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Special Issue on "Public/Private Partnerships in Science and Technology"

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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FOREWORD

Prepared by the OECD Directorate for Science, Technology and Industry, the *STI Review,* published twice yearly, presents studies of interest to science, technology and industry policy makers and analysts, with particular emphasis on cross-country comparisons, quantitative descriptions of new trends and identification of recent and future policy problems. Because of the nature of OECD work, the *STI Review* explores structural and institutional change at global level as well as at regional, national and sub-national levels. Issues often focus on particular themes, such as surveys of firm-level innovation behaviour and technology-related employment problems.

This issue of the *STI Review* examines the emergence of public/private partnerships for R&D, technology development and diffusion. The OECD Committee for Scientific and Technological Policy is examining public/private partnerships as part of the work on Best Practices in Innovation and Technology Policy. The papers in this issue are drawn mainly from an *ad hoc Thematic Workshop on Public/Private Partnerships* held in Paris on 12 December 1997, and additional contributions from academic and field experts. The rationale for public/private partnerships, the different approaches to partnerships, including initiatives at national and international levels, and the lessons from the experience of OECD countries in financing, implementing and evaluating them are among the main themes of this publication.

The views expressed in this publication do not necessarily reflect those of the OECD or of its Member countries. The *STI Review* is published on the responsibility of the Secretary-General of the OECD.

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PUBLIC/PRIVATE PARTNERSHIPS IN SCIENCE AND TECHNOLOGY: AN OVERVIEW

Background

Concurrent with the explosive growth in national and international R&D alliances among industrial firms in OECD countries, governments have facilitated and stimulated R&D partnerships between the *public research* base and industry. This trend has been further accelerated by the recent levelling of public R&D spending as OECD governments rely more on partnerships with industry to leverage R&D resources. Firms enter into R&D partnerships to overcome market failures that result from uncertainty and resource constraints and the inability to internalise significant spillovers. Private R&D partnerships are thus a *market* response to market failures that prevent firms from conducting the socially optimum level of R&D. In the same vein, public sponsorship of R&D partnerships is a *policy* response to similar types of market failures which are not resolved by market mechanisms alone. This occurs, for example, when the transaction costs associated with R&D partnering are too high to induce collaboration or when the incentives for partnering (*e.g.* cost sharing of inputs, appropriation of outputs) are insufficient and thereby result in the rejection by firms of socially beneficial joint R&D projects. *Systemic* failures that arise from mismatches in the incentives for co-operation among the various actors in the innovation system (*e.g.* universities, firms, laboratories) can also impede collaboration in R&D and technology, thus leading to lower social returns from public research.

A main appeal of public/private partnerships is that they reduce the risk of failure that results when governments try to ''pick winners'' through traditional R&D subsidisation schemes. Public/private partnerships entail the competitive selection of participants and greater influence from the private sector in project selection and management, helping ensure that the best participants and projects are targeted. While the direct and indirect benefits of public/private partnerships (*e.g.* cost and skills sharing) are often touted by industry and governments alike, there are potential costs, both in terms of resources and the opportunity cost of alternative market or policy solutions (*e.g.* via regulatory measures). The articles in this issue of the *STI Review* analyse the development of public/private partnerships in R&D and technology in OECD countries. The rationale for partnerships and the motivations for the public and private sector are examined, drawing on evidence from several Member countries, at both the national and the international level. Finally, the articles identify problems as well as good policy practices in designing, financing, implementing and evaluating public/private partnerships.

In the area of technology policy, the term ‘‘public/private partnership’’ can be defined as any innovation-based relationship whereby public and private actors jointly contribute financial, research, human and infrastructure resources, either directly or in kind. As such, partnerships are more than simply a contract research mechanism for subsidising industrial R&D. Partnerships can be formal or informal arrangements governing general or specific objectives in research or commercialisation and involve two or more actors (*e.g.* consortia). While informal arrangements exceed formal partnerships, such arrangements become more structured when costs and benefits are directly accountable (either in kind or direct). Formal agreements, as pointed out in the article by *Shapira* and *Youtie*, are universal whenever money changes hands. Public/private partnerships are not entirely new. In fact, collaboration between public research and industry has been characteristic of the German research system since the nineteenth century. In the United Kingdom, collaboration between university departments in science and engineering and industry at the beginning of the twentieth century involved academics working as consultants to industry, although this type of interaction was later replaced with the development of industrial laboratories.

In post-war Japan, partnerships have been an integral part of large government-sponsored industrial technology programmes (*e.g.* the Very Large Scale Integrated Circuit project between 1975 and 1985) to help Japan catch up in specific sectors. In the United States, even if university and industry research partnerships can be traced back to the second half of the nineteenth century, it was not until the Cold War that changes in government policy, led by heightened defence spending on R&D, resulted in increased collaboration between public research and industry. In the 1960s and 1970s, structural change prompted the states to take the lead in promoting collaboration between industry and universities as a means of harnessing technology for local economic development, especially job creation. By the early 1980s, the success of Japanese collaborative R&D and growing competition in global technology markets led to a paradigm shift in the United States, with public/private partnerships becoming a key component of federal technology policy and a tool for improving national competitiveness.

Rationale for partnerships

In many ways, the factors fuelling the rise in public/private partnerships are related to those that drive the increases in private R&D and market-driven alliances between firms. Three of the main factors driving public/private partnerships, in particular university-industry collaboration, are: *i)* increased speed of transition to the knowledge-based economy; *ii)* increased globalisation and competition; and *iii)* budgetary constraints faced by governments and their impact on patterns of funding of university research as well as the higher costs of research in general. To this list must be added several factors that affect the decisions of firms, notably shorter product cycles and hence shorter time horizons for R&D, the outsourcing of generic research including to public research bodies, the convergence of technologies and changes in intellectual property rules governing publicly funded research.

For government, the rationale for promoting partnerships in the context of innovation and technology policy is dual: to correct for the market failure that results in underinvestment in R&D by firms and to improve the ‘‘efficiency’’ of public support to R&D. Market failures associated with underinvestment in technology and innovation stem from problems in private appropriability and from the technical risks and uncertainty that private investors must assume. When the market failure is one of appropriating sufficient returns, the role of partnerships is to raise the incentive for private firms to invest in R&D (*e.g.* via intellectual property rights). When it is technical risk (from uncertainty) that precludes private sector investment either by single firms or consortia, government support for collaborative research may be appropriate. In sectors with high economies of scope that prevent firms from fully appropriating research outcomes, there may also be a case for public support for R&D. Given its positive network externalities, the environment sector, as shown in the article by *Fukasaku*, is among the most common targets of partnership initiatives. Considerations such as national security, economic competitiveness or sustainable development often play a role. As regards the second goal, partnerships help improve the *efficiency* of public R&D support by eliminating overlapping investments, reducing the time horizons for R&D and stimulating additional spillovers from public research.

The nature of the market failure, however, has a bearing on the rationale and shape of the public/private partnership. In theory, the stage at which the government supports R&D partnerships is the one where the market precludes a private solution to market failure. This is generally at the pre-competitive stage of technology but, as *Scott* discusses, public/private partnership at the commercialisation stage could also be justified if market failures (*e.g.* in financial markets) lead to underinvestment in the *use* and application of technology for developing new products and processes. Intense competition in the application of new technology in product markets with high substitutability may also lead firms to underinvest in technology. There is therefore an argument for tailoring government support, such as information provision or financing, according to whether the failure lies in the pre-competitive stage or closer to market. The policy challenge then is to match the *amount* of government support to the degree of market failure and to design the partnership in a way that allows maximum spillovers without inhibiting incentives for private sector participation.

Approaches to public/private partnerships

At a general level, public/private partnerships can be classified according to the types and characteristics of the actors involved, including: *i)* university-industry partnerships; *ii)* government (including laboratories)-industry partnerships; *iii)* research institute-industry partnerships; and *iv)* a combination of the above, such as partnerships linking multiple government research institutes to one another and to industry. With regard to the first category, the article by the *OECD Secretariat* provides a detailed typology of the various mechanisms for university-industry partnering, from general grants and fellowships through specific contract research, collaborative research and consortia agreements, to training, mobility and networking schemes.

