17% percent of PhD students and 14% of all other postgraduates came from outside Ireland.[59] The bulk of the post-doctoral fellows are funded to work in Ireland by the EC-TMR programme
- For the post-doctoral fellows for whom we have a subsequent destination, 13 out of 24 (54%) left Ireland. Most chose to stay in academia but 5 out of 24 found work in industry (2 in Ireland)
- Most of the students funded in the last couple of years are unlikely to have completed their studies. For the cohort of 82 postgraduate students funded by grants between 1989 and 1993 for which we have a subsequent destination, we find that 19 of them (32%) found work in industry and that 18 (30%) initially left Ireland

Project leaders were also asked to estimate how much of their time staff spent on the project and what percentage of project manpower these represented along with information on what percentage of total research training was provided by the grant research.

The grants provided a significant part of the research training of postgraduate students. On average, the grant was expected to account for 72% of the training of PhD students.

Extrapolation of the responses would indicate that the grant funding in 1996 accounted for the support of around 40% of the training of annual PhDs completed in the Sciences in Ireland.

3.1.4 The structure of research teams

The research teams funded rely heavily on Postgraduate labour. The limited amount of post-doctoral involvement is likely to constrain research productivity compared with international norms.

For 105 projects, we obtained responses indicating the proportion of project manpower accounted for by post-doctoral fellows and postgraduates. We identified 35 postdoctoral fellows and 131 postgraduates involved in the grants. On average, when post doctoral fellows take part they account for 40% of the project manpower, and postgraduates for 57%. Overall, post-doctoral fellows represent 13% of project manpower whilst postgraduate students represent 71% of project manpower. The rest of the effort is provided by the project leader, other tenured scientists or senior visiting fellows

The low level of manpower accounted for by postdoctoral fellows points to a gap in the hierarchical structure of Irish research. It is generally felt that innovative research tends to be performed by those in the middle of the hierarchy (i.e. the post-doctoral fellows and young lecturers) because they have up to date training and are still able to devote most of their time to research rather than teaching, administration and supervision.

The responses certainly indicate that when post-doctoral fellows are used it is very difficult to dedicate them exclusively to the grant research because of their high cost. Typically, they are used to supervise postgraduate students.

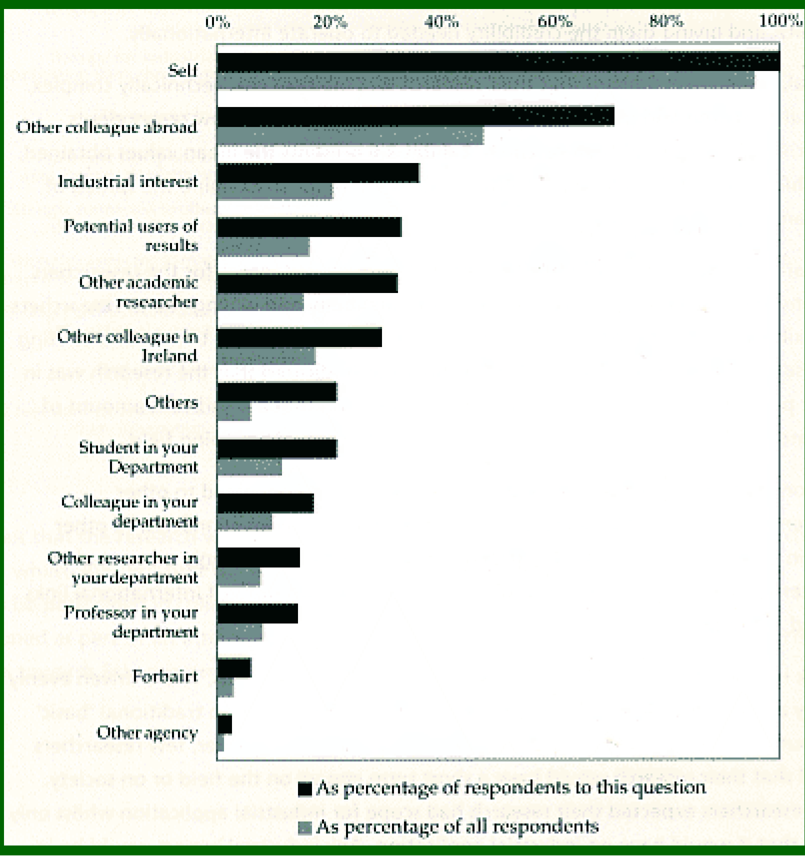
3.1.5 How respondents described their research

The grant-holders appear to have good international networks but to belong to rather small research communities in Ireland. The importance of industry and users in generating some of the research questions suggests the Scheme is funding Mode 2 as well as Mode 1 work.

We attempted to analyse the importance of different actors in generating the project idea, by asking respondents to indicate their level of involvement.

Not all respondents provided information on each category. We have therefore focussed our analysis on respondents who scored a particular factor as 3 or more.[60] **Exhibit 3.5** shows that nearly all researchers scored their own importance very highly. A surprising response is that foreign colleagues are far more important in generating project ideas than other colleagues in Ireland or in the same department.

Exhibit 3.5 The importance of actors in generating the project ideas



This is probably due to the smallness of the Irish research base, which has a specialised but fragmented research coverage. As a result some Irish scientists feel that their work is closer to research being undertaken abroad than to other research in Ireland. This confirms the function of the scheme as a “window on the world” which allows Irish scientists to be part of international research networks.

The strong influence of industrial interest in generating the project idea is also surprising. We did not expect to find this criterion ranked so highly in a Scheme which aims to fund fundamental research. It may be the result of the strong focus on applied research in Ireland.

The other unexpected response is the strong influence of potential users of the research. This can be either other scientists making use of the results, policy makers in need of evidence or industry wanting to understand a particular problem.

3.1.6 Nature of research

The questionnaire responses are broadly consistent with the view that the BRG Scheme plays a role in establishing new researchers within the rather fragmented Irish research community, and giving them the credibility needed to operate internationally.

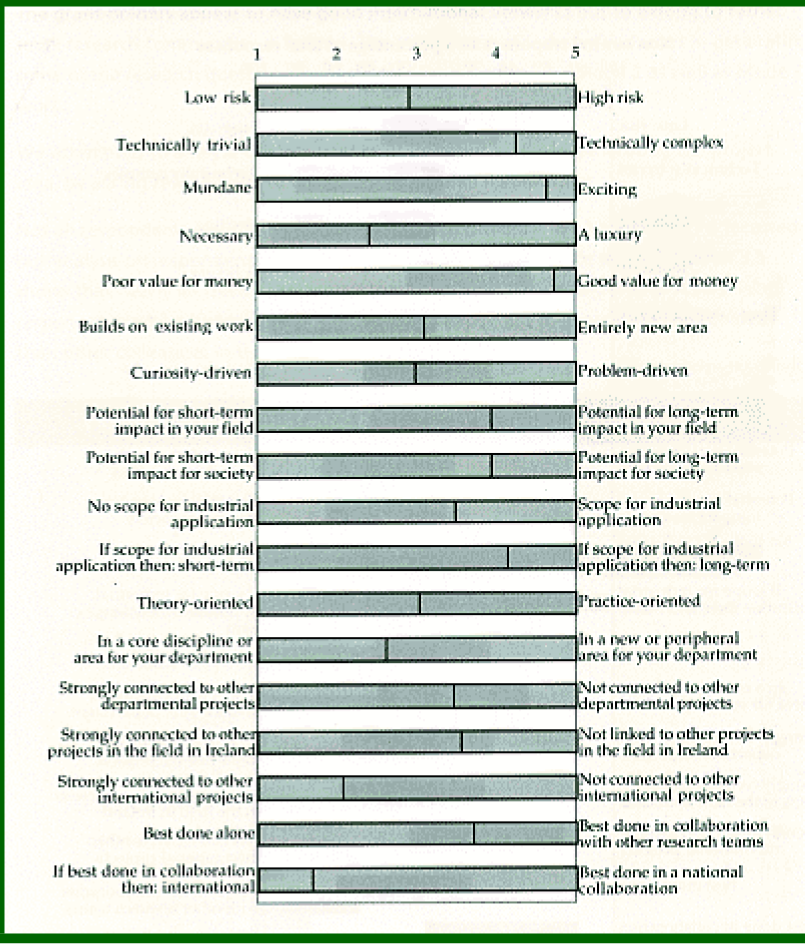
In general, researchers claimed that their research was medium risk, technically complex, scientifically exciting and good value for money. **Exhibit 3.6** shows how respondents characterised the nature of their research. **Exhibit 3.6** presents the mean values obtained, while **Exhibit 3.7** presents the non-neutral responses in order to examine the spread of opinion amongst respondents.

The research was spread evenly between entirely new research areas for the researchers and extensions of previous projects. This indicates an ability and willingness of researchers to be flexible in their research, i.e. they are able or forced to respond to new and existing areas to secure funding. Similarly, 35% of respondents indicated that the research was in a new or peripheral area for their department, suggesting that a significant amount of the research is driven by a need to establish a reputation in a developing field.

In addition, 55% of researchers felt that their work was not connected to other departmental projects and 56% indicated that their work was not connected to other projects in their field in Ireland. 72% stated that their work was strongly connected to other international projects. This confirms the data on the strength of international links presented in the previous section.

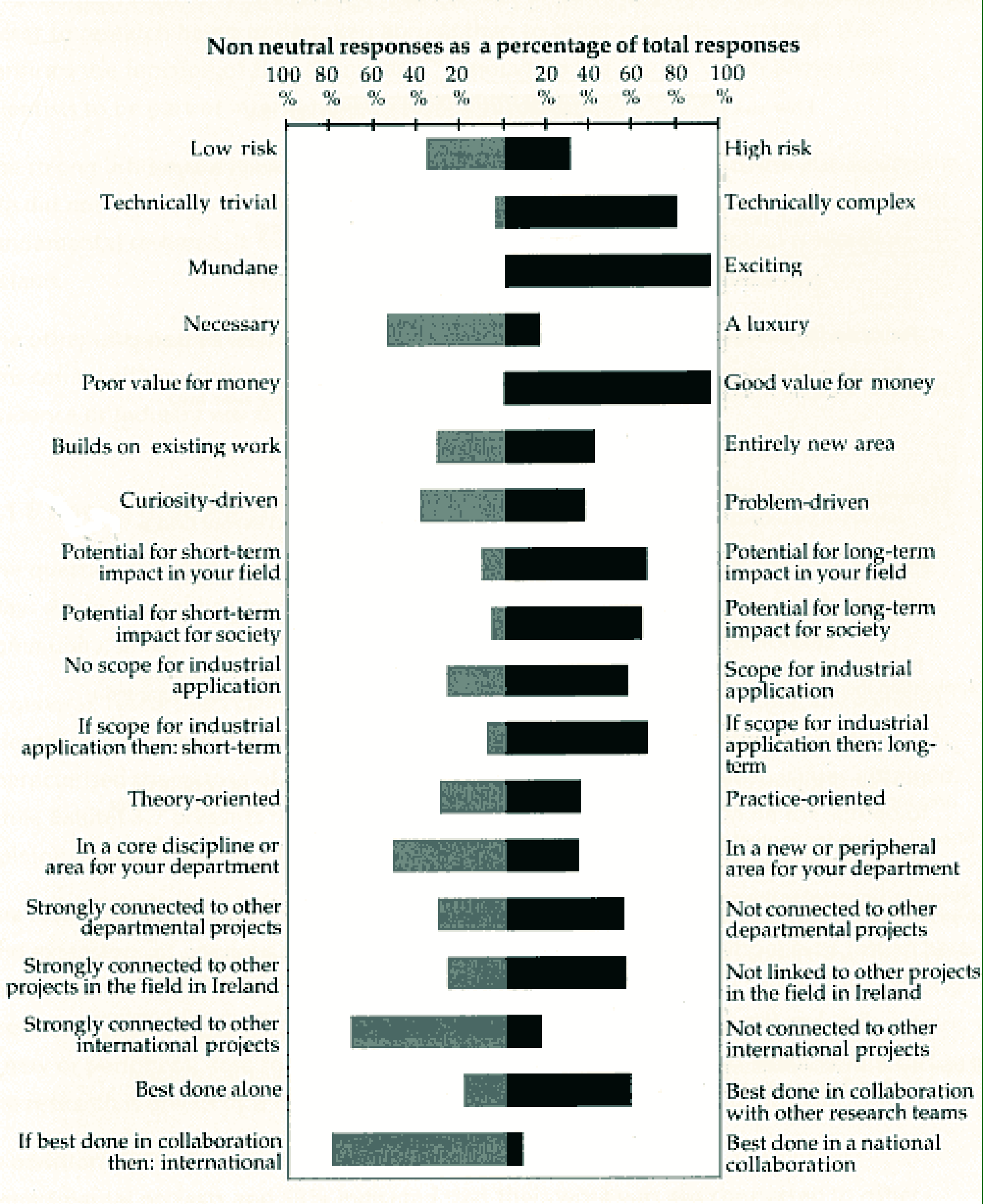
The work is an even mixture of problem-and curiosity-driven research, and is driven evenly by theory and practice. Again, this implies the work is not confined to traditional ‘basic’ science but comprises a mixture of Mode 1 and Mode 2 work. However, few researchers expected that their research would have a short term impact on the field or on society. 58% of researchers expected their research had scope for industrial application whilst only 26% felt that it would have no industrial application. Any industrial impact would be in the long term.

