ICSTI
IRELAND
Irish Council for Science,
Technology and Innovation

Measuring and Evaluating Research

Report of the ICSTI Task Force

Forfás

Established by the Government and Forfás to advise on Science, Technology and Innovation

CONTENTS

Functions of the Irish Council for Science, Technology and Innovation (ICSTI)

- To advise on science and technology policy-related issues in response to specific requests from the Government (through the Minister responsible for Science and Technology) or from the Board of Forfás.

- To advise the Minister responsible for Science and Technology, the Office of Science and Technology and the Board of Forfás, on the Council's own initiative, on policy for science and technology and related matters.

- To advise the Minister on the strategy for the preparation and implementation of national programmes in science and technology.

- To advise the Minister on the strategic direction for State investment in science, technology and innovation.

- To undertake from time to time such other functions as the Minister may decide. In this case, the information sought is to be submitted to the Minister.

1. Introduction

Recent years have witnessed a sea-change in Irish public policy towards Science, Technology and Innovation (STI), which is now regarded as central to this country's continued economic and social development. The key role of STI policy is signalled in the *National Development Plan 2000-2006,* and reflected in the initiatives of the HEA, Science Foundation Ireland, Forfás, Enterprise Ireland, and the full range of State agencies supporting the evolution of Ireland as a 'knowledge-based society'. This new policy environment brings with it many challenges, one of which is to develop mechanisms so that public support for STI can be prioritised, and so that the outcomes of such support can be measured and evaluated. This is important, not only for policy makers who are responsible for allocating public expenditure and for the tax payers who finance it, but also for the scientific and technological community in Ireland, insofar as they seek to provide evidence to the wider public of the social and economic benefits of support for STI.[1]

These concerns, of relatively recent prominence in Ireland, have been the focus of much international effort in the science policy community, as governments world-wide respond to the need for new indicators and evaluation techniques for knowledge based societies. This reports reflects that work[2], and its relevance to the Irish context, and provides a structured survey of the principal indicators and techniques used internationally to measure STI policy activities and to assess their impacts.

The choice of indicators and evaluation techniques depends to a large extent on our understanding of the underlying rationale for the public funding of research, so that a natural first step is to consider these issues. One broad approach argues that, in general, scientific knowledge has the characteristics of what economists refer to as 'a public good', and thus would be under-provided by free markets without state intervention, but more sophisticated rationales have recently been advanced. These are also considered below, along with their implications for the choice of indicators and evaluation techniques.

1 In June 1998 ICSTI released a statement on Mechanisms for Prioritising State Expenditure on Science and Technology. The ESRI endorsed this statement in its report on National Investment Priorities 2000-2006 and provided a discussion of the rationale for such investments in terms of the provision of 'public goods', a theme which merits particular attention in the present report.

2 Two background documents prepared for this report discuss this international literature in greater detail (Kane 2001a, 2001b).

2. Rationales for the Public Funding of Research[3]

There are both commercial pressures and public policy/economic arguments to support the public funding of research. The commercial pressures come from the technology sectors of industry which, before the current slow-down, had been the main driving force behind the strong economic growth over the past decade, particularly in the US. New developments in science and technology have been impacting on enterprise performance more quickly than ever before. The global technology firms, however, focus their own efforts on near-to-market research and development, and consider the role of funding basic research to lie with the public authorities. They expect to be interested in the results of some of this research for their own industries, to establish collaborative linkages with publicly funded researchers and to employ the highly trained and skilled graduates which these research programmes will spin off. They are supported in these views by recent research which found that up to 15% of new industrial products could not have been developed in the absence of academic research (Mansfield, 1998). Also, there are public policy objectives to increase the number and strength of technology companies as key components of an innovative economy.

2.1 Market failures, public goods and the linear model of innovation

There is an extensive body of economic literature detailing the contribution of technological progress to economic growth. This has given rise to discussions and arguments for the justification of public funding of research. The traditional justification centres around the concept of *'market failure'* and the need for government action to correct such failure. This 'market failure' approach to the economics of publicly funded research identifies the important role of knowledge and information in economic activity. Some of the scientific knowledge generated by research is economically useful information which can be classified as a *'public good'* and is freely available to all firms. Firms are reluctant to fund this more speculative, long-term research both because it is impossible to predict whether the results will be useful to themselves and because of their inability to

3 This ICSTI statement is concerned mainly with scientific research and development; the rationales and arguments developed here are applicable also to research in other fields such as the social sciences and humanities.

appropriate all the benefits. It is argued, therefore, that competitive markets by themselves fail to generate the socially optimal level of R&D.