Public/private partnerships can also be classified according to the functional objectives and goals of governments, such as support for strategic research and technology development; improving the mechanisms for commercialisation and technology diffusion; generating spinoffs of technology-based firms. In addition, providing access to innovation financing and training, and stimulating networking among innovation actors have become more explicit objectives of partnerships. From the point of view of the firms, *Guy et al.* propose four main goals associated with participating in public/private partnerships: knowledge goals; exploitation goals; networking goals; and stewardship goals such as cost reduction and sound R&D management. Although cost sharing is generally considered a main motivation for partnering in R&D, survey evidence from partnerships in advanced technology programmes suggests that knowledge goals rank highest among participating firms. This may reflect greater heterogeneity among the partners since scale-related issues (*i.e.* cost sharing) are more important among similar firms. As regards the technology focus of partnerships, sectoral-based programmes remain important but they are integrating multiple technologies. In her article, *Fukasaku* examines the integration of energy and environmental objectives in partnership schemes. This further highlights the growing importance for policy makers of linking improvements in industrial competitiveness to the promotion of sustainable development.

There is also an international dimension to partnerships, with cross-border relations increasingly being promoted either as part of national partnership schemes or specific international programmes. The paper by *Kemmis* reviews Australia's Co-operative Research Centres (CRC) programme, which allows participation from overseas research organisations and firms. This is relevant given that in Australia foreign subsidiaries account for 45 per cent of manufacturing R&D. Another trend in many partnerships is the participation of non-traditional actors such as industry associations, libraries, vocational and technical colleges and even museums. *Cannell* reveals that collaboration with such non-governmental actors or firms accounted for nearly 10 per cent of participants in the EU's

Fourth Framework Programme, compared to around 3 per cent during the Second Framework Programme. Even within government, partnerships increasingly involve co-ordination and co-operation across various ministries and agencies. The implementation of the UK Technology Foresight exercise involved co-operation among several government departments as well as external consultants.

University-industry partnerships

The importance of one form or another of public/private partnerships reflects different institutional structures and research specialisation in OECD countries. In the United States, for example, the predominance of university-industry partnerships reflects the specific national characteristics and embedded structures of (university) research financing. Scientists pursuing basic research in US universities largely depend on competitive grants from extramural funds. In many European OECD countries, university research has traditionally been supported by *internal* university research funds, although tighter budgets for higher education research have led universities in countries such as Belgium, the Netherlands and the United Kingdom to diversify their sources of funds. Since the 1980s, the share of higher education research financed by industry has increased strongly, especially in Canada, Germany, the Netherlands and the United States. *Senker* cites three main factors to explain the increase in university interactions with industry: *i)* the need for universities to look for non-government sources of funds; *ii)* the need for industry, spurred by competition and shorter time horizons for R&D, to access a broader science base than available in-house; and *iii)* the push for greater returns from government support for R&D (*e.g.* via the commercialisation and diffusion of publicly funded research).

In addition, several OECD countries have made changes in the intellectual property rights governing the results of publicly supported research, and this is partly reflected in the rise in university patenting activity. In the United States, changes in antitrust laws which allow the formation of private joint research ventures were institutionalised through legislation that allowed universities to retain title to innovations developed though federally funded research and via new rules that required federal laboratories to facilitate transfer to the private sector. Across the OECD area, governments have helped establish technology transfer and industrial liaison offices at universities, technology incubators, science parks and, more recently, centres of excellence – all with the goal of increasing efficiency from public R&D spending and diffusing knowledge. The success of these various ‘‘bridging institutions’’ has on balance been mixed. Public funding of these knowledge centres remains an issue as industry participation is insufficient for self-sustainability in the short to medium term (five to ten years). Among the most successful initiatives are those which have taken an interdisciplinary approach and concentrated on specific technology clusters (*e.g.* biomedical and information technologies).

Government-industry partnerships

Government partnerships with industry generally bring together central-government-funded research bodies with consortia of large firms that focus on pre-competitive or ‘‘enabling’’ research. The most well-known examples include consortia in the area of advanced manufacturing technologies such as microelectronics (*e.g.* the SEMATECH in the United States, the VLSI in Japan or the JESSI initiative in the European Union). *Guy et al.* evaluate the motivations and outcomes of firm participation in government-sponsored advanced technology programmes in Finland, Sweden, the United Kingdom and the European Union. A key aim of government programmes to fund industry consortia, including the US Advanced Technology Program (ATP), is to reduce the technical risks and induce firms to bear the remaining commercial risks which correspond to their market strategies. While partnerships between government and industry consortia may involve universities or laboratories in the execution of extramural research, generally the sponsoring government agency and firms are the main participants.

Another form of government-industry partnership takes the shape of joint research ventures between government laboratories/centres and firms. Following the privatisation of the government research establishments (GREs) in the United Kingdom, contract research became a source of funds for them as well as for the Research Councils. In Canada, external advisory boards have made public laboratories more applied and client-oriented. In the United States, legislative changes in the 1980s spurred the creation of the Co-operative Research and Development Agreements (CRADAs) which are not collaborative technology programmes *per se* but rather a mechanism that allows federal laboratories to enter into partnerships with industry as a way to commercialise dual-use technologies. While CRADA-initiated partnerships are mainly considered as promoting technology transfer rather than research, they nevertheless contribute to building the infrastructure for co-operative R&D. Government support for CRADA projects takes mainly the form of *in-kind support* including staff hours and access to federal laboratory facilities. At the same time, evaluations suggest that government laboratories in general have been less successful than universities in licensing technology. This may be due in part to their late entry and lack of experience in co-operating with industry or to the fact that few laboratory technologies are readily commercialisable and instead require substantial interaction among partners – well beyond the attribution of intellectual property rights. Laboratories also tend to have less flexibility in partnering with industry given that their objectives are pre-set by agency missions or national R&D plans and the bulk of their funding is generally allocated on a discretionary basis rather than through competition and peer review.

Partnerships between public research institutes and industry

In several OECD countries, industry partnerships with research institutes are more common than those with universities or laboratories. This likely reflects the divide between countries where universities play a larger role in both basic and generic applied research (*e.g.* Austria, Belgium, Canada, Sweden, the United Kingdom and the United States), including contributing to mission R&D, and countries where public research institutes play a rather substantial or larger role in both basic and applied research (*e.g.* France, Germany, the Netherlands, Norway). Sectoral or branch institutes are also important in Austria, Sweden and in central and eastern European countries, where many institutes have been restructured to improve co-operation with industry. It should be noted that during the 1980s there was strong growth in the establishment of US research institutes, mainly at universities, which focus on certain industry needs (*e.g.* robotics for manufacturing), although the high funding involved has meant that large research institutes have given way to smaller and more specialised types of centres.

In France, the CNRS (Centre national de la recherche scientifique) institutes and specialised research agencies (*Commissariat à l'énergie atomique, Institut national de la recherche agronomique*) are generally more active than universities and other higher education establishments in partnering with industry. In Germany, partnerships have been characterised by industry collaboration with both universities and applied research institutes such as the Fraunhofer or the Steinbeis Foundation centres. There has been, however, a recent shift in partnership policies away from ''institution-based'' collaboration towards project-based partnerships (*Leitprojeckte, Bioregio Projects*) that involve multiple actors in the innovation system. While public research institutes in France, Germany and the Netherlands have generally benefited from stable and permanent research funding, this situation is changing as institutes rely more on industry support. In Korea, where there is a weak tradition of research in universities, the Government Research Institutes (GRIs) are the main vehicle through which public/private partnerships are promoted. Within the public/private partnerships sponsored by the EU Framework Programmes, public research centres and higher education establishments now account for more than half of the total participants (firms account for 38 per cent).

SMEs as partners in R&D

Public/private partnership arrangements are increasingly targeting small and medium-sized enterprises (SMEs), often linking together groups of small firms and multiple public research providers. There are two reasons for this. The first is that successful innovation in firms will increase the number of competitors, leading to improved performance in product markets and consequently job creation. The second is that there is a general perception that SMEs face higher risk and uncertainty in technological innovation because of their more limited R&D portfolios and lack of resources such as information, human and financial capital. Market failures may also arise in product markets when the dominant position of large firms or the oligopolistic structure of a given market impedes innovation by SMEs. *Molero and Buesa's* evaluation of Spain's Centre for Technology and Industrial Development (CDTI), which provides financial support to SMEs, suggests that the financing of research partnerships with small firms may be appropriate in cases where venture capital or other sources of innovation financing are underdeveloped.