Exhibit 3.6 Respondents indicating the nature of their project (mean score)



58% felt that the research would be best performed in collaboration with other research teams, whilst 20% felt that the work would best be performed in isolation. If the work was to be performed in collaboration, 80% of respondents felt that it would best be performed as part of an international effort consistent with the strong orientation of Irish science towards EU programmes.

Exhibit 3.7 Non neutral responses indicating nature of research

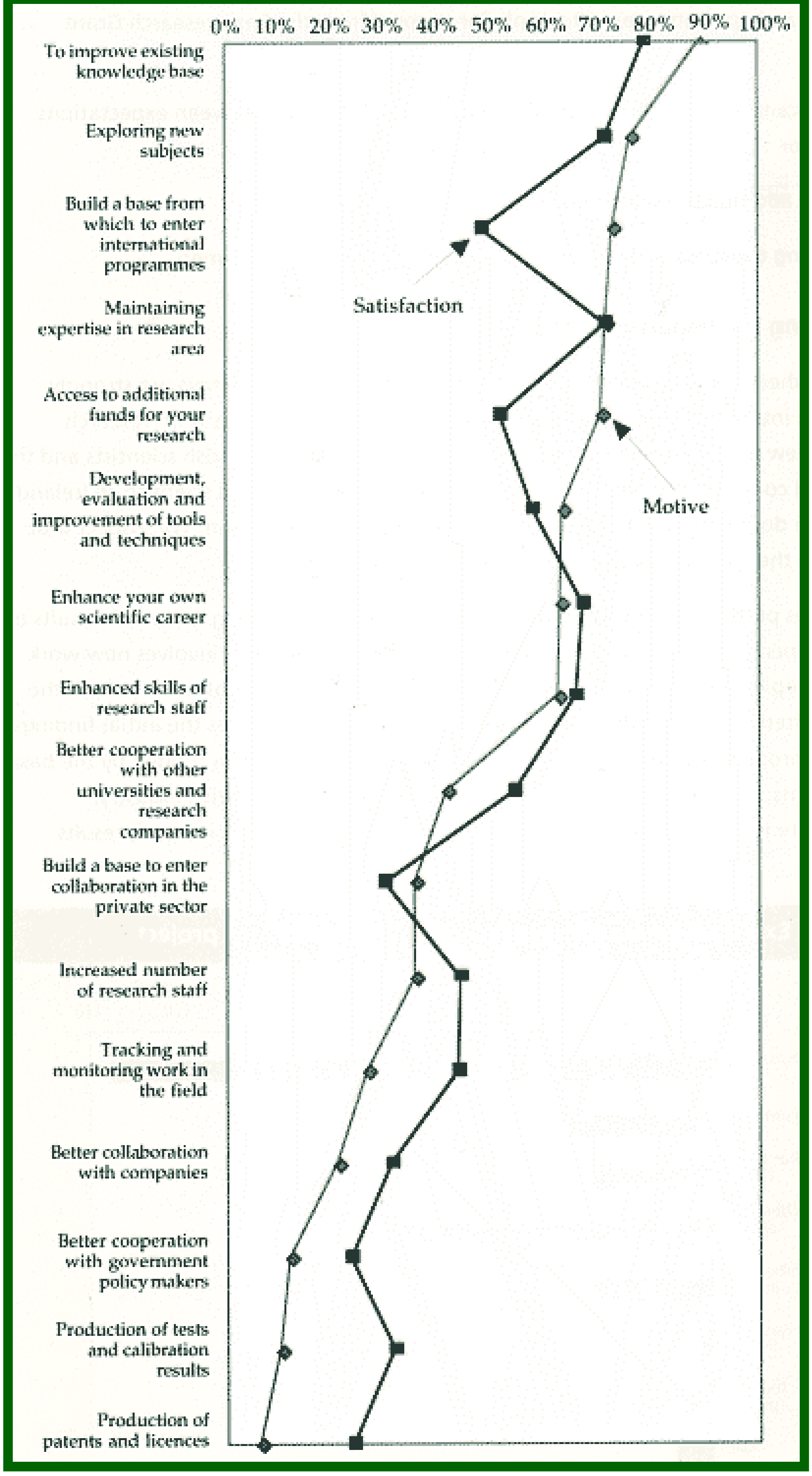


3.1.7 Reasons for submitting a proposal to the BRG scheme

Academics believe the scheme is failing to provide an adequate level of support to projects and that it is failing to help Irish scientists access other types of research programmes.

Project leaders were asked to indicate the reasons for applying to the Basic Research grant scheme and their satisfaction with the results of their participation. Exhibit 3.8 presents their responses expressed as the percentage of respondents awarding a score of 4 or 5 to any category.

Exhibit 3.8 Reasons for submitting a proposal



There is a strong interest both in developing an existing research base and in exploring new subjects. The development of new skills and techniques is also an seen as an important goal. Developing the skills of researchers is rated further down the list but is still rated as an important reason to apply for support from the Basic research Grant scheme.

Other significant points from the graph are the large difference between expectations and results for

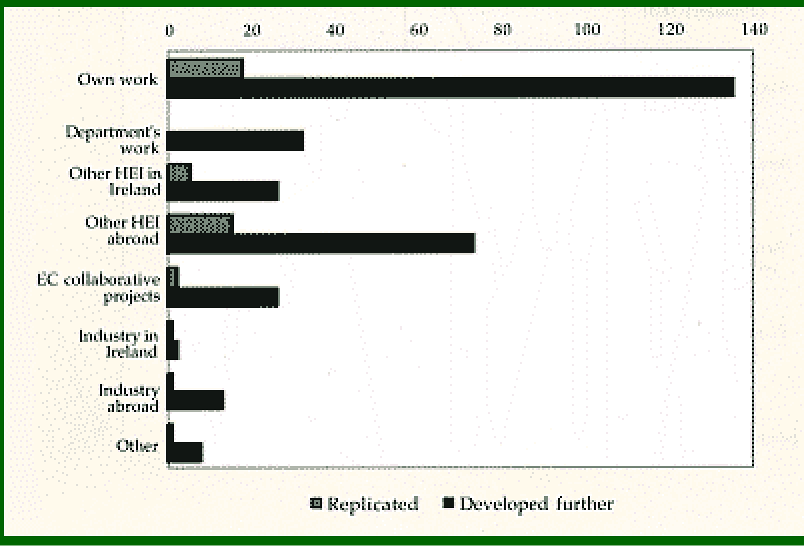
- access to additional research funds
- developing expertise with which to access international programmes

3.1.8 Tracking the impact of research

Looking at where research ideas originated showed that Irish researchers are strongly linked to the international research community and are able to access both research results and new research methods. In many cases, the links between Irish scientists and the international community seem to be stronger than the links between scientists in Ireland. Irish research does not seem to be dependent on new instrumentation. We suspect that this is due to the lack of funding available for new equipment.

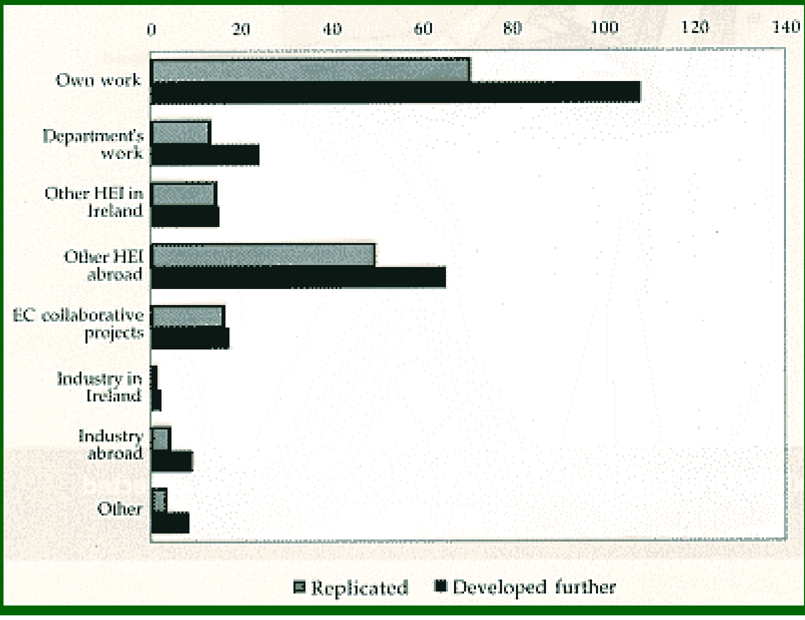
The responses presented in **Exhibit 3.9** confirm the influence of foreign research results on the research performed with the Basic Research Grants. The research involves new work rather than replication of results. In most cases, we found that replication as part of the research is often combined with further development. In 17% of cases the initial findings originated abroad but were further developed as part of the research funded by the basic research grants. As expected, there is little input into research from Irish industry. However there is is a small but not insignificant input from industrial research results abroad.

Exhibit 3.9 Research results as an inputs to grant project



The responses for the origin and development of research methods shown in Exhibit 3.10 below are broadly similar to the responses obtained for inputs to the research. It is common to make use of methods developed elsewhere and to import them as research tools. In most cases there is an incremental development in research methods with 30% of researchers stating that their methods originated with their own work but that they developed them further and 35% of methods imported from research institutions abroad also being developed further.

Exhibit 3.10 Sources of methods and instrumentation for projects



3.1.9 Impact of research grants

Apart from the project performer, the main destination of results seems to be: other departments abroad, other Irish departments and EU projects. **Exhibits 3.11** and **3.12** show how the research results arising from the grants have been transferred into different settings and how they were or are expected to be used. If we compare this to the pattern of inputs to the research, we see that the flow of research results is a two way process, with Irish scientists both drawing on and providing research results.

A concern here is the lack of impact of the research on the rest of the department in which it is performed, presumably owing to the fragmented state of Irish research.

Researchers expect that their results will in future be used most strongly in their own work, in other research groups abroad and within EC collaborative projects. The researchers expect that their work is more likely to be used, developed further or commercially exploited in industry than in their own department. In addition, researchers indicate that they expect to be in a better position commercially to exploit their research work than Irish industry and industry abroad.

Exhibit 3.11 Respondents indicating how their results have been used

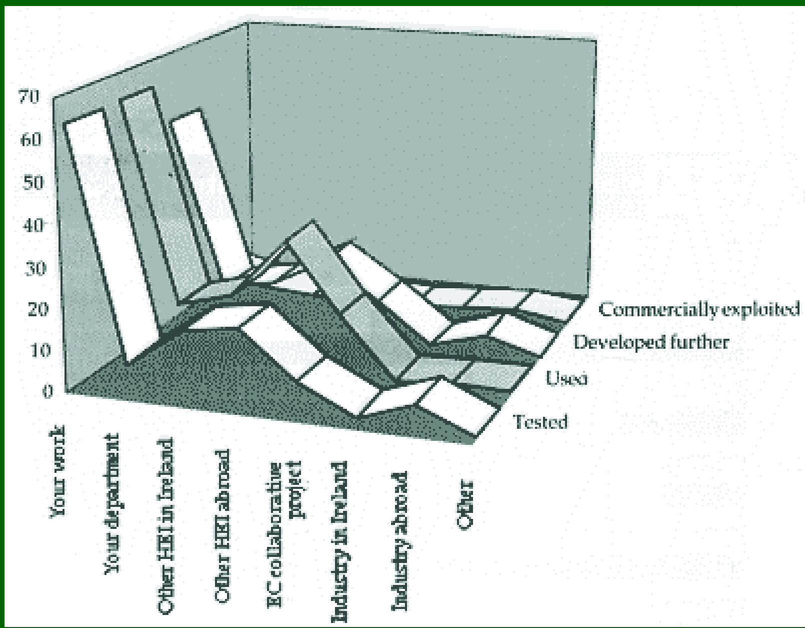
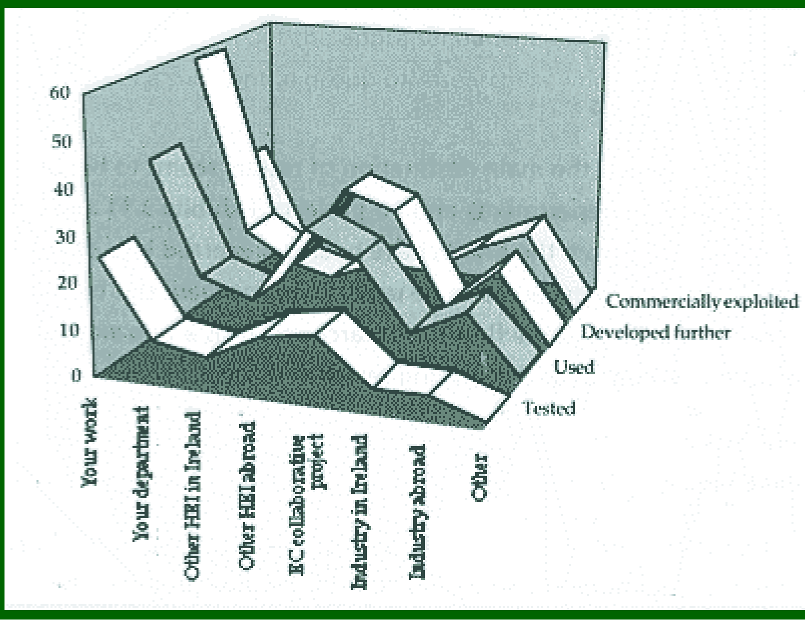


Exhibit 3.12 Respondents indicating how results are expected to be used



3.1.10 Opinion of the Basic Research Grant Scheme

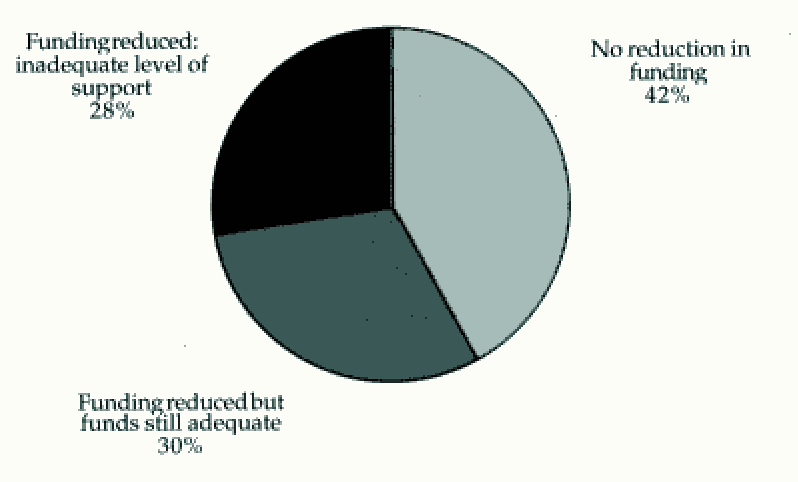
In order to measure the impact of the grants, we asked respondents to comment on their experience of the scheme. We asked them to provide us with information on the level of funding obtained and whether this had provided adequate support for their project.