Taken by itself, this view might imply that small economies, such as Ireland, could afford not to invest in scientific research insofar as scientific knowledge is widely available and easily acquired and appropriated: we could 'free-ride' on the investments of others. However, it is increasingly recognised that this 'public good' view of scientific knowledge is an over simplification. It is a traditional or neo-classical economic argument which relies on an unduly simplistic analysis of scientific and technological activities—a so-called *linear model of innovation*—which views innovation as a step-by-step development from initial invention (basic research), through applied research and development to the ultimate marketing of new products.

2.2 Evolutionary/institutional approaches and systems of innovation

More recent developments in the economics of science emphasise that the process of knowledge production is much more complex than the linear model would suggest. There may be many feed-backs between the various stages in innovation, so that the process is best considered as a system, where institutional relationships and the flows of knowledge between actors in the systems assume critical importance. This *evolutionary/institutional approach to innovation* stresses the extent to which knowledge is embodied in specific researchers and the institutional networks within which they conduct their research. Of crucial importance are skills, networks of researchers and tacit knowledge accumulated through experience and years of effort.

In this scenario, scientific research is not seen as a public good because scientific knowledge is not freely available to all, but only to those with appropriate educational backgrounds and to members of the scientific and technological networks. Information itself is abundant; it is the capacity to absorb it which is scarce. Hence, investment in research has a large human resources element, involving the training of skilled researchers able to link into global knowledge networks and absorb global developments.

This new evolutionary model is commonly referred to as the *'systems of innovation'* approach. Strengthening the Irish system of innovation has been a national policy objective since the STIAC Report (1995) and the White Paper on Science, Technology and Innovation (1996), and is the key rationale behind major recent public investments in research, including Science Foundation Ireland and the HEA Programme for Research in the Third Level Institutions.

2.3 The role of indicators and evaluation methods

The initiation of reviews of the effectiveness of science policy by politicians and other policy makers has arisen for a number of reasons. There has been external pressure on available funds for these activities and, consequently, renewed calls for increased accountability for their use as well as internal pressure to target resources more effectively. More than this, the demand for the review and assessment of government research programmes appears to stem from an interaction between these usual pressures and a longer term phenomenon referred to elsewhere as 'the re-negotiation of the science/society contract'.

Whatever the forces at work, a resulting pressure is the need to gather data, both in the interests of good management of the programmes and to develop strategies (rather than 'tactics') that will support the various fields of scientific research and enable the setting of priorities within these fields.

The complexity of the task involved in not only ensuring the funding agencies are satisfied that their programmes are working well, but also convincing Government and the public should not be underestimated. The assessment of the strengths and weaknesses of a funding body in a specific research field as well as the assessment of needs and opportunities for future support of the field is complex and difficult, but critical for the effective targeting of resources and for monitoring the ongoing health of the disciplines supported.

3. Measuring and Evaluating Research

Measurement is a process of counting or comparison using common characteristics and thus rests upon similarity between objects along a predictable scale. STI, however, involves novelty and change — changing units, changing scales and uncertainty — and so poses distinctive challenges for measurement and evaluation. The acuteness of those challenges is underlined by the evolutionary/institutional approach to understanding the production of scientific knowledge sketched earlier. Our indicators and evaluation techniques will inevitably reflect some such implicit model of how science proceeds.

The limitations of simplistic, 'cause and effect' type approaches to the evaluation of research activity need to be explicitly recognised. Research by its nature is uncertain, novel and risky. Its impacts can be long term, unexpected, or fail to materialise. They can be greatly affected by many external factors outside the scope of the initiative which supported the research. As such, it is important that evaluation and monitoring activities are supportive of these phenomena while also providing useful feedback to stakeholders on the nature, merits and likely impacts of research activity under review.

Three instances, from a myriad of possibilities in the history of science, make the point well:

- The **laser** was invented by Schawlow and Townes to help them study molecular structures. Neither was planning on producing a device that would launch a new scientific field and revolutionise desktop publishing, telecommunications, medicine and the entertainment industry.
- The seminal paper on **apoptosis** by Kerr, Wyllie and Currie in 1972 was not initially acclaimed by the scientific community and its full significance was not realised until the 1990s. Publications in the field now exceed 61,000 and the clinical applications of apoptosis are in areas as diverse as chemotherapy, the endocrine treatment of cancer, autoimmune disease and neurodegenerative disease.