The question arises whether the lack of co-operation is due to fundamental incompatibilities such as diverging time horizons – with small firms focused on specific solutions to specific problems and universities focused on long-term research – or whether there are institutional and market disincentives to partnerships. Blindly promoting partnerships between SMEs and universities could divert resources away from projects with larger firms that may have potentially higher social and private returns. An approach undertaken by several countries is to broaden public/private partnerships that involve both large and small firms and other actors in the innovation system. In *Shapira* and *Youtie's* analysis of the US Manufacturing Extension Partnerships (MEP) programme, SMEs are linked with various service providers such as federal labs, technology brokers and consultants, with support being tailored to different types of firms (*e.g.* firms in mature industries). The success of such broad-based partnerships, however, presupposes effective channels of co-operation and co-ordination among the different levels of government and service providers. At EU level, a number of special measures have been developed to encourage the participation of SMEs in Community research partnership schemes which until recently were dominated by large firms.

International partnerships

While firms have long maintained commercial and R&D alliances, joint research ventures and other forms of market-driven collaboration (*e.g.* marketing, distribution agreements), governments are also keen to promote international partnerships. Traditionally, there have been three main objectives of publicly supported international partnerships: *i)* tackling global-scale issues such as climate change, oceanography, renewable energy and space exploration (*i.e.* megascience projects); *ii)* promoting socio-economic/regional co-operation in R&D through bilateral agreements; and *iii)* technology transfer and co-operation, mainly between advanced and developing countries and as part of commercial/

trade agreements. The Intelligent Manufacturing Systems (IMS) Initiative, examined by *Parker,* aims to set the appropriate manufacturing quality standards and intellectual property rights for international co-operative R&D. This project illustrates the important role of government collaboration in what initially began as a private/private partnership. A key feature of the IMS initiative is its use of an extensive feasibility study and the development of terms of reference for intellectual property rights. Obtaining support from national governments and tapping into national umbrella organisations made the screening and selection of projects more effective.

At the EU level, various mechanisms exist to promote international partnerships in R&D and technology development. The EUREKA initiative aims to raise the competitiveness of European industry by funding projects which increase co-operation between firms and universities/research institutes in areas of advanced technology. The INNOVATION programme similarly brings universities and small firms together around specific projects. The article by *Cannell* reviews the present and past goals of the EU's Framework Programmes for international partnerships which are now moving away from sectorally based research to projects that require a high degree of interdisciplinarity and involve several member states. Recently, another aim of cross-border partnerships is the promotion of networking among and between actors of national innovation systems (*e.g.* between international consortia of firms and universities, business-to-business relations).

Problems in designing and implementing partnerships

Framework conditions and intellectual property rights

Framework conditions and intellectual property rights have a direct bearing on the infrastructure for public/private partnerships. At the economy-wide level, tax regimes and regulations affect the costs and incentives for investing in co-operative R&D ventures. Rules on competition (*e.g.* antitrust laws) help set the preconditions for public/private partnerships. Relaxing competition policy raises the question of how close to final product market development can co-operation be allowed before competition is distorted. This question is more relevant, however, in highly concentrated and R&D-intensive sectors, and depends on the type and objectives of the R&D partnership. The nature of intellectual property rights also affects the incentives for partnerships as do regulations governing public R&D support in universities, laboratories and research institutes. For example, excessive use of exclusive licensing rules by universities may preclude research financing by firms who see their support benefiting competitors. This raises the issue of balancing the need for a broad diffusion of public R&D with the prerogatives of private firms (increasing private returns). While older technology programmes in the United States have retained title to inventions and licensed their use to firms in exchange for royalties, newer partnerships, such as the ATP programme, grant title to the firms and do not require licensing or in some cases even royalties, for use of the invention, thereby stimulating diffusion. One reason is that the link between public funding of pre-competitive research and the eventual product emerging from the partnership is often unclear.

Within universities, regulations on academic co-operation with industry can promote or obstruct collaboration. Rigid institutional and hierarchical structures that prevent co-operation across university departments and within firms could also weaken the partnership. A main challenge in designing partnerships is to accommodate the various objectives of the actors involved. Differences in culture and expectations between universities and industry, including different time horizons for research, must be understood by all partners. The attitudes of management also matter in implementing partnerships: studies in the United Kingdom found that some firms have a higher propensity to partner with public research than others and this may be related to senior management attitudes, awareness and prior contact with public research. Another problem in designing partnerships concerns the effect of R&D assistance on product market performance. In cases of partnerships in concentrated industries there are policy concerns that R&D partnerships may increase product market collusion. Yet, insofar as partnerships aim to achieve other goals beyond cost sharing, such as learning and skills enhancement, this may lead to more intense competition. The risk for conflict between competing firms in the partnership can be reduced by focusing collaborative efforts on the links with suppliers rather than on core products. In fields where technology is changing rapidly, however, partners may diverge in terms of their goals and expected outcomes, resulting in termination of the partnership or requiring adjustment to the project.

In addition, partnerships are not cost-free. First, they require sunk costs to get started and involve significant transaction costs for both firms and public research actors. Identifying and selecting partners generates *time* and *information costs*. There are also *organisational costs* associated with partnering. In pre-competitive partnerships, increasing economies of scale do not always compensate for the additional *complexity* of managing joint projects. Thus, partnerships are not simply a question of doing more with less but of investing new resources and skills to make research programmes more efficient. In the United States, there has been a move to reduce administrative requirements (*e.g.* federal accounting methods in reporting inputs and outcomes) that increase the costs of participation to firms. Other problems relate to the changing priorities of managers. At the programme level, there is a risk of conflict between programme managers who are more keen to develop their own relations than to link programmes to other service providers. Public sector and non-profit partners such as vocational colleges may also be under pressure from their own priorities, so that limited attention and resources are available for the research partnership. Partners must be able to anticipate from the outset what the objectives are, how and what each partner is expected to contribute, how performance will be monitored and under what conditions partnerships will be institutionalised. Finally, there are potential limits to knowledge transfer and networking from public/private partnerships; some schemes, particularly those at regional level, are not open to firms outside the area (or even foreign-based firms) due to the need for public stakeholders to capture local benefits such as job creation. There is also a debate on whether emphasis on public/private partnerships with exclusive outputs (*e.g.* patents, licensing agreements) could restrict other forms of collaboration between public research and firms (*e.g.* joint publishing), thereby limiting diffusion.

Financing mechanisms

How should public financing of partnerships be designed? What form of finance (grants, loans, equity, etc.) is most appropriate for which type of partnership? The answer is that different types of public/private partnerships require different types of funding arrangements at different stages in the partnership (from the R&D to the commercialisation stage). From an economic viewpoint, there are two main questions in financing partnerships. The first concerns the optimum amount of public support and the second, the most effective mechanism for support (grants, loans, in-kind support, etc.). In theory, the answer to the first question would be the amount that lowers uncertainty (which is higher in the early phases of the technology life cycle) and/or inappropriability so that social marginal returns coincide with marginal costs. Another view is that the proportion of public funding should increase with the public content of the research being supported. Although that view is valid, it is problematic because the gap between private and social returns is not necessarily highly correlated with the extent to which insufficient private returns and uncertainty inhibit private investment.

With regard to the most effective mechanisms, the experience in OECD countries suggests some reasons for or against certain designs. Matching funding is often used in collaborative research programmes and consortia, although excessive bureaucratic procedures (*e.g.* accounting and reporting rules) may exert a heavy administrative burden on firms. At the same time, matching fund requirements as well as competition among programme participants reduce the risk that partnership projects attract only second-rate research projects and less qualified research teams. In the larger US partnership programmes, (which focus on generic technology), grants have tended to be favoured over contracts in some of the new government-sponsored collaborative research partnerships because they accelerate the selection and approval process. Similarly, while recoupment provisions in the event of success have been used, experience has shown that they may potentially undermine the government's basic intent of cost sharing. Loans at low interest rates are often used to fund partnerships in applied research, but it is important to reduce the risk of moral hazard and opportunistic behaviour by firms. In the case of the CDTI in Spain, the article by *Molero* and *Buesa* reveals that public financing may have been used by some of the larger firms as a substitute for more expensive funds, so that they were able to benefit from a substantial reduction in interest rates.