Reduction in Project funding compared with funds requested was an important problem in a programme which was otherwise seen as easy to deal with and an important part of the range of potential funders.

56% of all respondents indicated that their project had been modified before funding was obtained. More than 95% of these modifications were funding reductions. Respondents indicated that about half of these reductions (or 28% of total grants) resulted in inadequate support for their project.

The most common instances were those where the grant no longer covered the the cost of funding a postgraduate student for the duration of the project. A related problem was the inability of the grants to provide funds for post doctoral students to help supervise the projects.

Exhibit 3.13 Effects of reductions in project funding

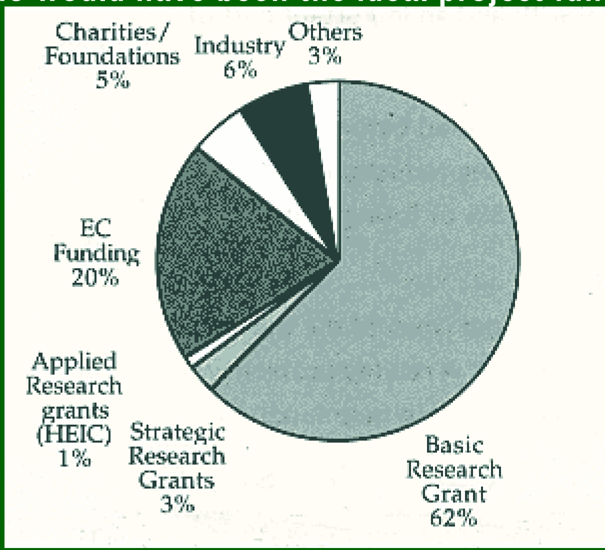


The questionnaire asked project leaders who would have provided the best source of funds for their projects and which source of funds currently funds related research projects.[61] **Exhibit 3.14** presents the importance of different sources as a percentage of all responses.[62]

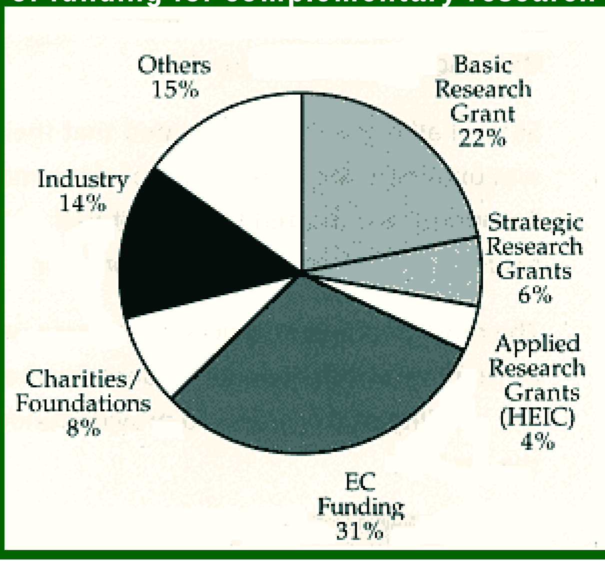
The responses indicate that despite the low level of funding it provides, researchers believe that the scheme is the most important source of funding for the type of research it supports (i.e. small pieces of fundamental research). EC funding is also a potential source of funds for projects. However, we believe that this is largely driven by the level of funding it provides rather than the type of project it supports.

Exhibit 3.14 Sources of funding for research

Who would have been the ideal project funder



Sources of funding for complementary research projects



Other projects were funded from a range of sources. EU grants were the most frequently identified. The responses for the Basic Research Grant scheme are largely driven by the fact that around 40% of our respondents had received a Basic Research grant in 1995 or 1996 which may still be providing funds. Excluding the Basic Research Grants, industrial funding is the second most frequent source of funding for grant recipients. This indicates that industry is strongly involved in supporting complementary projects in Ireland.

The source of funding for complementary projects varies significantly by field of research. Based on the information provided in the address field, we could allocate 60% of responses to one of five broad fields of research.[63]

- Geologists and chemists value the grants more than physicists and biologists. The scheme has a low impact on mathematicians
- Chemists seem to have the most varied sources of funding of all disciplines. They indicate strong links to both industrial and basic research grant funding, and seem to

obtain more funding from other Forbairt programmes than other disciplines. However compared to the other disciplines they have fewer links with EU programmes
- Physicists are the most dependent on EU funding which they supplement with Basic research grants and some industrial funding. They do not seem to have strong links to other Forbairt grants
- Biologists are also heavily dependent on EU funding, but they also have access to funding from charities and industry as well as other government programmes including medical research
- Unlike other fields, geologists are not able to access EU funding. As a result, we believe that they are more dependent on the Basic Research Grants to cover fundamental work than other fields. However, they have access to industrial funding for applied work[64]
- Mathematicians are in a similar position, in that they obtain less funding from EU programmes. However they are not able to attract funds from other sources and therefore see the Basic Research Grant scheme as an important source of funding. They are not able to obtain much in the the way of industrial support for their work

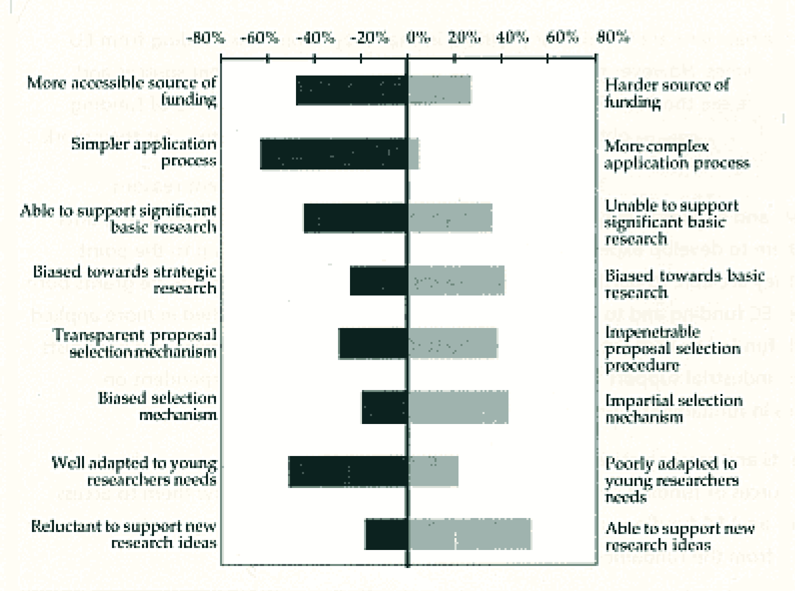
These results suggest that different scientists value the BRG for different reasons. Physicists and biologists may see it as a way to 'break into' EC programmes. The grants allow them to develop expertise which will develop their reputation up to the point where they are able to participate in EC projects. Chemists are able to use the grants both to access EC funding and to investigate fundamental problems identified in more applied research funded by Forbairt. In addition, the BRG may also allow chemists and biologists to access industrial support from an industry that is relatively more dependent on advances in fundamental research.

Geologists and mathematicians are more dependent on the scheme because they have fewer sources of funding available to them. The scheme does not allow them to access much (or any) EC funding and the research that is supported by industry tends to be quite separate from the fundamental research supported by the BRG.

Respondents believe that the scheme is a more accessible source of funding for basic research than alternatives. However, a significant number of physicists and biologists indicated that the scheme is less accessible than other sources of funding and that it is unable to support a significant level of fundamental research. Exhibit 3.15 presents non neutral responses expressed as the proportion of all respondents scoring a criterion. The bars on either side of the central axis represent the percentage of respondents that agree with the statement on the right or left of the chart.

Opinions are divided on the type of research the scheme funds[65] with the majority of responses indicating that the scheme does not tend to fund basic research.

Exhibit 3.15 Performance of the scheme

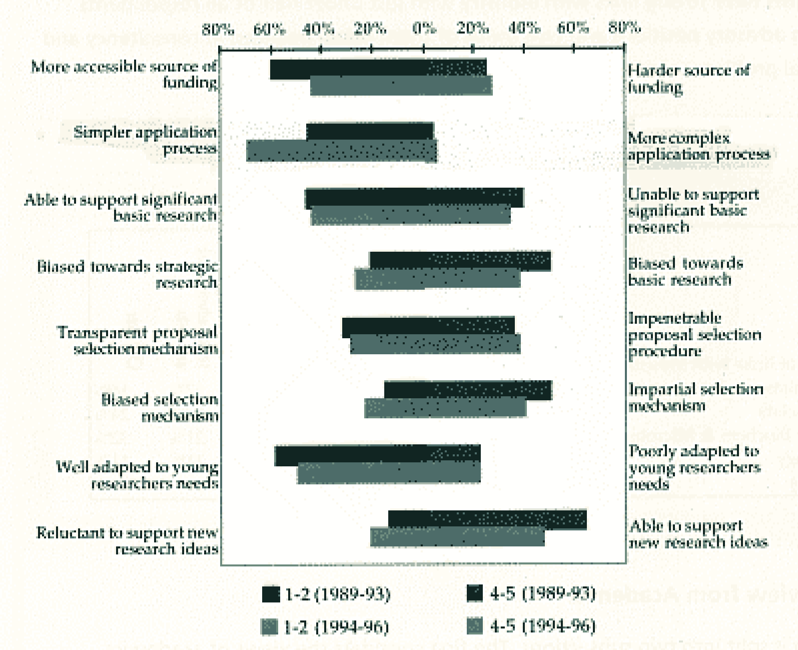


All agree that the application process is much easier than for other sources of fundamental research funding. However, opinions seem to be evenly divided about the transparency and fairness of the proposal selection mechanism. A significant number of respondents would be members of the appraisal panel and could be expected to score this favourably. This leaves a substantial group of researchers who are dissatisfied with the procedures.

Overall, the scheme seems well adapted to the needs of young researchers and is able to support new research ideas.[66]

We have also looked at the changes of opinions of project leaders over time. **Exhibit 3.16** compares the responses of those who were last funded between 1994 and 1996 (dark bars, on top) and those were last funded between 1989 and 1993 (striped bars, on bottom).

Exhibit 3.16 Changes in performance over time



This suggests that the accessibility of the scheme has declined in recent years despite an increase in the level of funding available (this may be due to an increase in the level of funding available from other sources). However, the application process is now a lot simpler compared to other sources of funding for basic research.

Overall, the perceived fairness of proposal selection and ability of the scheme to support research ideas has decreased marginally over time. We suspect that this is largely driven by the increased pressure that the selection mechanism has experienced as the amount of funding available through the scheme has grown.

3.1.11 Links with industry by research field

The number and strength of grant-holders' links with industry varied among fields. Exhibit 3.17 presents the types of links identified as a percentage of all respondents indicating a link. It confirms that there are links between fundamental research and industry and that these links are based on personal interaction which make use of the tacit skills which are embodied in researchers.

- Chemists tend to have strong links to industry with 72% involved in consultancy work and 88% providing informal support to industry
- Physicists, biologists and mathematicians have fewer links to industry with between a third and a quarter of them being involved in consultancy work
- Geologists have strong links with industry with just under half of all respondents holding advisory positions and two thirds of them being involved in consultancy and informal problem solving

Exhibit 3.17 Strenght of different links with industry

Type of links with industry	Directorship	Involvement in "spin off"	Advisory position	Consultancy	Informal problem solving	Providing access to a network of experts	Others
Chemists	12%	12%	52%	72%	88%	32%	16%
Physicists	8%	8%	8%	32%	36%	24%	24%
Bio & Biochem & Microbio	4%	0%	21%	29%	25%	21%	32%
Geology	11%	0%	44%	67%	56%	11%	11%
Maths	12%	6%	18%	24%	47%	29%	0%

3.2 The view from Academia

This section is split into two subsections. The first considers the views of academics regarding the function and operation of the Basic Research Grant Scheme. The second reports on the different types of links between university and industry identified by industry researchers.