- In 1980 a panel of reviewers for the National Institutes of Health classified the studies of Mario Capecchi on **targetted gene replacement** as 'not worthy of pursuit'. Capecchi used funds from another project to pursue the line of research which now has become the fundamental technology for testing the functional role of particular genes in mammals.

3.1 Approaches to indicators and evaluation methods

There are two main approaches to measuring the impacts of research. The first approach is an 'input-output' approach based on a number of indicators which measure inputs such as financial contribution, human resources and outputs such as number of publications, patents and products. While this approach has the virtue of simplicity it is fundamentally based on the 'linear' model referred to earlier, and accordingly suffers from the limitations of that underlying model. The second complementary approach is the 'throughput' approach which focuses on the actual process of research rather than the products. This approach is more difficult to undertake but does attempt to account for the complexities involved in scientific endeavour.

The 'input-output' approach is focussed on tangible resource and deliverable/product comparisons and is usually associated with reporting and monitoring. The 'throughput' approach is focussed on processes and relationships which require more qualitative and complex evaluative strategies. It is usually associated with formative or implementation evaluation. It is important that a clear distinction is drawn between the information required or utilised for reporting purposes and the information required for a more comprehensive evaluation.

Regardless of which approach is applied, there are many issues to consider before undertaking an evaluation, including:

- What **level(s) of the innovation system** is/are appropriate for the evaluation e.g., analysis of global, transnational, national, regional systems or those which focus on specific sectors, industries, firms or policy programmes, institutions, projects etc;

- The likely **time scale** involved for the impacts of the research to manifest;
- Are **inputs, outputs or impacts** being considered? Whether an indicator reports on inputs or outputs can be dependent on the context and the underlying analytical model; for example, patents can be both the output of particular firms and inputs into the innovative activities of others;
- The **type of policy intervention** or element of the innovation system to which the indicator/evaluation is most appropriately applied, e.g. some models of productivity spillovers have been used in the analysis of the benefits of R&D subsidies to the private sector, whereas bibliometric analysis and peer review might be more natural techniques in assessing grant/subsidies for publicly performed 'basic' research;
- The **stage of the policy or implementation process** being considered, e.g., the *ex ante* assessment of policy or selection of projects (for example, technology foresight), the on-going monitoring of initiatives, or *ex post* judgements of performance against stated objectives (for example, cost-benefit analysis or historical case studies);
- Whether the indicator/evaluation method is **'summative'** i.e., intended to inform a specific policy decision, or **'formative'** in being intended more to understand underlying processes and thereby improve performance. Indicators, taken in isolation, might often be summative; at least some evaluation methods can be integrated into a formative process;
- The **intended audience;** an evaluation might be internal to policy makers, or directed towards external sources of policy support such as a funding agency or regulatory authority, or the wider political and social system in which STI is embedded and in which policy is determined;
- Whether a technique is mainly **quantitative or qualitative**, which may have implications for the degree of expertise needed to interpret the information which it generates;

- The **underlying model** of the innovation process on which an indicator/evaluation is based—linear/neo-classical or evolutionary/institutional, for example;
- The **method of implementation** of recommendations arising from evaluations to ensure that any appropriate corrective action is taken in on-going activities or relevant lessons are incorporated in the design of new initiatives;
- The **information gathering and processing costs** of indicators and evaluation methods typically range between 0.5 – 2% of the overall costs of a programme and should be an earmarked element of the programme's overall budget. These activities can also impact on the behaviour of STI participants so there may be a need to set up incentives for compliance.