Ultimately, institutional and funding arrangements for public/private partnerships must be designed so that: *i)* the best projects, from a convergent social and private perspective, will be chosen; *ii)* the best private partners will be selected; *iii)* an optimal sharing of costs, risks and rewards among private and public partners will be found, avoiding unnecessary government expenditures; and *iv)* opportunistic behaviour will be discouraged and all partners will invest the necessary quality and quantity of resources. While financial arrangements are of critical importance, the share and forms of delivery of public funding are usually defined according to administrative criteria and do not give the government or the recipients the right incentives to make the best use of public money. *Scott* proposes an auction-based financing system whereby firms bid for the opportunity to participate in a partnership. The rationale is that firms rather than government know better where to direct research. Under the bidding system, public funding for the R&D partnership is leveraged since the mechanism ensures that the best firms participate at the lowest cost to government. Special mechanisms concerning royalties and cost sharing are put into place to avoid opportunistic behaviour on the part of government and firms. It is important to stress that the financing mechanisms must be tied to the evaluation apparatus which can signal when government support may no longer be necessary or whether it should be maintained.

Evaluation

Evaluations of public/private partnerships are essential to improving programme design, assessing costs and benefits and generating vital feedback for improving policy. Unfortunately, comprehensive empirical research on R&D partnership initiatives is limited even if a number of case studies on large and high-profile partnerships exist (*e.g.* VLSI in Japan, ESPRIT in Europe, SEMATECH in the United States). Generally, such studies are more concerned with the characteristics and objectives of participants in partnerships than with the factors driving co-operation or the measurable outcomes including the impact on additionality (*i.e.* the incremental amount of R&D performed). This reflects in part the lack of an effective methodological framework for measuring the inputs and outputs of the partnership process as well as the time frame of the evaluations (*i.e.* short term or longer term). Partnership outcomes such as patents, commercial products, and even jobs may be easily measured in some industries, in others, such as the services sector, they may take on a more diffuse character yet still contribute to the local economy.

Despite their limitations, evaluations can shed light on the theoretical justification for government support, notably the extent to which market and systemic failures actually justify policy action. Indeed, there is anecdotal evidence to suggest that certain market failures are not as important as would first appear. *Guy et al.* reveal that for participants in advanced technology programmes, reducing risk was not a main factor for participation. Similarly, while partnering allows for cost sharing, it is not always a prime motivation for collaboration (although this is the case in concentrated industries such as pharmaceuticals and aerospace). Access to knowledge, in contrast, may be a main driver, suggesting that market failures from asymmetric information and externalities in human capital development are more significant. Indeed, anecdotal evidence suggests that one of the main reasons why firms participate in partnerships with federal laboratories is access to technical resources rather than short-term and tangible payoffs.

Also, perceived networking and other intangible benefits suggest that partnerships can successfully address systemic failures. Evidence from *Shapira* and *Youtie's* analysis of the MEP scheme suggests that the focus on partnerships has improved the scale, scope, quality and efficiency of the services delivered to SMEs via the MEP network. Private sector surveys show strong support for partnerships, in particular for projects where industry provides input into project selection. *Senker* reveals that partnering associated with the UK Technology Foresight Scheme improved networking between academics and industrialists. But building networks takes time. Due in large part to the EU Framework Programmes of the past 13 years, international partnerships have now become firmly embedded in the European research landscape. Evidence from the United States indicates that a main benefit for firms participating in partnerships is the development of a process of peer review. Such a process often provides the credibility that helps firms raise capital for commercialising innovative ventures.

As regards the impact of partnerships on research outcomes, the evidence from large programmes in the United Kingdom, the United States and the EU indicates significant leverage effects in terms of the additional R&D generated. One US government study found that CRADAs generated a 3-to-1 return on private sector investment in CRADA projects, but found little evidence of job creation. As regards other goals such as new technological innovations, the impact depends on how close to market the sponsored research lies. *Molero* and *Buesa's* study of the Spanish CDTI centre shows that the majority of the innovations resulting from partnerships between the centre and firms were incremental improvements to existing products and processes rather than radical innovations. There is also the danger that government-led partnerships (*e.g.* sectoral priorities) could distort the allocation of scarce resources to branches/sectors where there is little comparative advantage.

Conclusions

Public/private partnerships are an integral element of the new paradigm in technology policy characterised by private sector and market-pull co-operative ventures rather than government-led technology-push programmes. For government, the benefits of partnerships between industry and universities, research institutes and laboratories include higher social returns from the exploitation and commercialisation of public R&D as well as a diversified source of funding and improved training of graduates. Besides reducing risk and cost sharing, partnerships can help firms access skills, monitor new developments and undertake exploratory research in areas outside their core business. However, partnership policies and schemes should not be designed solely on the notion that co-operation between industry and public research is intrinsically ‘‘good’’. Just as industry enters into public/private partnerships to achieve specific goals, both tangible and intangible, government and public research institutions should also set clear goals and time horizons for inputs and outputs.

There is a wide variety of public/private partnerships in OECD countries with some forms more prevalent in certain countries, reflecting different institutional arrangements for public support to R&D (including to universities and laboratories). Experience, and the articles presented in this issue of the *STI Review*, suggest that the type of partnership best suited for a given policy objective will depend not only on the stakeholders and their objectives, but more importantly on the type of market or systemic failure being addressed. Partnership programmes must thus be targeted and adapted to the market and institutional environments in which firms and public research partners operate. The size of firms, their sectors and their position on the innovation ladder (*e.g.* internal R&D capability) also have a bearing on their ability to collaborate with public research. Several OECD countries have undertaken reforms which, on the one hand, improve the framework conditions for private as well as public/private partnerships (*e.g.* antitrust laws, intellectual property rights, rules for academic researchers) and, on the other, promote partnerships at local, regional and national levels via indirect/direct supports (tax incentives, competitive grants, in-kind support) according to the type of market failure being addressed.

As regards the design and implementation of partnerships, there is again great diversity in the approaches of OECD countries. University-industry relations are perhaps the most common form of partnership and these take a variety of forms, from informal collaboration to targeted contract research, centres of excellence, and knowledge transfer and training schemes. Lessons from various countries suggest that public financing of partnership initiatives should be designed to maximise the contribution of industry through cost sharing, which increases the market relevance of the project, and to provide incentives for all partners while limiting the risk of capture and dead-weight loss. Moreover, public/private partnerships should be designed so as not to preclude other forms of collaboration between public research and industry which are important for the diffusion of public research.

Evidence on the outcomes of public/private partnerships for R&D and technology is limited, but case-study and anecdotal evidence suggest that such partnerships – provided they are properly designed – can have a leverage effect on R&D as well as generate many indirect and often intangible benefits (*e.g.* improved networking and flows of tacit knowledge). In this context, informal linkages, which act as ‘‘glue’’ to formal agreements and help broaden the sources of external knowledge, have implications for partnership policies, which tend to focus more on larger collaborative ventures. Improvements in the collection of data on public/private partnerships are also needed, not just in terms of their number, sector or geographic origin, but especially in terms of the organisation and management of partnerships, their financing mechanisms and outputs. In sum, public/private partnerships can enhance synergy between government missions (*e.g.* health, defence, environment) and market objectives. Public/private partnerships are also an effective tool for improving the efficiency of government support to R&D but, as pointed out in several of the articles, it cannot be assumed that industry funding can replace government financing of research, in particular longer-term R&D, which is increasingly crucial to the development of future innovations and economic growth.