3.2.1 Method

In order to confirm and deepen the responses we obtained from our questionnaire, we conducted several interviews with Irish academics in different fields of research at different universities.

Since we were attempting to validate the questionnaire, we concentrated our efforts on grant recipients. In all we conducted 17 formal interviews with grant recipients and held some informal discussions with researchers who had not received grants from the Scheme.

In some cases the researchers we interviewed were also members of the appraisal panels. All researchers were asked to comment on the grant selection process and we conducted telephone interviews with foreign scientists who acted as externs to validate these comments.

Exhibit 3.18 shows the different grant recipients we interviewed. Following some exploratory interviews, we selected researchers who had received grants from the scheme from the data provided to us by Forbairt. We then chose departments from various institutions for review in order to cover different third level institutions in Ireland. We aimed to cover a range of fields which included researchers in both applied and fundamental disciplines.[67]

Since the aim of the interviews was both to confirm the conclusions derived from the questionnaire returns and to generate case studies, we focused on fields from which we have solid questionnaire returns. In several cases, we conducted interviews with scientists from similar fields in different universities to validate comments.

Exhibit 3.18 Acadenic interviewees

	Biology	Chemistry	Physics	Mathematics
St Patrick's College Maynooth				
			•	
			•	
			•	
				•
University College Galway				
	•			
	•			
	•			
	•			
Dublin City University				
		•		
		•		
		•		
		•		
			•	
Trinity College Dublin				
	•			
			•	
				•
			•	

During our interviews we asked the scientists to explain how they used their grants and how, in their experience, they differed from other research grants.

Two main functions of the scheme were identified during the interviews. The first is to provide project funding for small projects that can be used to train students up to PhD (or MSc) level. The second is to provide a step up for researchers to access the more generous funding which is provided by the EC.

3.2.2 Training post-graduate students

All our respondents identified this as one of the key functions of the scheme. Although the project leader is a member of staff, much of the actual work is in fact performed by post-graduate students. The educational level of the students varied from one institution to another with some departments having insufficient funds and resources to support PhD students.

The application for funding operates in a response mode. From the point of view of the grant recipients, the funding provided is not always clearly linked to a specific project. Rather, it makes up part of the larger pot of resources that the project leader can draw on to pursue his or her research. He or she is then able to allocate the resources provided by the grant in order to work on the area of research identified in the proposal. The project leader will already have postgraduate student(s) and allocates resources to students to provide a minimum of funding for each student.

In the majority of cases reviewed, Project leaders argued that the resources provided by the grant were not sufficient to cover the cost of supporting a PhD student through postgraduate training. The length of the grant was considered to be a problem as the two year funding made it impossible fully to support a PhD student.68 Project leaders solved this problem by:

- funding MSc students rather than PhD students
- drawing on departmental funds to provide part of the funding
- cross-subsidising students by using funds allocated to other projects

In some cases project leaders had agreed to supervise PhD students in the hope that they could find further funding for them at the end of a two year project. This led to subsequent funding problems in a few cases. In nearly all cases, project leaders spent a large amount of their time trying to juggle funds from different sources to support their post graduate students.

In laboratory-intensive research, senior project leaders felt that the funds provided by the grants were not sufficient for them properly to supervise their students. Senior members of staff typically have more responsibility for non-research activities (committees, course supervision, conferences, etc). Some felt that the grants did not account for this, and they felt that the grants should have provided some funds for a post-doctoral fellow to make up for this. Younger researchers had more time to devote to their students than senior members of staff but were less likely to receive grants.

3.2.3 Accessing larger sources of funding

The other function of the scheme that was identified by researchers was its role as a stepping stone to access larger sources of funding (typically Forbairt Strategic funds or EC funding). The level of support provided by the grants was thought to be quite low in comparison to that provided by Forbairt Strategic Funds and EC funding.

In several cases the Basic Research Grants had allowed researchers to establish themselves in a developing field or allowed them to change from one research area to another. The grants provided a small level of funding to look at new developments which allowed researchers to publish and achieve recognition from the research community. In 12 out of our 17 interviews, researchers had obtained funding from the EC or Strategic grants after they had completed their Basic Research Grant project. The enhanced visibility achieved by the publications encouraged more established scientists (often abroad) to invite them to join larger EC consortia.

The ability to provide this step-up funding was one of the most valued aspects of the grant. However, many researchers felt that whilst this mode of operation was a cost effective way to boost Irish research, it made Irish science over dependent on EC funding.

Unlike other countries which provide sustained funding for fundamental research, the Irish system was only designed to ‘kick-start’ researchers and could not support large-scale or programmatic fundamental research. Young researchers in particular were worried about their ability to obtain funds in the long term. They expected that they would have to drift into more applied research to secure reasonably sized grants.

The other issue that was discussed was the problem of equipment funding within universities. The majority of interviewees in equipment intensive fields argued that the dearth of equipment funding within the BRG and other national and international schemes had forced them to develop different approaches to their problems compared to what was seen as the state-of-the-art approaches in other countries. Whilst many felt that this was positive in several respects, they feared that in the long term Irish researchers would be unable to compete with their European counterparts in EC consortia. One researcher in the biological sciences explained that his department could no longer work within a EU projects because he was unable to compete with well equipped European laboratories. He argued that they had both the equipment and the technicians to perform applied research at a fraction of the cost that his department would have to charge.

The other fear was that the lack of funding of equipment would make it hard to attract post-doctoral fellows from abroad through the EU's TMR programme.

3.2.4 The importance of the BRG scheme as a source of funding

The importance of the scheme for particular researchers varied with their position in the departmental hierarchy. More established researchers indicated that the majority of their research income came from the EU (or on a few occasions from the Forbairt Strategic grants or the HRB) whilst for younger researchers the Basic Research Grants represented an important source of funds.

Several of the more established researchers indicated that funding from the BRG had been more important to them earlier in their career to develop new areas upon which they have now build their reputation. Less senior researchers indicated that obtaining a BRG would be a real boost for their research as they had not yet achieved sufficient recognition to access EC funding. However, the BRG scheme was one of several sources of funding available to them, and although it allowed them to formulate relatively fundamental research problems, other sources of national funding provided significantly better support and were therefore often more interesting.

3.2.5 Non experimental fields

Mathematicians had a different view of the scheme than experiment based subjects. Few other schemes provide funds for mathematics. Because mathematicians do not typically require equipment funding (apart from computers), they felt that the function of the scheme was different for mathematical research. There are no large scale EC funds for mathematics so the scheme was not seen to provide access to larger sources of funds.

One of the interviewees argued that:

Until recently, the scheme has largely been irrelevant for mathematicians. As a department we obtained more funding for travel from US departments than we did from Forbairt.

The funding provided by the BRG scheme was mainly used to train postgraduate students and to fund research in the department.

3.2.6 Experience of the scheme

In general, researchers who were not involved in the appraisal process did not understand how proposals were selected for funding. This was particularly true for researchers who had not received any funding from the Scheme in recent years. Their view was that the grant selection process was flawed. They did not understand how proposals had been selected and they could not believe that the appraisal process was a fair one. Several of the researchers we interviewed had submitted similar proposals every year and could not understand why they had obtained funding in one year and not in the other. Others believed that their chances of obtaining funding were so small that it was not worth spending time to draft a proposal.

They felt that there were two problems. The first was that they believed that there was a strong correlation between membership of the selection panel and the likelihood of receiving grant funding. In one department we visited, it was explained to us that there had not been anyone on the appraisal panel who represented their particular discipline. It was alleged that since there was no-one capable of assessing their proposal, it was no surprise that not one of their proposals was selected.

The second was that the panel tended to prefer 'safe' projects from established researchers in solid departments which did not involve exciting research. Interviewees thought that this was driven by the fact that the panel members were often senior members of staff who were detached from current research because they had other administrative duties or that they were simply not aware of recent developments.

They thought that this was a serious problem given that one of the aims of the scheme was to stimulate exciting new research. As a result of this some interviewees had decided to stop applying to the scheme.

In a related point, two researchers we interviewed also alleged that in some cases they had been told informally in one year that their proposal was 'not applied enough' and in a later year that 'the proposal did not address fundamental issues'. They felt that the scheme was not sending out clear messages.

Despite the increased transparency and robustness of the proposal selection procedures our interviews indicate that the selection procedures are still not highly regarded by those who are not members of the appraisal panel. This is reinforced by the lack of feedback provided to applicants. In some cases they said they had not been given any information as to why they had not received funding and had only learned of their rejection through an article announcing the projects that were selected.

Interviewees who had been members of the appraisal panel on the other hand felt that the appraisal process was a fair one. A few commented that although they had had their doubts about the process before becoming members of the selection panel, they now felt that it was as fair as it could be, given the resources available for the selection process and the scheme.

They indicated that the panels tend to adopt a strategy of spreading funding as widely as possible by cutting the funding for individual grants to its bare minimum. One panel member we interviewed indicated that the level of funding provided had caused surprise among foreign referees who could not believe that these projects could be performed on the proposed budgets (let alone the reduced funding that was usually awarded).

In order to validate these views we conducted telephone interviews with some of the foreign peers who acted as externs on the selection panels. The externs are either British scientists who have taken their first degree in Ireland or researchers working in Northern Ireland.

Their comments confirmed the description of the appraisal process by the Scheme manager and the Irish members of the panel. They noted that in most cases they had a fairly good idea of how much funding was available in their area. Although grants were not rejected because they requested a high level of funding, the costings were scrutinised and often reduced to the minimum possible to carry out the project. One of the externs was disappointed at the effort that had gone into writing good proposals considering the amount of funding available. They noted several other points:

- Some areas of research did not seem to be properly covered by the appraisal panels
- The grants request were significantly smaller than grant requested from the UK funding councils (the amount of funding obtained was smaller still).
- They noted that the emphasis on track record meant that established scientist would be in better position to get grant funding despite the role of the programme as a 'start up' mechanism

Despite these caveats, they felt that the grant selection process was as fair as it could be given the funding available.

The fundamental differences in perception of the fairness and openness of the scheme between applicants and panel members and externs, suggests that the problems that are perceived are probably not due to the selection process itself but to the apparent lack of transparency that surrounds it.

3.2.7 Academic Links with Industry

During our interviews we reviewed the different types of links that might exist between academics and industry. We used the six types of links identified in Chapter One to structure our discussion. In all cases our interviewees found it difficult or impossible to look at the grant they had been awarded in isolation from the rest of their research.

One of the important functions of the scheme seems to be to help scientists establish the reputation and experience needed to do further work. It is this further work which is likely to generate links with industry. We therefore chose to ask our interviewees about the links to industry from their overall work. **Exhibit 3.19** summarises the links that were discussed in our interviews.

Exhibit 3.19 Links between academics and industry

	Increasing Stock of useful Information	New Methodologies and Instrumentation	Skills of Students	Access to Networks of Experts and Information	Solving Complex Technological Problems	Spin-off Companies
Mathematicians						
	Y	Y	Y	N	Y	N
	N	Y	Y	N	N	N
Physicists						
	Y	Y	Y	N	Y	N
	Y	N	Y	N	N	N
	Y	Y	Y	N	N	Y
	Y	Y	Y	Y	N	N
	Y	Y	Y	N	N	N
	Y	Y	Y	Y	Y	N
Biology Based						
	Y	Y	Y	N	Y	N
	Y	N	Y	N	Y	N
	Y	Y	Y	N	Y	N
	Y	Y	Y	N	Y	N
	Y	Y	Y	N	Y	N
Chemists						
	Y	N	Y	N	Y	N
	Y	N	Y	N	Y	N
	Y	N	Y	Y	Y	N
	Y	N	Y	N	Y	N

Providing new useful information

This proved to be the hardest link to examine because the impact of current or recent research take a certain amount of time to diffuse. Additions to the stock of knowledge are often incremental, which make it impossible to attribute a subsequent use in industry to an individual piece of research. However, 16 out of the 17 grant recipients we interviewed could point to some current or previous contribution to new useful information arising as a result of their research. In addition, all of these felt that they would continue to make contributions.

A concern voiced by several of the researchers was that their contribution could only be grasped by technologically sophisticated firms. In several cases they felt that the low level of industrial research in Ireland would mean that their contribution would be exploited abroad.

Some of these contributions originating from Basic Research Grants had clear applications outside the original field of research:

Fundamental research on the factors influencing interactions between bacteria in anaerobic conditions at the microbiology department at the University of Galway has been used in bioremediation to clean up contaminated areas and to improve the production of methane gas - which is a sustainable source of energy - at a waste recycling plants in Cork.

Work on the photochemical properties of materials at the chemistry department at DCU has led to: the development of sensors which are capable of identifying the chemicals which are produced when certain foods are ‘off’; and the current development of polymer solar cells which have the potential to dramatically reduce the cost of using solar energy and are capable of operating in diffuse light

Other contributions were not so visible, for example:

The results of bio-informatics research which involves looking at genetic sequences using powerful computers are now published on the internet at TCD. The site at TCD can be used as a reference for genetics research and there is evidence to show that pharmaceutical companies make use of data provided by the site

The Basic Research Grant funded research on the synthesis of new compounds and their use for chiral analysis systems at DCU is leading to the development of new chiral separation systems. This of particular interest to pharmaceutical companies that need to separate chiral compounds. Chiral separation could be used for example to remove the unwanted side effects of drugs such as thalidomide.