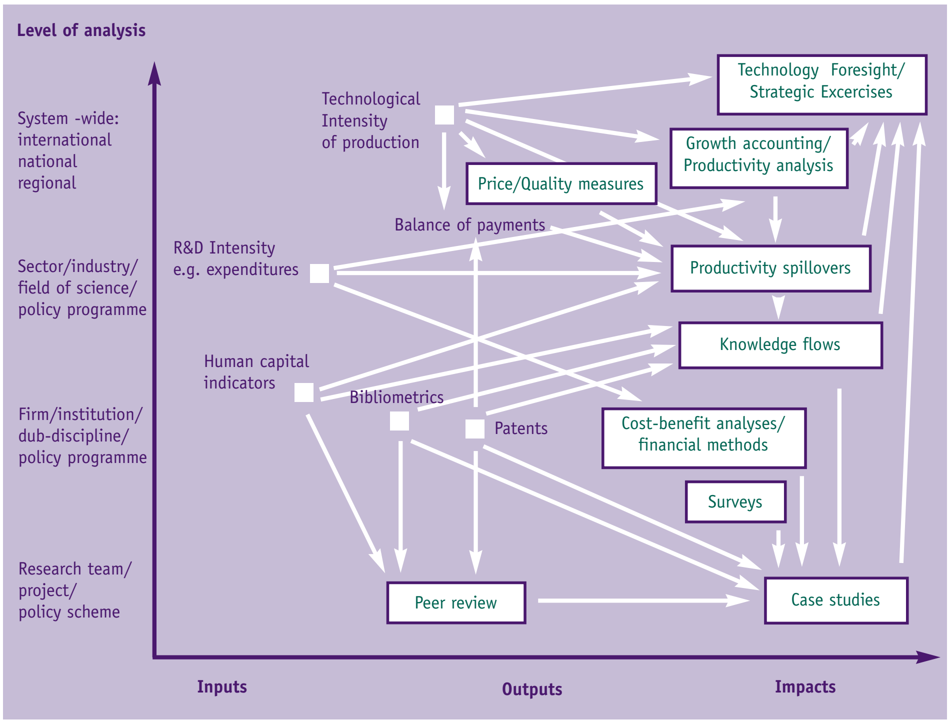
This last concern deserves particular weight: a defining theme in economic analysis is the simple notion that people respond to incentives; it is all too possible for policy makers to set up, through inappropriate evaluation mechanisms, a set of damaging or even perverse incentives for researchers. Further, the undertaking of an evaluation exercise pre-empts resources which might otherwise be used, for example, in the substantive work of scientific research.

3.2 Indicators and evaluation techniques from best international practice

The following sections summarise a range of indicators/evaluation techniques. Implicit in these summary accounts are commonalities among and differences and linkages between the techniques. The multiplicity and diversity of techniques signals to us that there is no one 'obviously correct' method in what is a complex domain. Any given technique can only provide a partial picture of what is being measured/assessed and each has associated limitations and constraints. The intelligent application of such techniques requires an appreciation of these problems, rather than the mechanical application of crude quantitative methods to produce indicators of illusory certainty.

Figure 1, in summarising much of the present discussion, provides an overview of the indicators and evaluation techniques discussed here, showing how they can be understood as relating to particular levels of analysis of an STI system (international, national/regional, or at the level of individual research teams and projects) as well as relating them to particular aspects of the STI process (e.g. accounting for inputs, outputs or wider socio-economic impacts.

Figure 1: Indicators and Evaluation Techniques for Science, Technology and Innovation



Source: Kane(2001b)

3.2.1 The 'input-output' approach: principal indicators/ evaluation methods

The following indicators/evaluation techniques essentially measure inputs or outputs in the production of knowledge, or explicitly relate inputs to outputs. In that sense, they can be related to the neo-classical/linear approach to innovation referred to earlier and while they have the virtue of relative simplicity, they tend to underplay the intrinsic complexity of scientific endeavour which more modern approaches attempt to capture:

- **Indicators of R&D expenditures**, based on measures of R&D expenditures which can be distinguished by the sector in which the activity takes place and by sources of finance e.g., government, business, higher education;
- **Human capital indicators**, including employment data, especially on R&D workers, scientists and engineers, data on educational attainments and indexes of human capital which aim to capture quality improvements, as well as indicators of the mobility of human capital;
- **Bibliometric analysis**, by which the quantity, quality and impact of published scientific literature are assessed insofar as this literature is a key social mechanism by which scientific knowledge is embodied and transmitted;
- **Patent analysis**, including relatively simple patent counts, but also more elaborate analysis in a bibliometric style aimed at tracing flows of knowledge between science and near-to-market innovations and a number of techniques which attempt to assess the economic impact/value of patents;
- **Indicators of the technological intensity of production**, which scale national and sectoral productive activities according to some predefined notion of high-technology;
- **Balance of payment indicators**, including measures of the technological intensity of exports and imports of goods and services, as well as the technology balance of payments which report on trade in technological knowledge, e.g. by licences sold abroad for domestic patents and trade in technological services;

- **Growth accounting analysis**, which separates the technologically driven component of economic growth through measures of the productivity of capital and labour from that part of growth which arises from the increased use of capital and labour inputs;

- **The measurement of price and quality changes**, which underlies the practice of growth accounting, raises a set of issues of particular importance where, as in STI, the introduction of new and improved products and processes is a defining characteristic.