Mario Cervantes

RATIONALE FOR PARTNERSHIPS: BUILDING NATIONAL INNOVATION SYSTEMS

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I. INTRODUCTION

The historical origins of R&D institutions in the United Kingdom can be traced to the emergence of the chemical and electrical industries towards the beginning of the 20th century. For a while there was a great deal of interaction between university departments of science and engineering and emergent industrial research organisations. Academics were frequently employed as consultants to advise on the direction of corporate R&D and companies exerted influence on the development of university education in engineering and chemistry (Freeman, 1982; Noble, 1977). As industrial research laboratories became established, interaction decreased; from the end of the Second World War until the mid-1970s, it was a marginal activity for industrial and academic researchers. It has become more important in recent years. Measures of the amount of money spent by industry on research in university and government laboratories since the early 1980s show that links between industry and public sector research (PSR) have been increasing world-wide (Table 1). Indeed between 1987 and 1992, industry provided 11 per cent of university income.

Table 1. **Industrial support for public research in selected OECD countries, 1981-87**

Million US$, 1985 prices

	1981	1983	1985	1987
France	26	27	42	82
Germany	52	147	157	201
Japan	67	88	125	158
United Kingdom	51	57	77	119
United States	344	413	561	763

Source: OECD (1990).

However, it should be appreciated that:

– These funds are not evenly spread: there is great variation across disciplines and institutions. High-prestige institutions like Oxford and Cambridge and Imperial College in London may receive as much as

15-20 per cent of their funds from industry, but this will tend to concentrate in specific scientific and engineering departments.
– Companies' expenditure on PSR represents a tiny fraction of their total research budgets – perhaps 1-2 per cent by those companies who spend most on PSR.

There are several factors which explain increased university-industry links:

– ''Supply push'' – the inability of governments in industrialised countries to sustain previous growth levels for research expenditure. Ziman (1987) has called this ''steady state science''. Universities or laboratories wishing to maintain or expand their research activities have to look for new non-government sources of funding.
– ''Demand pull'' – industry itself getting involved in university collaborations because, firstly, increased competition demands increased innovation and shorter development cycles. Secondly, it enables industry to get close to major sources of new knowledge creation around the world. In the new research-intensive sectors, the underlying science is extremely dynamic, with new knowledge emerging all the time; the technologies are strongly science-related; development sometimes happens at the interface between different disciplines and fields; companies need to cover more fields than can be covered by company R&D alone, and their ''search'' for new knowledge requires that they be plugged in to PSR in order to be aware of the new knowledge and new opportunities arising.
– Relatively poor economic performance in many industrial countries during the late 1970s and early 1980s led governments to put increased emphasis on stimulating market demand for scientific and technological knowledge, and promoting the supply of such knowledge through so-called ''technology transfer'' programmes. Programmes provide grants for pre-competitive collaborative research in fields deemed to be strategic to future industrial growth, encourage the commercialisation of university research and promote university/industry interactions.

Webster and Etzkowitz (1991) argue that these developments amount to a ''Second Academic Revolution'' with implications for academic practice and norms. (The first revolution occurred between the two World Wars, with the beginning of substantial government support for university research.)

Gibbons *et al.* (1994) describe these changes as a major transformation from Mode 1 – the traditional production of disciplinary-based knowledge in universities, mainly seeking to expand understanding – to Mode 2. Mode 2 is driven by social and economic needs and is characterised by transdisciplinarity and by more research being conducted outside than in the public sector, for instance in industrial and government laboratories, in think-tanks, consultancies and research institutes. Research is being conducted around the world in more and more sub-disciplines, and many different types of temporary research alliances are developing. Mode 2 has arisen from the growth in mass high education and research, which means that the number of able, trained people outside universities rises continuously, relative to the numbers of those in universities, and increasing numbers of people are familiar with the methods of research. They are thus able to understand and judge the quality and significance of what university researchers are doing.

II. THE UNITED KINGDOM'S POLICY TO PROMOTE UNIVERSITY-INDUSTRY LINKS

Policy to promote university-industry links in the United Kingdom has developed in a rather incremental fashion. Early experiments were undertaken by one of the United Kingdom's research funding organisations, the Science Research Council, a predecessor to the Science and Engineering Research Council (SERC), which was reorganised as the Engineering and Physical Sciences Research Council (EPSRC) in 1994. In the mid-1970s, its Engineering Board decided to direct support to research which had economic, industrial or social relevance. This policy was adopted after the Engineering Board had investigated the extent of academic-industrial collaboration in engineering research and identified a ''pre-development'' gap, *i.e.* the gap between the completion of academic research and the demonstration in pilot form that it had a predictable time scale to profitability (Science Research Council, 1975).

Policy to promote university-industry research collaboration became more widespread during the 1980s. Three phases of government policy can be identified: the first up to 1987, the second after 1987 and the third from 1993. In the first phase, the scientific community was affected by government policy to restore competitiveness to the economy by cutting taxation and restraining public expenditure. government hoped that restrictions in public funding would create an incentive for the academic world to move closer to business. Positive encouragement was also provided by schemes for university-industry research collaboration in strategic areas of science. At the same time, government promoted programmes such as ALVEY (in advanced information technology) and ACT and CARE (in engineering ceramics) for near-market collaborative research to bolster the academic and industrial science and technology base. These programmes supported collaborative research carried out in company and university labs. Part of the rationale for these programmes was to correct poor capability in new strategic technologies, and this goal was achieved. However, the programmes did not, as had been intended, enhance the competitiveness of British industry; rather they showed that support for pre -competitive R&D is a necessary, but insufficient, means to enhance industry's innovation performance (Guy *et al.,* 1991).

In the second period, the government withdrew from supporting near-market academic research, emphasized its responsibility for basic research and strengthened its machinery for establishing priorities for science and technology expenditure (Jackson, 1989).

The third phase was marked by a major government review of science and technology policy and, after extensive consultation, the publication of the White Paper, *Realising our Potential* (UK Government, 1993) which emphasized the importance of applying the United Kingdom's scientific and engineering excellence and skills to national wealth creation and improving the quality of life. The White Paper announced the setting up of a Technology Foresight programme, both to inform the government's research priorities, but also to achieve a cultural change to facilitate better communication, understanding and interaction between the worlds of academia, industry and government. The government next turned its attention to the competitiveness of British industry and published two White Papers; both recognise that government can promote innovation by establishing a framework of incentives for collaboration between academics, research facilities and companies, and by maintaining the strength of the university research base (UK Government, 1994 and 1995).

The majority of British public sector research takes place in universities where it is closely linked with teaching, in Research Council Institutes and in government laboratories and research establishments (GREs). Programmes for public-private links initially focused on the university sector alone. The recent privatisation of GREs, which were formerly fully funded, means that they now perform contract research for government and also seek contracts from industry. Research Council Institutes also now seek to supplement decreased budgets with contracts from industry. Since the early 1990s the government has also withdrawn long-running support for private industrial research associations (RAs) to undertake strategic research and development. In 1997, the government opened up some of its programmes for university-industry links to selected Research Council Institutes, to RAs and to GREs.

III. GOVERNMENT PROGRAMMES FOR UNIVERSITY-INDUSTRY LINKS

The main government programmes in the United Kingdom for university-industry links in 1998 are the following.

Technology Foresight

The United Kingdom's Technology Foresight Programme aims: *i)* to increase competitiveness; *ii)* to create partnerships between industry, the science base and government; *iii)* to identify exploitable technologies over the next ten to 20 years; and *iv)* to focus the attention of researchers on market opportunities and hence to make better use of the science base. The programme has been organised by the Office of Science and Technology with the help of other government departments, and has involved extensive use of consultants. It has been overseen by a Steering Group made up of leading figures from industry, university and government. In addition, 15 panels (again consisting of experts from industry, academia and government) have directed the foresight efforts in different sectors.

The programme has had three main phases, the first being the ''pre-foresight'' stage, during which seminars were held with the industrial and scientific communities to explain what foresight is and why it is important, and to seek their views on how best to carry it out. In the main foresight phase, the 15 sector panels collected information from a variety of sources including surveys of experts, regional and topical workshops, and a large Delphi questionnaire survey. Each panel then produced a report examining the technological opportunities for contributing to wealth creation or improved quality of life and identifying a list of priorities together with a set of key recommendations for their implementation. The Steering Group synthesised the findings of the panels, identifying a total of 27 generic technological priorities and 18 infrastructural priorities and setting out a strategy for their implementation.