There was considerable difficulties in differentiating between research results and the methods and instruments (including software) used to perform the research which are discussed in the next section. We were told that pharmaceutical and chemical companies often tracked new publications because this allowed them to track the development of new methods and new uses for instrumentation.

We had a particular problem in deciding whether the work of a physicist on modelling techniques was a research result or the development of a research tool for astronomy. As a result we have not counted his research results as a contribution.

Only one researcher (a pure mathematician) felt that the results of his research would never be a source of new useful information for industry, or for anyone else outside his field.

New instrumentation and techniques

The importance of developing new instrumentation and techniques tend to vary from field to field. Chemists and biologists, for example, tended to develop less new instrumentation than physicists. However, chemists and biologists tended to develop more experimental methodologies.

The experience and methods acquired though the research performed at St. Patrick's college to develop communication equipment for the Mars Pathfinder mission is currently being used to develop fault tolerant electronics for use in intensive care applications.

The development of sub-millimetre wave modelling techniques for use in radio astronomy at St. Patrick's college can now be used to develop the use of sub-millimetre wave communications between telecommunication satellites.

In most cases a piece of fundamental research provided the initial project idea which was then often developed though EC or strategic grants:

Research on the interface properties of metals and semiconductors at TCD initially led to the development of a buried probe to look at the interface at a depth of 500 nm. This new technique is of interest to the semiconductor industry and for developing anti corrosion coatings. A BRG split between between the TCD group and a research group at DCU which was interested in understanding sol gel formation led to further optical development of the sensor through a Strategic Research Grant. This has led to the further development of a sensor capable of sensing dissolved oxygen concentration which has been patented and is on the point of being commercially exploited.

A Basic Research Grant to study the Genetic Characterisation of Marine Archaea - a common salmon parasite - at the University of Galway has led to EU funding to development a DNA test capable of identifying the outbreak of the disease caused by this organism. The test method, which has been patented by the national diagnostics centre, could significantly reduce the use of antibiotics by fish farmers

In many cases the development of new instrumentation did not feed in directly to industry but allowed the research team to work more efficiently, both on fundamental and applied projects.

The development of a sensor capable of overcoming the problems associated with trying to cultivate and measure the activity of anaerobic organisms was developed at UCG. The sensor operates by measuring the pressure generated by the methane produced in the sample. This sensor has allowed the department to increase the speed of the research on anaerobic organisms. The sensor which was developed by a young technician is now in regular use in this field of research in Ireland and abroad.

Software development tended to cut across disciplines as a generic research tool. We found examples of software development in Biology, Physics and Mathematics. In some cases there were examples of inter-field collaboration and exchanges relating to software:

For example there were links between the mathematical physics and biology department at TCD. Both researchers were using software to do multiple sequence analysis, one was working on DNA sequencing whilst the other was working on spin theory. They had exchanged ideas because they were essentially using software to automate pattern recognition in large sequences.

Skills of researchers

The proportion of associated post-graduate students moving into industry varied from one project leader to another. In many cases our interviewees did not always know the current location of former PhD students. Our interviewees did not believe that the PhD students supported by their BRG differed significantly from the other PhD students they supervised.

After their PhDs, students who wished to pursue an academic career were often forced to emigrate (mainly to the UK or the US). In fact some of our interviewees indicated that they had also left Ireland after their doctoral degrees. This was driven by the low level of post doctoral places in Ireland and partly by a desire to develop their skills abroad.

The rest of the students either went into industry in Ireland or abroad, or into the public sector in Ireland. In general, industry seemed to value the skills of PhD students. One researcher indicated that the competences of her students made them so attractive to private companies abroad that she could not afford to keep them on as postdoctoral fellows.

Although PhDs moving into the private sector stopped being active bench scientists, their technical competences allowed them to act as line managers in quality control or to form part of the technology transfer teams that are responsible for introducing new processes in Irish manufacturing plants.

During our interviews we obtained a detailed survey of the subsequent destination of Chemistry PhD students from UCD. The survey shows that over 50% of Chemistry PhDs are currently employed in industry. The majority of these are in the Fine Chemicals and Pharmaceutical Industries in Ireland. The report indicates that the number of PhD graduates in permanent residence abroad now accounts for 15% of the total as a result of the expansion of the Pharmaceutical and Fine Chemical sector in Ireland.[69] The report confirms that PhD students tend to be employed in senior post in production or technical development functions.

Physicists in both St. Patrick's College Maynooth and TCD argued that their students usually possessed skills which were different from those acquired by engineers or computer scientists because they took into account both hardware and software skills and could interface the two. They also felt that their students possessed strong problem solving skills which made them attractive to a range of potential employers in: software development, medical instrumentation development, electronic component manufacture and semiconductor research.

Biologists indicated that the job market for their students was much stronger than for some other fields because of the strength of the pharmaceutical sector in Ireland. As a result several of our interviewees indicated that students often did not wish to pursue a PhD and were satisfied with an MSc as this allowed them find technical work in the pharmaceutical industry. Students who embarked on PhD degrees were usually hoping to remain in academic research. This claim was supported by the fact that only four out of the 22 PhD students identified as graduating from the microbiology department at the university of Galway were in employment in industry.

Mathematicians indicated that their students possessed strong analytical skills that enabled them to find employment in a variety of sectors. The applied mathematician we interviewed indicated that his PhD students had gone on to post doc at the NMRC in Cork and at the Rockefeller high energy physics research centre in the US.

The other mathematician we interviewed indicated that with one exception - a student who was now in charge of developing software for use with mobile phones for Ericsson - his 5 PhD students had remained in academia. His MSc students, however, had tended to go mainly into financial services as analysts or as maths teachers in Ireland.

Access to a network of experts.

When we discussed these links with our interviewees only two indicated that they had provided access to a network of experts. One had helped a pharmaceutical company to identify researchers with particular skills. However, this had not led to any technical problem solving projects. The other had previously served as a contact point within the department. However since the establishment of a Programme in Advanced Technology (PAT) in his field he had played less of a role and he assumed that industrial scientists now contacted the PAT centre directly.

In many cases our interviewees argued that the norm in Ireland was for industrial scientists to maintain informal contacts with university researchers. Technologically sophisticated companies in Ireland already had a network of experts that they could draw on. Our interviewees felt that compared to other countries there would be less of a need to access a network of experts as companies' existing informal contacts would currently be able to provide the advice sought.

However, based on our interviews with industrial scientists (see section below) we believe that academics actually embody the networks that industrialists wish to access because they provide technical information on an informal basis without realising that the queries or questions that they are answering - and which they often consider to be trivial - are of value as a source of advice to industry. This may explain their inability to identify their role of informal service providers during our interviews.

Solving complex technological problems

Our interviews indicated that Irish academics are regularly asked to undertake projects or short pieces of technical work for the private sector. Twelve of our 17 respondents indicated that they had undertaken projects for the private sector.[70] These interactions are more visible because they require more of an investment than the informal problem solving or information providing functions that we reviewed above. They often involved formal contracts and or confidentiality agreements.

In most cases the work performed had not involved much new research but had involved using their technical skills to solve problems that companies were unable to address internally.

In general, the requests for assistance from industry were generated through informal contacts although one of our interviewees is strongly involved in a Programme in Advanced Technology centre.

As a member of the centre he was regularly involved in both formal and informal trouble shooting work for clients such as: Pilkington, Loctite, FMC, and Summit Technologies. He had also undertaken research projects on using fullerenes to laser-proof armoured vehicles

Other researchers tended to receive occasional invitations to provide assistance:

One of our interviewees provided consulting support to Farran Technology to develop sub-millimetre receivers. Farran Technology subsequently funded a two year postgraduate project to investigate this new area

Another had been involved in applying standard mathematical techniques to help Irish banks improve the way in which they calculate loan rates for projects in developing countries

The chemists we interviewed had all been involved in providing support to industry. Their projects included:

Providing consultancy services to G E Abrasives to look at ways to improve the way in which they separate their waste products

Working for Agrotech to develop a synthetic molecule that could be used as a pesticide

Working as chemical consultants for Barclays agro-chemicals

Working on a Pfizer research grant to design and synthesise molecular receptors to allow the rapid screening of compounds for chiral purity (this had led to a joint Pfizer DCU publication in analytical chemistry)

Applying Nuclear Magnetic Resonance techniques to help Loctite Ireland to solve production problems

The biologists we interviewed had been involved in industrial projects such as:

Working on a six month project sponsored by ADM Cork to investigate the factors influencing the production of methane in sewage treatment works

Undertaking research for the US navy and for pharmaceutical companies on the potential to develop a vaccine against intestinal microorganisms

Providing confirmation on procedures and solving small scale problems for salmon farmers

Working on industrial projects was not a priority for the researchers we interviewed. Only one actively sought industrial projects. Others tended to interact with industry either because the problem formulated was interesting or because it would provide funds to support their research.

Young researchers often thought that they were wasting their research time by interacting with industry. They argued that in order to further their careers they needed to publish articles on fundamental research. Any routine or unpublishable project was of little interest to them. Senior researchers were more receptive to industrial project suggestions because they had already established themselves and they often saw this as a way to increase funds for their research group. They also valued the donations (often in the form of equipment or material) that industry could make to their research group.

Spin-off companies

We only saw one serious example of spin-off companies during our interviews although a number of shell companies had been created to hold patents.

The company employs twelve members of staff which have strong links to the experimental physics department at St Patrick's College, Maynooth. The company was established to capitalise on the experience that had been gained by a senior member of staff in developing technology for space use.

The company works in a range of areas both developing and commercialising technology developed in-house and at the experimental physics department. The association between the company and the department is very strong with doctoral students and departmental equipment being funded by the company.

Other interactions between Researchers and Industry

The chemists and physicists we interviewed indicated that they were occasionally asked by industry to perform what they considered to be routine tests on samples using NMR equipment. They were usually quite willing to do this as the companies involved made in-kind contributions to the department (chemicals, old equipment etc.)

In addition researchers were occasionally asked to help firms calibrate new equipment (including NMR equipment), this was particularly the case for departments with strong relationships with particular firms.

3.3 The view from Industry

In order to confirm the links identified in our interviews with Irish researchers we held a series of case study interviews with Irish industrial research and technology managers. We selected companies for interview based on firms identified by University scientists and by using a list of R&D intensive companies provided to us by Forbairt. Exhibit 3.20 shows that our sample focused on technology intensive industries - these are the ones which are most likely to be able to confirm the links identified by academics.

We used a structured interview format to obtain information on the activities (including relationships with third level institutions) of the company and of the most technology dependent department.

Exhibit 3.20 Intensity of Industrial links with university research

	Increasing Stock of useful Information	New Instrumentation and Methodologies	Research Skills	Access to networks of experts and information	Solving complex technological problems	Spin-off companies	Access to facilities
Loctite	Strong link	Good link	Strong link	Strong link	Good link		Good link
Élan Pharmaceutical Technology	Good link	Strong link	Strong link	Strong link	No Link		Weak link
Schering Plough	Moderate link	Moderate link	Strong link	Moderate link	Good link		Moderate link
Bristol Meyer Squibb	Moderate link	Moderate link	Strong link	Strong link	Moderate link		Good link
Merck Sharpe and Dohme	Moderate link	Moderate link	Strong link	Moderate link	Moderate link		Moderate link
Farran Technology	Strong link	Good link	Strong link	Strong link	Good link		Moderate link
Intel Ireland	Moderate link	Moderate link	Moderate link	Moderate link	Weak link		No Link
Apple	Weak link	Moderate link	Weak link	Weak link	Weak link		No Link
Kerry Group	Weak link	Moderate link	Moderate link	Weak link	Weak link		Moderate link
Guinness	Strong link	Good link	Strong link	Strong link	Moderate link		Moderate link

● Strong link ◕ Good link ◐ Moderate link ◔ Weak link ○ No Link

3.3.1 New useful information

It proved difficult to separate new useful information from developments in the enabling technology and techniques that were linked to the production of new useful information. Industrial chemists and biologists often tracked information to identify methods to create new materials. The researchers at Guinness tracked published information both as an input into their fundamental research and to their production process.

The interviews showed that the interest in new useful information varied by firm and type of sector. The more technology intensive the industry was, the more likely they were to be interested in new information on science and technology. Companies that carried out research in Ireland were the ones which were most interested in new useful information: Loctite, Élan and Guinness all had formal or informal relationships with Irish universities and kept up to date with developments in their field. In a few cases they actually funded research to obtain new information.

These types of projects were often funded as ‘insurance policies’; they allowed firms to keep an eye on a developing technology. If the technology ever became commercially viable these firms would have advance knowledge, be able to exploit the technology rapidly or at least be able to understand the implications for their business. Many of these projects are commercially sensitive.

Apple, whose Irish plant does not really depend on local R&D, funds two PhD students to research video compression techniques because this is seen as a technology that may become important if the market for powerful multi-media capabilities expands in the future.