3.2.2 The 'throughput' approach: principal indicators/ evaluation methods

The following indicators and evaluation techniques can best be understood as attempts to reflect the complexity of the process of scientific endeavour, as emphasised by evolutionary/institutional models of innovation. While often drawing upon the more linear/neo-classical approaches just summarised, these methods elaborate on them, to provide more nuanced understandings for policy makers and the scientific community.

Evolutionary/institutional models of innovation emphasise that policy making in STI is best conceived of, not as the application of algorithmic techniques in well-defined situations, but as a dynamic process of learning within institutions and technological environments characterised by change, complexity and uncertainty. This is taken to imply a move away from naïve notions of indicators and evaluation methods as providing one-shot, summative, numerical measures which can mechanically determine policy decisions, towards a view of them as part of an experimental and learning process for STI policy makers, researchers and participants alike. Furthermore, such perspectives on STI tend to make a case for a portfolio of evaluative techniques and measures, given that particular techniques capture only certain dimensions of innovative activity, whereas the over-arching goal is to address systemic performance in a holistic manner.

Some principal techniques are:

- **Peer review**, which has traditionally been a key social process in the scientific community with varying degrees of adaptation in structuring public policy decisions e.g. some reliance on formal bibliometric analysis and wider selection pools for 'peers';
- **Surveys/Interview**, which find wide application in evaluating STI activities, not least because of the opportunity to integrate quantitative and qualitative data;
- **Case studies**, which may draw upon many of the other techniques to provide comprehensive retrospective accounts, especially of well-defined projects with complex evolutionary development paths;
- **Cost-benefit analysis/quasi-financial methods**, which attempt to capture some of the non-market flows of welfare impacts attributable to STI activities, including models which estimate returns using the concepts of consumers' and producers' surplus, and rates of return, by partial analogy to private sector investment decision making;
- **Models of productivity spillovers**, which draw upon growth accounting analysis to statistically estimate the magnitude and direction of non-appropriable benefits to R&D exports between and amongst firms, productive sectors, regions and nations;
- **Models of knowledge flow**, which draw upon bibliometric and patent citation data, in order to map the quantum of knowledge of varying types, patterns of knowledge diffusion and interaction, and the strengths of linkages between knowledge-producing and knowledge-using sectors;
- **Technology foresight exercises**, which similarly can be informed by the eclectic use of information sources, but which also can be enabled by techniques specific to the prospective strategic analysis of STI options;

4. Research Measurement and Evaluation in Ireland

In common with all OECD countries the Irish innovation system has three main groups of actors - the business sector, third level colleges and government institutions with a financial sector underpinning their activities as illustrated in Figure 2. Figure 3 elaborates on the public research element of the system.