The third phase of implementation has a number of objectives including: *i)* shaping new government R&D priorities (*e.g.* in ministries, Research Councils and the Higher Education Funding Councils); *ii)* influencing company R&D strategies; *iii)* improving partnerships between industry and the science base; *iv)* influencing wider government policy (*e.g.* for regulation); and *v)* drawing lessons for the next Foresight Programme (scheduled for 1999/2000). At the time of writing, this phase is still in operation but already considerable progress has been made with most of these objectives, and a number of specific foresight projects are under way. An independent review of the programme by the Parliamentary Office of Science and Technology found that it had improved networks between academics and industrialists and resulted in the development of ideas which were previously unfeasible (Parliamentary Office of Science and Technology, 1997).

Foresight priorities now inform many of the following technology transfer programmes, and well as much of the research funded by Research Councils. A large proportion of Research Council grants are thus allocated to projects which fall into the research priorities identified by Technology Foresight, giving academics little opportunity for securing grants for ''blue-sky'' or pure research. This bias has been introduced to direct government-funded academic research into areas of relevance to industry. Technology transfer programmes are even more targeted. The main ones are described below.

LINK

The LINK programme was launched in late 1986 and aimed to ‘‘bridge the gap’’ between the research base and industry. It supports long-term enabling and generic research, rather than fundamental research or short-term development work. LINK supports collaborative research in areas of strategic importance to the national economy which will enhance the competitiveness of industry in the United Kingdom, and quality of life.

Each LINK programme is made up of a number of projects lasting from one to five years. LINK projects involve collaboration between industry and the public sector science base; they involve one or more firms working together with one or more research base partners on a particular project, and are carried out ‘‘in the places best suited for it’’ (LINK Secretariat, 1992). By 1997 there had been 57 LINK programmes, 24 of which are still in progress. To date, the government has spent £183 million on these LINK programmes, and committed another £344 million to ongoing projects; there has been similar expenditure by industry.

A central Steering Group oversees LINK. The Steering Group is made up of senior representatives from industry, government, higher education and other research institutions. Management of LINK programmes rests with government departments or Research Councils. The government contribution to each programme must not exceed 50 per cent, although in some cases the government may contribute more than 50 per cent to projects in the early stages of programmes, especially when commercial opportunities are unclear. Public funds allocated to individual programmes may come from a number of departments and Research Councils with related interests. LINK programmes cover a wide range of technology and generic product areas, ranging from food and bio-sciences, through engineering, to electronics and communications. Examples of current LINK programmes include: Sensors and Sensor Systems for Industrial Applications; Advanced and Hygienic Food Manufacture; Genetic and Environmental Interactions in Health; Waste Minimisation through Recycling, Re-use and Recovery in Industry; and Inland Surface Transport. In 1997, the Department for Trade and Industry (DTI) allocated £10 million to Foresight LINK Awards, for research which addressed Foresight priorities. It was anticipated that the DTI’s £10 million investment would be complemented by £10-20 million from business. LINK has recently been opened up to research and technology organisations (RTOs) including privatised government research establishments, industrial research associations and Research Council institutes. They can act as academic partners and receive 100 per cent of the costs of the research carried out if their research is considered to be of a sufficiently high standard.

Teaching Company Scheme

The Teaching Company Scheme (TCS) was set up in 1975 as one of a number of initiatives taken by the Engineering Board of the Science Research Council to support research which had economic, industrial or social relevance. TCS operates through programmes in which academics in universities work with companies to contribute to the implementation of strategies for technical or managerial change. Its principal objectives are:

- to facilitate the transfer of technology and the spread of technical and management skills, and to encourage industrial investment in training, research and development;
- to provide industry-based training, supervised jointly by academic and industrial staff, for young graduates intending to pursue careers in industry;
- to improve the level of academic research and training relevant to business by stimulating collaborative research and development projects and forging lasting partnerships between academia and business (Teaching Company Directorate, 1996).

Each TCS programme involves academic participation with company managers in the joint supervision and direction of the work of a group of young graduates, known as Teaching Company Associates (TCAs). These TCAs are recruited by the university, but work in the company. The Scheme makes a grant towards the basic salaries of the TCAs and provides the academic department with the costs of a Senior Assistant, who takes over a proportion of academics' normal workload so they can spend time at the company, supervising the TCAs' work. The programmes are closely managed by TCS consultants through regular meetings at the company with senior company management, the TCAs and the academic and industrial supervisors. The meetings serve to check the progress of projects and to ensure that work programmes are adhered to. The technology/ knowledge involved in TCS projects has been applied to product design, manufacture and management.

After a slow start, TCS expanded rapidly in the early 1990s, establishing its 1500th programme in 1994-95. In 1995-96, a large number of government departments and Research Councils committed over £21.3 million to 253 new TCS programmes, complementing about £10 million of direct funding committed by participating companies. It has been estimated that the actual costs to these companies could well be in excess of £25 million, when additional overhead and investment costs are taken into account (Teaching Company Directorate, 1996).

Almost every British university has been involved in the scheme, with participation from a wide variety of academic departments. A 1996 review of TCS estimated that each £1 million of government grant spent in the programme produced 58 jobs, £3.6 million of value added, £3 million in exports and £13.3 million of turnover (Teaching Company Directorate, 1997). From September 1997, research institutions, government research establishments and independent research and technology organisations became eligible to participate in TCS on a similar basis to universities.

The LINK and TCS Directorates have regular contact to identify LINK projects from which a follow-on TCS programme might be arranged (Department of Trade and Industry, 1997). Although there is some integration between Technology Foresight, LINK and TCS, the two following schemes are more ‘‘stand-alone’’.

Realising Our Potential Awards

The Realising Our Potential Awards Scheme (ROPAs), set up in 1995, is run by the six UK Research Councils. It is intended to reward academic researchers who receive financial support from private sector industry and commerce for basic or strategic research through the award of grants with which researchers can carry out curiosity-driven, speculative research of their own choosing. ROPAs are also intended to foster future opportunities for collaboration between the science base and industry and commerce.

The scheme uses industrial or commercial funding of academic research as an indicator both of the fields which industry and commerce considers strategically important and of the researchers carrying out high-quality research. Eligibility for applying for a ROPA demands that researchers have received a minimum of £25 000 per annum from industry or commerce. The value of ROPAs is in the range of £25 000 to £150 000 and most are of one to two years’ duration.

Co-operative Awards in Science and Technology (CASE)

CASE Research Studentships were introduced by the SRC in the early 1970s to promote university-industry links. Other Research Councils have adopted this scheme more recently. CASE supports doctoral research on projects jointly devised and supervised by an academic department and a company. The cost to the company is minimal (less than £2 000 per annum); part of this amount is directed to the supervising university department and the remainder is paid to the student, as an incentive to take up a CASE award. These amounts are in addition to the normal studentship awards made by Research Councils to students to cover maintenance and research costs, and to the institution to cover fees and research training support costs.

IV. BARRIERS TO UNIVERSITY-INDUSTRY LINKS

Firms differ in their ability to make use of the knowledge produced by university research; the main barriers concern ‘‘access’’ to external knowledge and ‘‘absorption’’ of external knowledge. The problem of access was identified by Gibbons and Johnston (1974), who found a significant difference between university- and industry-trained problem solvers in their use of external knowledge. University graduates had ‘‘knowledge of knowledge’’ – if they had a problem they knew they could find answers by reading the scientific literature or by contacting public sector scientists. There was a perceived barrier in the use of such sources by those in industry who lacked a university education. This barrier was thought to inhibit the transfer of scientific knowledge to industrial applications. The analysis by Gibbons and Johnston explains why science-based firms have been more involved in collaborations with universities than firms in traditional sectors which lack qualified scientists and engineers (QSEs). But it also indicates that university/industry links may be stimulated by encouraging industry-trained problem solvers to use external scientific sources initially.

Firms not only require access to external knowledge, they also require internal capability to understand and apply this knowledge – ‘‘an absorptive capacity’’ (Malerba, 1992). This absorptive capacity is often provided by a company’s R&D department. When firms need to modernise their traditional approach or apply areas of science and technology which are new to them, they need to access or acquire formal and tacit knowledge from external sources: through technology transfer, by recruiting individuals with the requisite education or work experience, by engaging consultants and by interacting with individuals and groups outside the organisation who already possess the relevant experience and knowledge (Senker, 1993). However, if they lack staff with competence in the new area, this inhibits their ability to understand the potential of the new field for their particular range of products or processes; nor do they know how to identify external experts, or evaluate new technology in the marketplace. Two recent studies throw light on how programmes in the United Kingdom are helping to overcome these barriers to the industrial use of public sector research.