These types of 'insurance projects' are different from the type of information flows that are discussed in the literature because the projects are largely driven by the need for industry to keep up to date with current developments. Information about developments has already been passed on to companies which have taken a decision to maintain or increase the level of information available to them by funding research.

However, because these are sophisticated R&D organisations their main focus was on tracking international developments in their field. They did this in-house and with help from the universities and consultants.

Although it does not perform much in the way of in-house research, Farran Technology also tracked development in its field through its formal and informal links with the University of Cork.

Other companies which performed process or product development also maintained their access to new technical and scientific information. Bristol Meyer Squibb, Merck Sharpe and Dohme, and Shering Plough all had access to new scientific information. In general the more technology dependent the company was, the more it kept up to date with recent developments.

The main exception to this group was Intel which kept up to date with recent developments through a strong exchange programme with its R&D labs in the USA and through its recruitment of technically qualified graduates.

Apple Ireland and the Kerry Group did not have strong mechanisms for identifying new useful research.

3.3.2 New instrumentation and techniques

The overlap between tracking new information and tracking new methods and instrumentation is apparent if we compare the first two columns in Exhibit 3.19. Most of our industrial interviewees were interested in developing incremental improvements to their production process and so were also interested in new methods or instruments. However, information on new techniques was often available from sources inside the industry and so there was often less interest in tracking these through academia.

Elan was an exception to this rule. They were interested in tracking developments relevant to new drug delivery techniques. Apple was more interested in tracking software development, particularly new programming languages. They supported two computer science PhD students whom they used as evaluators for new languages such as Java. Kerry Ingredients tracked developments in protein research in order to maintain their understanding of current production possibilities in that area.

There was also evidence of 'insurance projects' in developing new techniques. Farran Technology for example supported a two year postgraduate project at St. Patrick's College to develop software for modelling sub-millimetre wave guides because at the time they felt that this was an area where they needed to have capability.

3.3.3 Skills of research students

All but two of the companies within our sample actively recruited PhDs to work in R&D. The ability to recruit such people was seen as a precondition for operating an R&D department in Ireland.

The companies we interviewed said that PhD students embodied the links to university research by bringing with them

- Theoretical and practical experience of research
- Access to informal scientific networks
- Awareness of new results
- Up to date knowledge of methods and instrumentation

For example: the PhDs recruited by Guinness are often involved in post doctoral level fundamental research on yeast genetics which they would not be able to perform if they did not have their PhD experience. Similarly, our interviewee at Élan technology drew on her research experience to manage a portfolio of research projects in new technologies. Our other interviewees at BMS and Schering Plough argued that their PhD allowed them to consult on an informal basis with their supervisors (now often senior members of staff or heads of departments at universities). In addition, our interviewees argued that having a solid experience of academic research allowed them perform and manage R&D in-house and to supervise research projects that have been contracted out to university departments.

But PhDs do more than simply provide companies with R&D skills. Merck Sharpe and Dohme, for example, expects PhDs to become senior managers in their organisation. Most of the management posts are filled internally from the R&D department in order to ensure a high level of technical expertise within senior management.

Intel did not recruit a large amount of PhDs. However, they put a heavy emphasis on recruiting graduates and MSc students with up to date technical skills. They did not need to hire experienced researchers but valued research as an activity which developed the use of modern techniques and instrumentation.

3.3.4 Access to a network of experts

The literature identifies access to a professional network as allowing individuals to participate and interact with a world-wide community of leading researchers.

Unlike the academics we interviewed, our industrial interviewees identified this as one of the most frequent types of links they had with universities. The strength and frequency of the links varied with the level of R&D activities performed in-house.

The links were often informal ones that had been forged whilst our interviewees were studying at university. This was the case at Bristol Meyer Squibb, Farran Technology, Loctite and Élan. This allowed industrial scientists to contact colleagues in academia to:

- Discuss current problems
- Check current practices
- Obtain an in-depth assessment of the potential of their current research and its relevance to industry.

The head of research at Guinness is the secretary of the Biochemical Society. As such he has strong informal links with national and international experts. In general, because of the research it performs in-house, Guinness scientists had good relationships with fundamental researchers at a range of different Universities. They form part of the scientific network and are able to draw on the experience of their counterparts in academia.

Farran Technology had the strongest links to university research. Members of staff are still active in applied research at the NMRC. This allows them to obtain second opinions on their plans to develop new products.

In addition to the above examples which largely confirm the importance of networks as a source of scientific and technological information, other types of benefits were identified from access to scientific networks.

Informal access to university scientists often facilitated the recruitment process. For example, Schering Plough have been able to speed up their recruitment by asking university colleagues to nominate PhDs who would be suitable for a particular opening.

Other organisations have also been able to use their informal contacts to obtain confirmation that a candidate (PhD or graduate) that they are thinking of recruiting is suitable for their needs.

Intel had an academic relations manager who was responsible for managing the links between the company and the higher education sector. Although it does not have significant research based contact with universities, other contact with universities means that Intel has a strong input into undergraduate teaching (particularly in the last two years of study). It also expects to expand its access to researchers in charge of supervising a MSc course from which it plans to recruit.

The decision by firms to fund 'insurance research' projects (discussed in section 3.3.1) also allows firms to access emerging networks in new technologies.

3.3.5 Solving complex technological problems

The literature identifies this type of link as academic research directly contributing to technological knowledge which is then accessible to to both university and industrial scientists. These links are usually indirect and are represented through the skills of trained problem solvers, instruments and techniques and background techniques.

Most of our interviewees had contracted out some problem solving work to universities. In some cases firms had asked university researchers to help them solve a small technological problem that they could not perform in-house because of lack of personnel or equipment. This was the case at Bristol Meyer Squibb, Schering-Plough, Farran Technology, Guinness and Kerry ingredients.

Guinness, for example, regularly funds university researchers to investigate the property of food dyes, whilst pharmaceutical and chemical companies were interested in developing new synthesis routes for compounds or new ways to identify and measure enzymes. Farran Technology had contracted out development work on diodes to NMRC and has contracts with UCD to work on reverse engineering of components. Intel funds MSc students to perform research to improve its understanding of the impact of different techniques on their production methods.

Élan was an exception to this trend of contracting out small problem-solving contracts because of the high level of confidentiality it needs to maintain and because it feels that Irish universities do not always have the capabilities to perform these types of project.

3.3.6 Spin-off companies

None of the companies we interviewed identified themselves as spin-offs from Irish universities.

3.3.7 Other links

The formal and informal contacts developed with Irish third level institutions allowed several of the firms within our sample to make use of facilities in Irish companies on a preferential basis.

For example, in return for contributions in kind (chemicals, old equipment) the chemical and pharmaceutical companies in our sample often made use of the NMR facilities in academia to analyses and identify samples. BMS and Loctite, for example helped to fund the existing NMR facility at UCD and benefit from preferential treatment when they need to have samples analysed. Guinness and Kerry both make occasional use of the small scale-up plant facilities at the food science department of UCC.

3.3.8 Publications by private sector R&D performers

During our bibliometric search we ran a simple test to identify journal publications in the period 1989-1997 for the Irish companies we interviewed. The search was designed to confirm that Irish-based companies publish in the same journals as Irish scientists which would suggest that these companies have strong links with Irish universities. While the results of this test are limited, they do confirm the importance of this type of publication for the companies performing comparatively high levels of R&D in Ireland.

We identified 47 publications by Élan Pharmaceutical technologies, 33 publications by Loctite Ireland, and 10 publications by Farran Technology. The pattern of research collaboration is consistent with the material obtained during our interviews with industry. The list of co-authors for these papers indicates that Élan tends to publish in-house research without much collaboration with academic institutions whilst most articles in which Loctite and Farran Technology are listed tend to be published in collaboration with university researchers.

In the case of Loctite, a significant number of co-authors had also received basic research grants for chemistry. This confirms the interest Loctite has in keeping abreast of current research developments.

3.4 Conclusions

The Scheme is effectively playing its role of generating PhDs. A smaller number of post-doctoral fellows is passing through the Irish university system than might be expected, largely because (unlike many equivalent programmes abroad) the Scheme has few resources to allocate to these. In fact, the EU is the major source of post-doctoral fellowships in Ireland.

The BRG Scheme plays an important role in helping build the research careers of Irish scientists. The researchers tend to be international in outlook, not least because the Irish research community is itself fragmented and small-scale. Researchers have to move quickly onto the international stage, often with the help of EU funding. As a result there is a constant pressure to move from basic into more applied research. In practice, a good deal of 'Mode 2' work is being done within the Scheme, with many projects being seen as problem-oriented and a fair number being done at the direct suggestion of industry.

The empirical studies confirmed that the six links between science and industry identified in Chapter 1 were in fact operating in practice, namely

- New, useful information
- New instrumentation and methodologies
- Skills, especially skilled graduates
- Access to networks of experts and information
- Solving complex technological problems
- 'Spin-off' companies

The extent of the individual links varies by discipline, as does the importance of the BRG Scheme itself. Researchers were generally positive about the Scheme, which was felt to be accessible and to complement other available sources of funding. Some criticisms were, however, voiced about the adequacy and transparency of the appraisal process.

2. Conclusions and Recommendations

Introduction

In this final Chapter, we pull together the implications of the preceding analysis.

The section on conclusions addresses the evaluation issues set out in the Introduction. By looking at the ways in which basic science interlinks with industry, the study has confirmed the importance of having a basic research component within policy to maintain and develop the national innovation system. The basic science research community needs to be strengthened over time in order to reinforce the virtuous circle of economic and industrial development which is becoming a feature of the Irish economy. There are some opportunities to improve the way the Scheme is defined and run, most of which are tied to the need for expansion.

Our recommendations address the need to expand basic science research funding in Ireland. We make some immediate suggestions for how this should be done, but also point to some larger needs for change within the science and technology funding system, which are needed in order to operate a viable national strategy.

4.1 Conclusions: The BRG Scheme and Ireland's Economic Development

4.1.1 Appropriateness

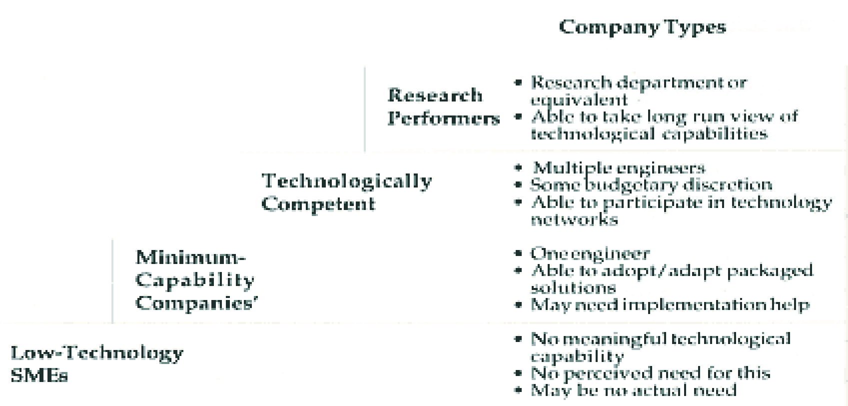
Ireland's state spending on basic research - like overall national spending on R&D - accounts for an unusually low proportion of GNP. The central issue for this study has been to understand the relationship between Irish basic science and the economy. Does it make sense to spend so little on science? It is clear that countries (eg Finland and the UK) which are to some degree seen as role models and others which remain competitor locations for footloose international industry assign higher priority to basic science funding than Ireland does today.

Rather than attempt the impossible task of replicating in Ireland the whole body of international research into science-industry links, we chose in this study to review the literature and to test whether the policy implications also hold true in Ireland. We cannot simply take the results of the foreign studies as given, because they have largely been conducted in larger and wealthier economies.

The literature says - and our work in Ireland has confirmed - that basic science is one of the building-blocks of national innovation systems. The traditional view that science generates information is, of course, partly correct. But it provides much more than just this. It provides the instrumentation, methods, trained people and interpersonal networks needed to do high-quality R&D. Sometimes it helps create spin-off companies or activities. Because of these other, non-information effects of science, it is not possible to be a 'free rider' on the back of world science and at the same time to have a modern industrial economy capable of self-sustaining development and growth.

However, not all parts of the economy can directly draw benefit from these links with basic science. Exhibit 4.1 shows a simple way to segment companies according to their level of research and engineering capability.

Exhibit 4.1 Simple hierarchy of company types



Our segmentation suggests that there are four reasonably distinct levels in the development of firms' engineering and research capabilities. At the bottom level, there is no meaningful capability and there will tend to be a presumption that none is needed. At the next level up, the 'minimum capability' level, the firm acquires at least one person able to speak the language of technology, to monitor and understand the significance of technological changes happening outside the firm. These bottom two levels of firm rarely have contact with universities. They do not share a common language or interest with them.

In OECD countries, many larger firms belong to the third level of 'technological competence', where there is enough capability to do fairly serious development work and where there tends to be a specialised innovation or development function. The highest level firms - 'research performers' - are of two types. Some correspond to the ideal of the very large company with capabilities in research as well as development and the strength and vision to work for the long term as well as the immediate future. Others are new, technology-based firms, many of which exist primarily to do research. These highest-level firms' research departments communicate easily with scientists - they have the 'complementary assets' needed to do so. Third-level firms often have difficulties.