Figure 2: The National System of Innovation

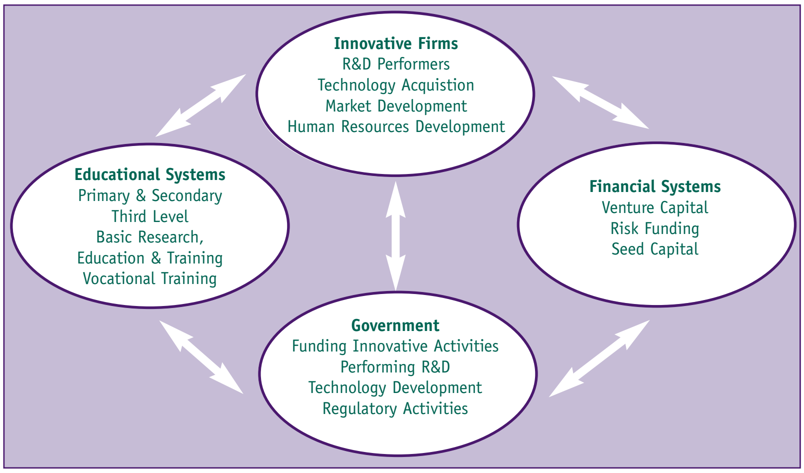
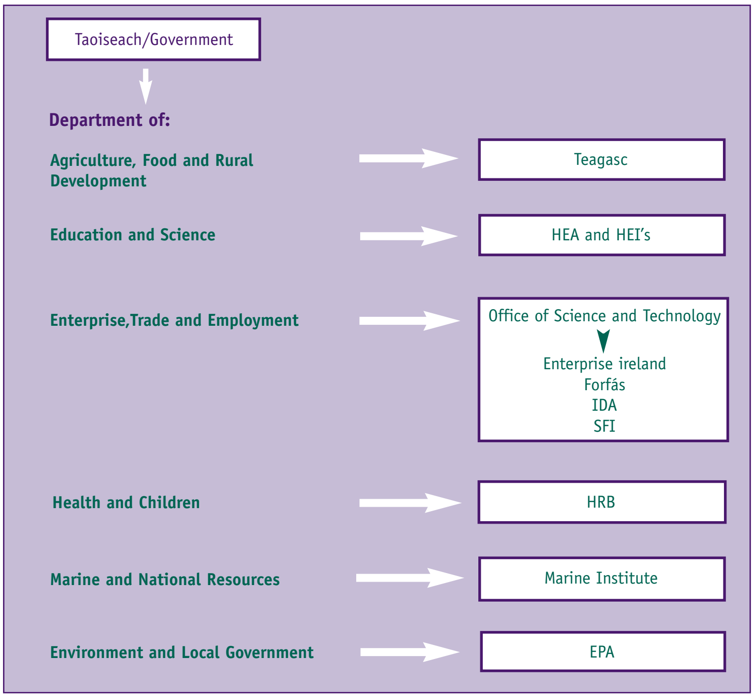


Figure 3: The Irish Public Research System



Indicators are used mainly for monitoring Ireland's technological performance within the Irish economy vis-à-vis other EU/OECD countries. Comparisons are made with other countries when targets of performances are being set and monitored.

Responsibility for the collection, analysis and publication of primary S&T indicators rests with the S&T Indicators unit in Forfás. These indicators are compiled and published regularly by both Eurostat and OECD. They are mostly R&D indicators, although in recent years Eurostat has been organising the collection of wider innovation indicators to measure innovation in the business sector.

The Higher Education Authority has responsibility for the collection of all personnel data for the higher education sector, i.e. inputs to, and graduation from, the sector, numbers doing post-graduate study etc.

An important locus of evaluation methodologies arises from Ireland's participation in EU funded programmes. There is a Community Support Framework Evaluation Unit, established in 1996, in partnership between the Department of Finance and the European Commission. The Unit's central function is to advise and assist the national authorities and the European Commission on the evaluation of structural fund programmes. An evaluation of the RTDI Priority and the Regional Innovation Strategies Measures in both the BMW and S&E Regional Operational Programmes is planned and will be undertaken during 2002.

There is an evaluation section in Forfás which carries out evaluations of S&T programmes on behalf of the Office of Science & Technology (DETE) and monitors the implementation of recommendations arising from such evaluations. These programmes are operated mainly by Enterprise Ireland.

Teagasc, the Higher Education Authority (HEA), the Health Research Board (HRB) and Enterprise Ireland each carry out evaluations/surveys to measure and set targets and objectives for their particular programmes or initiatives. For example:

- Teagasc has a formal system in place for assessing the effectiveness/impact of its programmes. The techniques used to assess research are periodic international peer review of programmes, cost benefit analysis of selected programmes and expert consultation. Recent developments in Teagasc will lead to the establishment of a dedicated Evaluation Unit to oversee and co-ordinate developments in this area. This will include a comprehensive evaluation plan and a cyclical programme of evaluation of all operations.

- The HEA's executive requires institutions to report at least annually on activities related to any particular programme. Such reports are examined internally and measured against the aims and objectives already agreed for such schemes. The HEA conducts ad-hoc evaluations on particular programmes or initiatives and will carry out evaluations of all programmes funded under PRTLI.

- Enterprise Ireland reviews/evaluates activities and outputs of technological programmes and initiatives it funds. All research and technological contracts which Enterprise Ireland enters into require recipients to report progress on project spending and activity and on achievement of objectives.
- The Universities have a quality review system in place known as the QAQI programme.