V. CASE STUDIES

An assessment of the Teaching Company Scheme (Senker and Senker, 1994) found TCS programmes to be an effective method of helping companies absorb knowledge which is new to them (*i.e.* not necessarily totally new knowledge). TCS programmes are able to transfer technology and expertise from universities to industry in any area of the economy where there is a potential for better use of technology and management techniques. To assure long-term benefits, companies need to make provision for diffusing the new knowledge to other members of staff. In companies which have introduced methods for widespread absorption of new knowledge, organisational learning from TCS programmes has sometimes been so extensive that it is justifiable to talk about a ''cultural change''.

This has involved transformation of a company's attitudes and procedures from a basically ''craft'' mode of operation to a ''scientific'' mode of operation, and to radical changes involving the use of more scientific methods for ensuring quality in processes and products. This has been achieved, to no small extent, by the experience of the TCS programme, which has created a positive attitude to employing graduates – the TCAs have often been recruited by the firm at the end of the TCS programme. However, individual TCS programmes were only successful when the university partner *a)* had knowledge about the programme's topic which exceeded that of the industrial partner; and *b)* the programme was cohesive and central to the firm's core strategy. Another study (Faulkner and Senker, 1995) comparing companies' links with PSR in three emerging technologies – biotechnology in pharmaceutical companies, parallel computing and advanced engineering ceramics – investigated to what extent companies linked with PSR, as well as their methods and reasons for these links.

It found, first, that PSR contributes most to innovation by training qualified scientists and engineers, and by being a potent source of new knowledge. Firms see the role of PSR as carrying out basic, rather than applied, research. Second, it found that the number of informal links between industry and PSR far exceeds the number of formal linkages. Although large-scale collaborations may contribute a great deal of knowledge to industry, for the most part this is only the tip of the iceberg. Industrial researchers gain knowledge and assistance from PSR by reading journal articles, as well as through personal contacts. The two channels provide complementary types of knowledge: the literature is read so that industrial researchers keep up with developments in the science base, but they also supplement their reading through discussions with academics of the issues arising from the literature.

On the other hand, when industrial researchers seek practical help and assistance from their academic contacts they may be directed to read the scientific literature. The study also found that, in general, companies only interact with PSR when they have a specific reason for so doing. Government programmes enable them to explore peripheral and speculative areas of research which it would be difficult to justify undertaking in-house. These programmes also enable companies to discover which academic researchers are good collaborators, an important criterion for placing fully funded external research contracts.

In confirmation of earlier research, the study found that even in emerging technologies, in-house knowledge makes a greater contribution to R&D than external sources. All companies use similar formal linkage mechanisms to access new knowledge in specialist fields of science and engineering and as a form of public relations. Informal links are used for a whole range of issues including practical help and assistance related to specific problems, learning new experimental techniques or accessing PSR research instrumentation and related expertise to interpret the results.

The study also found that there were great differences among technologies in terms of the inputs which PSR made to innovation. Biotechnology companies had the greatest number of formal contracts with PSR and made most use of government programmes. In particular, PSR was used to provide help with new experimental techniques and as a source of new recruits. Lack of relevant research in PSR on advanced engineering ceramics led companies to depend on empirical knowledge flows from other companies up and down the supply chain. However, PSR played a significant role in providing access to advanced instrumentation and expertise. Parallel computing firms had the fewest formal links, but the most links with PSR users of their computers. Sophisticated university users of prototype parallel computers made an important contribution to the technical development of these machines and provided market knowledge about the types of use to which these machines could be applied.

The study concluded that reasons for diversity in industry-PSR linkage were explained by a number of factors. At the industry level, the character of new product development had an obvious impact. In pharmaceuticals, for instance, new product development is close to the linear model of innovation, and is strongly research-led, rather than user- or production-led. The latter model is more appropriate in the ceramics industry, which relies heavily on other companies to exchange vital but largely tacit knowledge about materials specifications and performance. Firm size is also significant. Large firms have more human and financial resources to invest in linkages do than small firms.

The second factor concerns PSR. Linkages can only occur when relevant PSR expertise exists, as emphasized by the dearth of linkages in ceramics. However, government programmes to build up the science base and support collaboration can stimulate linkages. When PSR is a key user, as for example in parallel computing, links can play a vital role in the development of the technology.

The third factor relates to the general character of the technology involved, and the importance of PSR in making key scientific discoveries in the technology. Interaction is also likely to be greater where a technology is being used as a research tool rather than being applied to product or process innovation. The age and dynamism of the technology also have an effect. PSR linkage is likely to be more important in new fields, where industry has little existing capability. But dynamism in an established field can also promote linkages, to enable companies to keep up with the constant emergence of new knowledge and techniques.

The final factor concerns the firm itself and its existing knowledge base. Links are likely to be strongest where a firm is trying to build up capability in a new area. There is also evidence that some firms have a higher propensity to link than others, and this may be related to senior management attitudes.

VI. CONCLUSIONS

Programmes for university-industry links in the British National System of Innovation are set in a general environment which recognises that PSR should be relevant to users. Therefore, industry has been involved in identifying priorities for research in the foresight exercise. These priorities influence both general academic research and programmes for promoting links with industry, and there has also been an attempt to achieve some integration between the Technology Foresight, LINK and TCS schemes.

Moreover, recognition that companies differ in their capabilities to seek and use university research affects the nature of the main programmes, which have been tailored to meet two constituencies. Companies that employ qualified scientists and engineers (QSEs) are encouraged to ‘‘explore’’, ‘‘learn’’ and ‘‘absorb’’ knowledge about emerging areas of science and technology through schemes such as LINK and CASE. TCS can also help these firms to expand into areas of science and technology where they lack capability. Traditional firms that lack QSEs are helped to apply science and technology to their products and processes through TCS. In the long term, this can lead to the recruitment of QSEs, and a continuing capability to absorb external knowledge.

The United Kingdom’s system for providing companies with access to public sector research is characterised by an emphasis on university links, but no longer excludes other public sector research providers. In recognition of the great variance between companies (related to size, industrial sector, geographic location), between research providers and in companies’ demands for knowledge, government is not very interested in examples of ‘‘best practice’’, but allows many variations within its various programmes. The new Labour Government is in the process of reviewing all of its programmes, and time alone will tell whether it judges that its policy for providing access to knowledge is appropriate, or that major changes are required.

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TRENDS IN UNIVERSITY-INDUSTRY RESEARCH PARTNERSHIPS

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This article was written by the OECD Secretariat based on consultancy studies and other sources.

I. SUMMARY

Research co-operation between industry and universities has increased dramatically over the past few decades. Fuelled by a number of forces, including shrinking government support for research, pressures from global competition and the increasing importance of science-based knowledge to the innovation process, university-industry research partnerships have grown markedly in almost all OECD countries. Although industry still accounts for only a small share of university research funding (an average 5 per cent), there has been a significant change in the traditional framework of interaction between universities, the private sector and governments. Knowledge flows from universities to industry no longer have to pass through the public domain, and resource flows from industry to academia are more targeted to specific research outcomes. Universities no longer see public money as the only appropriate source of financing for their activities. This raises the question of the advantages, disadvantages and longer-term implications of a larger share of industrial support for university research.

University-industry research partnerships take many forms, ranging from the informal to the institutionalised. Industry has traditionally interacted with universities by giving support for general research activities in the form of endowments and gifts. Informal collaboration between industry and university researchers has been accompanied by various advisory exchange programmes and student training schemes. More recently, these linkages have been supplemented by increasing levels of contract research in universities financed by companies. And now governments are underwriting a variety of co-operative research programmes, ranging from specific collaborative research projects, through participation in large-scale research consortia, to specialised research centres featuring partnerships among industry, institutes and universities.