Correspondingly, research performers tend to demand access to scientific networks and to potential employees with postgraduate research training. Lower-level companies tend to be interested in more packaged forms of technology transfer, advice and other services from the research and higher education sector - aspects which in various ways help make up for their internal lack of capabilities. In Ireland, the Programmes in Advanced Technology play a role here, as brokers between company needs and university capabilities.

The success of Irish inward investment policy coupled to measures which develop indigenous technological capabilities can be seen not only in the presence of 'screwdriver' plant in Ireland - of which there are still many - but also in the slowly growing willingness of the multinationals to undertake technological development in Ireland and in the growing number of smaller, Irish-owned high-technology companies emerging in fields such as software and telecommunications.

The size of this research-performing segment in Ireland is still small. Continuing growth is needed in this part of the economy in order to develop a sustainable innovation system and contain the 'footlooseness' of international industry. Our interviews confirmed the findings of studies outside Ireland, namely that the quality and accessibility of local scientific infrastructure is one important criterion (among others) used by research performing firms in deciding where to locate. Since a basic science infrastructure takes a long time to build it is therefore important to develop it ahead of the growth of research-performing industry. At the same time, some mechanism is needed to manage that growth in directions which will eventually have industrial synergies.

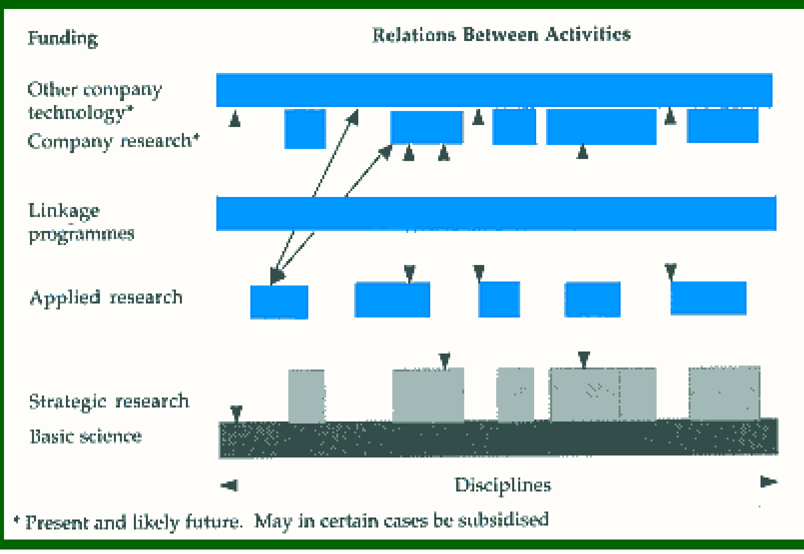
The scientists involved in the BRG Scheme were using it to do a wide range of activities, including both basic and applied or strategic research. A few were clearly operating in Mode 1 - traditional, discipline-based, curiosity-driven research. The greater number appeared to be working in Mode 2. This involved moving between rather basic research and more applied activities - for example, moving from BRG to EU finance. Many of the people we interviewed tended to regard this as a one-way street. A natural career development might begin with BRG money to establish a reputation and some experience. This would enable participation in the (much better financed) EU programmes. However, the imbalance in funding between the two sources seems to be a factor making it unattractive for successful scientists to move back to asking basic questions. If Gibbons et al have adequately described how science works in Mode 2, then there should properly be a two-way street between basic and more applications-oriented work.

Within the Irish funding system the Strategic Grants programme partly serves as a smaller-scale, national equivalent of applied EU funding for Mode 2 work. Formerly, overlaid on the inherent distinction between basic and strategic research was the principle that the Strategic Grants exist to supply scientific inputs to the PATs. Thus, the BRG Scheme used to pick up not only basic but also ‘strategic’ or even applied research relevant to disciplines not covered by the PATs.

The nature and intensity of science-industry linkage varies among disciplines and branches of industry. A monolithic solution to funding science may not, therefore, be the best approach. It is right to have a range of mechanisms in place, and it is right that at least one of these mechanisms should include among its ‘client’ disciplines those where the links to industry are limited in the short term.

Exhibit 4.2 sketches how state-funded science may be linked into industrial needs. It focuses on pure and applied science, taking no account of the many other important linkages involved in innovation and the development of more routine technological capabilities.[71] It builds on ideas used by the Swedish National Board for Technological Development (STU) during the 1980s.

Exhibit 4.2 Basic research in the innovation funding system



The **Exhibit** indicates that there is a need to do a certain amount of basic science (the dark grey box), spread broadly across most, if not all, disciplines and irrespective of whether there is any direct industrial requirement. This research

- Enables university teachers to stay current
- Provides the nation with the minimum amount of scientific capability needed to provide a growth node if more capability is needed in the future
- Provides answers to policy questions

We found examples of scientists using the BRG scheme to do this kind of work inter alia in mathematics and geology.

The lighter grey areas mirror those where industry does research in addition to doing more routine technological work in development, design and production. This additional element of basic - or, more strictly, 'strategic' - work is funded specifically in order to provide a resource to industry. For this reason, in the Nordic countries industry plays a significant role in selecting the areas which should receive funding and has some say on the topics to be funded within these disciplines. In the Irish situation, where the amount of research-performing industry is smaller and where its composition risks being unstable (because of footlooseness among the multinationals and the precariousness of existence in small, technology-based firms), slightly different planning mechanisms are needed. It is necessary to make a strategic choice of areas, based partly on the existing needs and partly on the prospective requirements of industry. This was done in Ireland at the start of the 1990s when areas were defined for the PATs. This prospective analysis needs to be updated, and to be conducted in partnership with existing industry.

Applied research in the university sector needs also to be funded by the state. The market failures which apply to basic science apply here with little less force, and applied disciplines play many of the same linking roles with industry as do basic ones. Equally, to the extent that state-funded applied research is to have economic benefits, a fair degree of user direction is needed, not least through the active participation of industry in the governance of applied science.

Linkage programmes are used in most R&D funding systems to improve the connections between different parts. Projects are often collaborative. Links may be 'vertical', between different levels of the same discipline or technology cluster, or 'diagonal,' vectoring knowledge between different parts of the system. Many EU programme fall into this category.

We find, therefore, that while the BRG Scheme is essentially an appropriate action, it needs to be

- Bigger - providing more grants to grow Irish academic and industrial research capabilities and providing the bigger grants needed to enable 'Mode 2' researchers to 'pendulum' back and forth between basic and applied research
- Part of a larger planning framework, which ensures the provision of broad funding across the basic sciences and which selectively adds basic or 'strategic' research funding in areas of particular (present or future) importance to Irish-based industry

4.1.2 Operation and Achievements of the Scheme

Forbairt has succeeded in devising a management process and an annual cycle which fit well with the rhythm of academic life and which deliver contracts and PhD researchers to the academic community in a timely way at the start of the year. The system copes rather smoothly with the annual uncertainty about budget allocation - though we do not see this as a problem with which the Scheme should have to deal.

Users rated the Scheme highly on some dimensions, compared with alternatives. It particular, its simplicity and accessibility were admired, even if its usefulness for funding substantial pieces of work was very limited.

The appraisal of projects follows normal practice in this type of programme by using scientific peers. However, relying principally on Irish peers, with a couple of UK additions per panel to provide a level of quality control, places the Scheme at some distance from best practice. In comparison, the Nordic countries are relying increasingly on foreign peers. This serves two purposes. First, it reduces the risks of conflict of interest and 'friendship corruption' which may induce peers in a small community to recognise the prisoners' dilemma in which they are being placed and to act cooperatively. Second, it promotes networking with the international scientific community - itself a matter of particular importance in a research community as small as the Irish one.

Quite a number of people criticised the present peer review arrangements during the course of both our questionnaire survey and our interviews. The allegations we hear that unless one has a colleague on the 'inside' of a review panel one is unlikely to win a grant are - bluntly - typical of the type of gossip found in most small communities. We have no way to judge whether these claims are justified, nor have we attempted to do so. A second category of criticism of the process is that the panels' remits and compositions leave important gaps. As a result, certain sub-fields cannot adequately be assessed. A third, and very important, problem is the review panels' practice of reducing grants compared with the requested financing. Our fieldwork suggested there was a significant proportion of grants which became sub-critical as a result of this process. Operating without benefit of discussion with the applicants,[72] the presence of applicants' colleagues or clear tariffs, the chances are that such unilaterally-imposed reductions will indeed be arbitrary and that they will encourage the submission of inflated cost estimates in the expectation of a cut.

Whatever the truth of these matters, we heard enough concern to believe that the appraisal system needs to be reviewed by independent scientists in order to protect it from potential disrepute.

A related matter is the internal rule of thumb which says that grants should be 'spread about' rather than allowed to flow to those offering the highest-quality proposals. This is achieved by limiting awards to any one scientist to a single grant each year. The most likely result of this is to limit the quantity and quality of the scientific output produced. Equally, constraining scientists to two applications per year leaves the Scheme with little information about the size of potential demand for the grants, and may be an important factor explaining why applications numbers have not risen in line with the increased amount of money available.

Over the past three years, the application-to-acceptance ratio has declined from over 5:1 to some 3:1. This is rather low for a scientific research programme. The number may, of course, change if large grants are included within the BRG Scheme. The quality of project proposals funded needs careful monitoring lest the calibre of the marginal projects begins to decline in response to the rising budget. In order effectively to do such monitoring, the scoring system used in appraisal needs to have at least five points. The rather coarser scale used today will not easily enable changes in quality to be identified.

The recent increases in funding have allowed the duration of grants to be increased from two to three years, aligning them with the minimum length of time in which it is reasonable to expect PhD students to research and complete their theses. It should nonetheless be recognised that a decision to pursue a PhD in Ireland (whether funded from this Scheme or elsewhere) is to choose penury. The short-term opportunity cost in terms of lost income to the individual is probably of the order of £I 30 - 60 000. The long-term financial benefits of taking a PhD (especially as compared with an MSc) are not clearly significant.73 While recent modifications to the BRG Scheme are therefore positive, they make no substantive difference to the more fundamental inadequacy of PhD training finance in Ireland.

Like Research Council funding in the UK, grants from the BRG Scheme are made on the basis that they finance research done in a 'well-found laboratory': namely, one that is adequately equipped, staffed and supported in the university. We were repeatedly told that this was not the case. The context of a total research equipment grant for the current year of £I500 000 to cover the needs of all the Irish universities lends a deal of credibility to these claims.

This type of programme faces a trade-off between the production of PhDs and research results. From the point of view of producing results - and therefore from the perspective of the grant-holders - it is highly effective to employ post-doctoral fellows rather than PhD students. The research experience of post-doctoral fellows of research means that grant-holders can 'leverage' themselves very effectively by handing down routine parts of the research process. By comparison, PhD students are inefficient, demanding of time and prone to making mistakes. In general, the grant-holder can generate more publications using a post-doctoral fellow than a PhD student, and publications are above all the measure of scientific success in our performance-indicator-minded age.

It is clear that the Scheme does produce numbers of PhD students, and that these go on to make contributions in both industry and academia. The quality of the research results - based on a very simple spot-check - seems nonetheless to be high. At the present scale of the Scheme, it is probably more important for the nation to produce PhDs than to maximise professorial productivity. However, this should change as the Scheme grows and as the strength of research-performing industry in Ireland increases. Over time, therefore, it would be reasonable to expect the proportion of post-doctoral fellowships in the Scheme to increase.

The Scheme plays an important role in bringing researchers to the stage where they are capable of winning money in EU projects. If they stay in EU work, however, they are to a considerable degree lost to basic science. Clearly, the attractiveness of the Scheme to these maturing scientists must be increased to prevent the route towards EU funding becoming a one-way career move.

4.2 Recommendations

Our overall findings are that the Scheme is important, should be bigger and needs some minor operational overhaul in order to keep pace with modern practice and to maintain the confidence of the Irish research community. We therefore recommend as follows.

4.2.1 Programme size

The scale of the Scheme should rise over time, in order to underpin present and future industrial and economic development in Ireland. STIAC's 1995 recommendation of £6m

is probably a good initial target. allowing for GDP growth since 1995, this compounds to £7.6m today.[74] The minimum funding for the Scheme should be fixed as a percentage of Irish GDP. We suggest a rise of a least £1m per annum in real terms until that target is achieved.[75]

During this period of growth, the quality of proposals should be monitored. Any evidence of decline should trigger a review of further expansion.

At the latest at the point where the Scheme reaches its target size, it should be subject to a new evaluation[76], which should combine an overall economic and management study with peer reviews of the best-funded disciplines within the Scheme. By this time, the character of the Scheme will have changed owing both to its greater scale and its wider role in the innovation system. Policy makers will need to know whether this much larger Scheme adequately fulfils its role or whether it is in need of further redefinition.

Once the Scheme exceeds £4m in annual funding, it should begin to prioritise groups of disciplines for programmatic investment based not only on their respective shares of total project applications but also based on industrial structure criteria. If these are not available from another authoritative source, they should be developed in consultation with industry and the Department of Enterprise and Employment. Programmatic funding allows Ireland to

- Develop a more strategic approach to supporting Science and Technology
- Reduce its dependence on the vagaries of European funding
- Develop areas of particular strength ad attractiveness to foreign investors

Therefore, these criteria should apply across both Basic and "Strategic" research programmes, making the allowance for the need for the BRGS to continue funding work which is not seen as immediately strategic.