While information on indicators on inputs to the S&T system is reasonably well developed in Ireland, there is a scarcity of information on the outputs and impacts of STI initiatives. The increased priority accorded to STI policy has not yet been accompanied by a general, embedded capacity to monitor and evaluate such policies, beyond specialist agencies and units: policy makers are on a learning curve, which should be facilitated.

The public research system is undergoing dramatic change with significant injections of public funds. This will bring Ireland more into line with the international level of public research funds (public research funding as a percentage of GDP), but Ireland lies behind other OECD countries in evaluating research programmes and scientific fields.

5. Conclusions and Recommendations

The recommendations set out below reflect a number of themes which recur in this report:

The role of indicators and evaluation techniques in addressing the concerns of a number of audiences, e.g.,

- For policy makers in meeting the requirement of public accountability in the disbursement of public funds,
- For the scientific and technological community in demonstrating the economic and social benefits of publicly supported scientific endeavour,
- For both policy makers and researchers to enable learning about policy design and delivery, and to facilitate the continued development of the innovation system.

That the choice of indicators and evaluation techniques rests on underlying, sometimes implicit models of the production of scientific knowledge:

- This carries with it the implication that an unduly simplistic view of the process of science, its uncertainties and complexities might be reflected in the uncritical use of crude indicators and evaluation methods, to the detriment of the shared goal of advancing Ireland's national innovation system.
- In particular, it must be acknowledged that evaluative processes themselves involve the use of scarce resources, and so need to be carefully aligned to the goals of policy, and the setting up of incentives for members of the scientific and technological community.

That in general, the re-orientation of Irish public policy towards Science, Technology and Innovation has not been yet reflected in an increased and generally embedded capacity to evaluate such policy initiatives, particularly in relation to ex-ante evaluation, and to appreciate newer indicators of the 'knowledge-based society'.

We recommend:

- That expertise in indicators and evaluation techniques for STI policy be more widely embedded in public policy agencies in Ireland, to more fully reflect the centrality of this domain of policy to economic and social development, by
  - The continued development and use of such techniques by specialists agencies such as Forfás, the HEA, and SFI and evaluation units involved in STI activities,
  - The dissemination of information on, and the results of, such techniques in the wider policy community, through publications and conferences/seminars on these themes,
  - Consultation with the scientific and technological communities as to the evaluation approaches adopted or under consideration.
  - The much wider use by funding sources (typically government departments) of a formal ex-ante evaluation prior to approving the introduction of any new or revised STI initiatives.
  - The provision of a specific allocation for the costs of monitoring and evaluation within the overall budget for each STI support programme.
- That the production of indicators and the conduct of evaluative exercises should take full advantage of the range of techniques available, or under development internationally i.e. a 'portfolio approach' is recommended, rather than the reliance on unduly simplistic, one-shot summary measures.
- That the choice of indicators and evaluation techniques be generally governed by an appreciation of the underlying complexities and uncertainties of scientific research and technological development, the resource costs of such exercises, and the impacts they may have on the incentives of researchers.

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ICSTI Statements to Date*

Commercialisation of Publicly Funded Research	April 2001
Report on Biotechnology	February 2001
Benchmarking School Science, Technology and Mathematics Education in Ireland Against International Good Practice	February 2000
Science in Second Level Schools	October 1999
Public Sector Research and Technology Services for Innovation in Enterprises	September 1999
Technology Foresight Ireland[1]	April 1999
Investing in Research, Technology and Innovation (RTI) in the Period 2000 to 2006	March 1999
State Expenditure Priorities for 1999	January 1999
Innovation in Enterprises in Ireland	November 1998
Science Technology and Innovation Culture	November 1998
Science in Primary Schools	September 1998
Mechanisms for Prioritisation of State Expenditure on Science & Technology	June 1998
A Partnership Approach to Research Funding-The Need for a National Science and Engineering Board	May 1998
£250 million Scientific and Technological Education (Investment) Fund	January 1998
State Expenditure Priorities for 1998	September 1997

** A CD of the Statements published between 1997 and 2001 is available from the ICSTI Secretariat.*

1 A suite of nine reports comprising an ICSTI overview and eight individual reports from expert panels established in the following areas: Chemicals & Pharmaceuticals; Information & Communications Technologies; Health & Manufacturing Processes; Health & Life Sciences; Natural Resources (Agri-Food, Marine, Forestry); Energy;Transprot & Logistics; Construction & Infrastructure.

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