One possible mechanism is a form of 'technology foresight' although the existing large-country foresight approaches are not helpful. They are too expensive and rely for their operation on the availability of larger numbers of academic and industrial experts than are to be found in an economy as small as that of Ireland. A new, smaller-scale model would need to be developed which included prospective analysis as well as considering the ideas of existing actors.[77]

4.2.2 Programme structure

We expect that as the scheme grows the programme managers will have to alter its funding structure to allocate programme support to substantially larger strategic projects. Structural changes in programme support mechanisms should reflect the new prioritisation of disciplines discussed above and be taken in collaboration with the research community.

The proportion of grant monies awarded to projects using post-doctoral fellows should rise over time as large awards become possible. Since the appropriate proportion of resources to use in this way varies by discipline, it should be monitored by the discipline- based project appraisal panels. This proportion should in any case not exceed 50% ahead of the next evaluation of the Scheme.

The amount of funding provided to PhD students through the Scheme should be raised, in the context of a wider review of the adequacy of PhD funding.

The proposal appraisal process should be overhauled as the Scheme grows in size. This could include

- Reducing the proportion of Irish academic peers to below 50%
- Recruiting foreign peers, and extending the reach of the peer selection process beyond the UK to at least the rest of Europe
- Including at least one industrial peer on each panel, where it is possible to find an authoritative person employed in research-performing industry in Ireland
- The proposal selection mechanism should be revisited. We suggest a review orchestrated by an independent scientific body such as the US National Science Foundation or the UK Royal Society

Since BRG research appears to be performed in laboratories which are less than well found, an immediate review should should be undertaken of university research equipment levels, quality and vintages as a basis for setting a higher budget.

ENDNOTES

1. E Mansfield, “Academic Research and Industrial Innovation,” Research Policy, 20, pp 1 - 20
2. Zvi Griliches, “R&D and Productivity,” in Paul Stoneman (ed.), Handbook of the Economics of Innovation and Technological Change, Oxford: Blackwell, 1995
3. Ken Arrow (1962), “Economic Welfare and the Allocation of Resources for Invention,” in Nathan Rosenberg (Ed.) (1971), The Economics of Technological Change, Harmondsworth: Penguin
4. Keith Pavitt, “Academic Research, Technical Change and Government Policy ,” in J Krige and D Pestre (eds), Science in the 20th Century, Harwood Academic Publishers, 1995
5. Michel Callon, “Is Science a Public Good?” Science, Technology and Human Values, 19, pp 395-424
6. Michael Gibbons, Camille Limoges, Helga Nowotny, Simon Schwartzman, Peter Scott and Martin Trow, The New Production of Knowledge, London: Sage 1994
7. Gibbons et al, op. cit., p19
8. See, for example, Bengt-Åke Lundvall, National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning, London: Pinter, 1992; RR Nelson, National Innovation Systems, New York: Oxford University Press, 1993
9. Walter G Vincenti, What Engineers Know and How they Know It: Analytical Studies from Aeronautical History, Baltimore: John Hopkins University Press, 1990
10. OECD, The measurement of Scientific and Technical activities: Proposed standard practices for surveys or research and experimental development, Frascati manual, OECD, Paris, 1981
11. This section draws heavily on Ben Martin, Ammon Salter et al, The Relationship Between Publicly Funded Basic Research and Economic Performance, report to HM Treasury, Brighton: Science Policy Research Unit, 1996
12. R Nelson and R Levin, “The Influence of Science, University Research and Technical Societies on Industrial R&D and Technical Advance,” Policy Discussion Paper Series No 3, Research Programme in Technological Change, Yale University, Newhaven, Connecticut, 1986
13. Keith Pavitt, “The national usefulness of the research base,” paper presented to the Advisory Board of the Research Councils, 16 April 1991
14. Office of the Director of Defense Research and Engineering, Project Hindsight - Final Report, National Technical Information Service, 1967
15. John Irvine, Ben R Martin and Phoebe Isard, Investing in the Future: An International Comparison of Government Funding of Academic and Related Research, Aldershot and Brookfield, Vermont: Edward Elgar, 1990
16. Nathan Rosenberg, “Scientific Instrumentation and University Research,” Research Policy, 21, 1992, pp381-390
17. Nathan Rosenberg, “Scientific Instrumentation and University Research,” Research Policy, 21, 1992, pp381-390
18. Derek De Solla Price, “The science/technology relationship, the craft of experimental science, and policy for the improvement of high technology innovation,” Research Policy, 13, 1984, pp3-20
19. Jacqueline Senker, “Tacit Knowledge and Models of Innovation,” Industrial and Corporate Change, 4, pp425-477
20. Michael Gibbons and Ron Johnston, “The role of science in technological innovation,: Research Policy, 3, 1974, pp220-242; C Lyall, The 1993 White Paper on Science and Technology: Realising our Potential or Missed Opportunity? MSc dissertation, Science Policy Research Unit, University of Sussex, Brighton, 1993
21. Ben Martin and John Irvine, "Assessing basic research; some partial indicators of scientific progress in radio astronomy", Research Policy, Vol. 12, 1983, pp61-90.
22. Keith Sequeira and Ben Martin, Physics and Industry, Science Policy Research Unit, University of Sussex, 1996; Erik Arnold and Peter Senker, Designing the Future: The Effects of Interactive Graphics CAD on Skill Requirements in the Engineering Industry, Watford: Engineering Industry Training Board, 1982
23. Derek de Solla Price, Little Science, Big Science, New York: Columbia UP, 1963
24. Diana Hicks, “Published Papers, Tacit Competencies and Corporate Management of the Public/Private Character of Knowledge”, Industrial and Corporate Change, 1995, 4, pp401-424
25. A Arundel, G van de Paal and L Soete, Pace Report: Innovation Strategies of Europe’s Largest Firms: Results of the PACE Survey for Information Sources, Public Research, Protection of Innovations and Government Programmes, Final Report, Maastricht: MERIT, University of Limburg, 1995
26. Erik Arnold and Ken Guy, Evaluation of the IT4 Programme, Final report of the evaluation of the IT4 Programme of pre-competitive, collaborative R&D in Information Technology, SPRU and Technopolis, Stockholm: IT4 Delegation, 1992; similar results were found for the corresponding UK ‘Alvey’ Programme, see Ken Guy, et al, The Evaluation of the Alvey Programme for Advanced Information Technology, HMSO: London, 1991
27. Keith Pavitt, “National policies for technical change: Where are there increasing returns to economic research?” Paper prepared for the Colloquium on Science, Technology and the Economy, organised by the US Academy of Sciences at the University of Irvine, 1995
28. Only firms performing formal R&D and having sales in excess of ECU 1.5 billion were included in the sample. The response rate was 54%
29. Arundel et al, 1995, p ii
30. D Massey, P Quintas and D Wield, High-Tech Fantasies: Science Parks in Society, Science and Space, London: Routledge, 1992
31. Ken Guy, Erkko Autio, Tomi Laamanen, Bill Wicksteed, Tero Kivisaari, Vesa Jutila, The Evaluation of the Otaniemi Science Park Cluster, Technopolis, Brighton, 1995

32. Rikard Stankiewitz, Academics and Entrepreneurs, London: Francis Pinter Publishers, 1986; Erkki Autio, Sympletic and Generative Impacts of New Technology-Based Firms in Innovation Networks, Doctoral Dissertation, Institute of Industrial Management, Helsinki University of Technology, 1995
33. Bania, Edwards and Fogarty, 1993
34. This observation is based on interviews with: ALMI's inventions service in Sweden; the Swedish Inventors' Union; the FORNY programme in Norway which systematically searches the research and higher education sector in Norway for commercialisable ideas and helps establish firms or sell the intellectual property rights; the PUFFA programme, which serves a similar function in Swedish biotechnology. Similarly, the experience both of the British Technology Group and of US universities' Industrial Liaison Officers is that one or two patents are likely to produce the overwhelming majority of the revenues from a portfolio of university-derived intellectual property. See also Guy, K, et al, The Evaluation of the Alvey Programme for Advanced Information Technology, HMSO: London, 1991
35. Erik Arnold, Patries Boekholt, Patrick Keen, Jez Lewis and James Stroyan, Evaluation of the Technology Transfer and Partnership Programme, Dublin: Forfás, 1997
36. S Lowe and R Rothwell, The Sussex Technology Transfer Centre: A Background Report, Brighton: Science Policy Research Unit, 1987
37. J Senker and W Faulkner, "Public-private research linkages in advanced technologies", paper presented at the Indo-British Seminar on Industry-Institute Interaction, British Council Division New Delhi, March 6-7 1995
38. Pari Patel, "Are large firms internationalising the generation of technology?" IEEE Transactions on Engineering Management, 1996 (forthcoming)
39. P Stoneman, "Overseas financing for industrial R&D in the UK," paper presented to Section F of the British Association for the Advancement of Science, Sheffield, 1989
40. J H Taggart, Determinants of the Foreign R&D Location Decision in the Pharmaceutical Industry, University of Strathclyde Business School Working Paper No 89/7, 1989
41. The best review of evidence about the effectiveness of 'technology push' and 'demand pull' in promoting innovation is DC Mowery and N Rosenberg, "The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies", Research Policy, 8, 1978
42. Exhibits 2.2 and 2.3 do not include figures for 1997. In 1997 the BRG scheme initially funded 110 projects worth a total value of £3.7 million; an additional 16 were subsequently funded bringing the total value up to £4.3 million
43. This is intended to avoid 'lottery applications' where a single researcher submits a large number of proposals in the belief that this will increase his or her chance of receiving funding
44. The research supported by the grants tended to be published in journals rather than in books. This excluded contributions to a book made by a geologist
45. CIRCA, 1997, Irish Scientific Output 1981-1994: a bibliometric analysis of the output and quality of scientific publications with special emphasis on the HE sector in Ireland, Dublin, CIRCA group
46. Four fully attributable publications with no citations are excluded from the graph, partially attributable publications were always cited
47. The paper with over a 100 citations is a high energy physics project with over 50 co-authors. This would represent a significant proportion of the research community in that area and there may be a tendency to increase citations to these types of publications through self citation
48. CIRCA, 1997, Irish Scientific Output 1981-1994: a bibliometric analysis of the output and quality of scientific publications with special emphasis on the HE sector in Ireland, Dublin, CIRCA group
49. The proportion allocated to response mode funding varies by field from 86% for mathematics to 57% for physics
50. Including postgraduate and post-doctoral research assistants although postgraduate scholarships are also available
51. This is intended to cover full salary, cost and travel for 2-3 researchers
52. This is intended to cover full salary, cost and travel for a single researcher
53. These figures includes EU funding
54. Typical grants would be £6,500 p.a. for those studying in Portugal, and roughly double that amount for those studying abroad
55. Portugal gives around £6,500 a year to students roughly the amount that Irish students need to live on; however, the cost of living in Portugal is much lower than in other countries. Portuguese students studying in Ireland get £13,000 a year!
56. 48% of the 361 selected projects, or 43% of all grants awarded
57. All figures between 22.6 months in 1989 to a maximum of 24.9 in 1992
58. Exceptionally, several Post-Doctoral fellows were funded through the grants in 1990
59. This is our best estimate of nationality. Some of these may be Irish students returning after having completed postgraduate studies abroad. Based on their names and subsequent destinations (i.e. back to their department of origin) we believe that most of the individuals counted are non-Irish.
60. The results are presented either as a percentage of all respondents, or as a percentage of respondents answering this specific question (in any case there is no significant difference in the ranking order produced).
61. Respondents were given the opportunity to identify multiple sources
62. In the case of complementary source of funding we only used one set of responses from project leaders who had received more than one grant
63. We identified 25 Chemists; 25 Physicists; 28 Biologists, Biochemists & Microbiologists; 9 Geologists; and 17 Mathematicians.
64. The responses for geologists are not as robust as for the other disciplines and should be treated with caution
65. Only 40% of respondents indicate that the scheme funds basic research, 35% gave neutral responses indicating that it funds research which is somewhere between basic and applied and 25% indicated that the scheme fund applied research. Geologists and mathematicians account for the majority of

favourable responses which confirms that the scheme is a more important source of funding for their research

66. Again mathematicians and geologists tend to represent a significant number of the favourable responses for these two criteria.
67. Of course, there are multiple sub-disciplines within these areas which vary in their level of potential application.
68. The project leaders were referring to grants available between 1989 and 1996. Grants are now able to provide funding over a three year period.
69. UCD Chemistry department, Survey of PhD graduates 1969-93, University College Dublin
70. One of the scientists we interviewed was also a director of a spin off company. This person tends to solve complex industrial problems as part of her commercial work, so we have not counted her as a positive response
71. For a discussion of these, see Erik Arnold and Ben Thuriaux, Supporting Companies' Technological Capabilities, OECD DSTI (Mimeo), 1997
72. Compare the European Commission's practice of 'negotiating' the size of grant once projects have been approved
73. This is a matter that might usefully be studied as one input to determining an economically sensible rate of grant funding for PhD students
74. Compounded GDP growth (including inflation) over the period 1995 to end of 1997 is around 27% (estimates from The Economist)
75. The target will have to be modified to take into account GDP growth
76. Obviously, in the interest of objectivity, this should not be conducted by us
77. We understand that a technology foresight initiative has recently been inaugurated by OST and Forfás.