Most observers have emphasized the benefits which can come from these partnerships, including improved transfer of knowledge and technology, the increased relevance of university education, and enhanced competitiveness and job creation. However, others have stressed the potential costs for academia in terms of diluting the university's central commitment to the pursuit of knowledge and learning. The following are the major issues arising with regard to university/industry partnerships:

Funding – a portfolio of research funding sources and different types of interactions with industry seem to be the best approach for universities.

Implementation – universities need to provide sufficient flexibility and rewards for individual researchers involved in industry partnerships.

Intellectual property rights – balance should be maintained between the need to disseminate research findings and the desire of companies to protect their investments.

Commercialisation – while a good source of revenue, an overemphasis on patenting and licensing could jeopardise traditional university research and teaching functions.

Evaluation – evaluation approaches need to be both expanded and refined to assess the outcomes and impacts of research partnerships on universities, companies and the economy.

II. INTRODUCTION

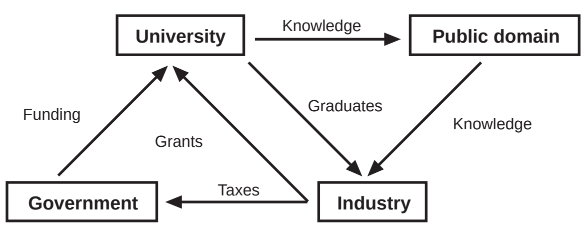
Universities have always been major knowledge creators in national systems of innovation. However, the belief is growing that universities have to expand their role and become more involved in the transfer of knowledge to economic actors in the private sector. As governments strive to find ways to improve the comparative position of their national economies, they have turned their attention to enhancing systems of innovation and their distributive power (OECD, 1997). Closer university-industry collaboration is believed to have the potential to enhance the economic impact of the knowledge created within academia. Consequently, university-industry collaboration has become an attractive tool for policy makers and one of the main items on the innovation policy agenda in many countries.

Traditionally, society at large viewed universities as government-funded institutions serving the public through the pursuit of knowledge and higher education (OECD, 1984). All three elements of this description – *government funding*, *public service* and *higher education* – have provided the framework for the role of universities and the types of activities appropriate to them. The principle of public funding allowed the use of private funding only to support the main social objectives of the university – pursuit of knowledge and education. It was previously considered inappropriate to accept private funding to perform activities that would directly benefit the private donor. In other words, private money was acceptable only in the form of grants and donations with no strings attached. The objective of serving the public also limited the possibility and the admissibility of co-operating with private sector companies. Conducting research for such companies was seen as antithetical to serving the public. Since such research would cater to specific objectives of companies, it would not benefit the public as the whole.

Finally, adjusting to and accommodating the needs of employers for particular skill sets was not the objective of the educational agenda of universities, which were intended to open the ‘‘intellectual horizons’’ of the broader student body.

Consequently, curiosity-driven basic research has been accepted as the most appropriate kind of academic research and as a key part of the university’s mission. Contributions in the area of basic research were seen as the most appropriate role for universities in a nation’s research and development effort. Publishing research results and making them available to all who wanted to take advantage of them was the main means through which universities were expected to contribute to the economy and the principal form of interaction between universities and the private sector. By publishing the results of research, universities were fulfilling their obligation to serve the public. Education of highly skilled individuals was the second form of university input into the economy. Graduates were seen as the complementary vehicle of knowledge transfer from university to the private sector. The relationship between research and training was also relatively straightforward – research and the knowledge obtained through research were to be used as a tool for education. The traditional flows between universities, industry and government are presented schematically in Figure 1.

Figure 1. **Traditional links between university, industry and government**



III. RATIONALE FOR PARTNERSHIPS

The traditional framework of interaction between universities, the private sector and governments has undergone a significant change over the past two decades. In particular, knowledge flows from universities to industry no longer have to pass through the public domain. Similarly, resource flows from the private sector to the university are no longer limited to grants, endowments, etc. At the level of national economies, these changes have been mostly dictated by three factors: *i)* increased speed of the transition to the knowledge-based economy; *ii)* increased globalisation and competition; and *iii)* budgetary constraints faced by governments and their impact on patterns of funding of university research as well as the increased cost of research in general. The interplay of these three factors has put governments in an unenviable position. On the one hand, they recognise the need for increased expenditure on R&D and for greater efforts to disseminate and apply knowledge. On the other hand, diminishing resources have led many governments to limit their spending on research and development.

Not surprisingly, governments have responded by seeking ways to improve the efficiency of the innovative base of the economy. Encouraging and supporting various forms of collaboration between universities and the private sector is seen as one way to achieve this objective. Today, most policy makers subscribe to the view that such collaboration increases the distributive power of innovation systems by allowing the smoother and faster flow of knowledge from universities to the final users of this knowledge – private sector companies. With regard to human resources, collaboration enhances the training of graduates and facilitates personnel mobility between the university and private sectors. In addition, governments expect that a closer collaboration between the two – universities and the private sector – will allow universities to compensate for lost government funding. It would also be seen as a response to private sector demands for bringing university research closer to market demand.

In addition to the evolving government perspective, the nexus between universities and industry has strengthened since the mid-1980s due to changes on both sides (Box 1). For their part, university attitudes towards industry-sponsored research have changed, owing to cutbacks in government funding and to new opportunities to benefit from these ties through increased knowledge exchange (*e.g.* personnel flows) and commercial relationships, including patent licensing and fees from technology transfer. The establishment of technology transfer offices or industry liaison offices at many universities and the explicit inclusion of technology transfer obligations into university mission statements are some of the indicators of changing attitudes within academia. Similarly, universities no longer see public money as the only appropriate source of financing for university activities – even though it remains the main source of university funding. Such attitudes are encouraged and stimulated by the trend for governments to refocus their criteria for R&D funding towards performance and economic impacts.

Box 1. **Motivations for research partnerships**

University motivations:

- to obtain financial support for educational and research missions;
- to fulfil the service mission of the university;
- to broaden the experience of students and faculty;
- to identify significant, interesting and relevant problems;
- to enhance regional economic development;
- to increase employment opportunities for students.

Industry motivations:

- to access the research infrastructure of the university;
- to access expertise not available in corporate laboratories;
- to aid in the renewal and expansion of a company's technology;
- to gain access to students as potential employees;
- to expand external contacts for the industrial laboratory;
- to increase the level of pre-competitive research;
- to leverage internal research capabilities.

Source: Industrial Research Institute, 1995.

On the industry side, there is growing appreciation for the quality of research conducted by universities. This is partly due to the emergence and expansion of science-based (high-technology) industries such as biotechnology and microelectronics, where firms need access to the skills and research input of universities. Faced with their own declining profit margins, many firms are also outsourcing a greater share of their basic research, including to universities. A recent study on the growing trend to outsource research and development found that corporations take two sets of factors into account: *i) internal drivers,* which reflect corporate acceptance that they are not large or wealthy enough to know and develop everything and yet need to manage in an increasingly complex and demanding environment where innovation is the key to corporate survival and prosperity; and *ii) external drivers,* which are based on the increased opportunity to obtain knowledge available outside the corporation, particularly through partnerships with universities and research institutes (Conference Board of Canada, 1998).

Universities carry out different proportions of government-funded research in the OECD countries, ranging from a larger share in countries such as the Netherlands and Austria to relatively less in countries such as France and Australia. Although overall industry funding of university research remains modest, it has rapidly increased in the past decade and can be expected to expand further. At present, industry funding of university research in the OECD countries averages about 5 per cent, ranging from 2 per cent in Japan to an estimated 6 per cent in the United States and the United Kingdom to almost 11 per cent in Canada (OECD, 1998*a*). However, it is estimated that as much as 20 per cent of university research in the United States and Canada is in some way associated with industry. In Korea, the large conglomerates (*chaebol*) fund about 16 per cent of university research in order to secure the most qualified graduates. In most OECD countries, increased industry funding of university research is providing a minor offset to declining government support. In other countries, universities are taking advantage of industry partnership opportunities to supplement a dominant government support base. In still others, universities may be looking at a scenario where industrial research support may play a long-term structural role in financing research and development activities. This raises the question of the advantages, disadvantages and longer-term implications of a larger share of industrial support for university research (OECD, 1998*b*).

IV. TYPOLOGY OF PARTNERSHIPS

Research interactions between universities and industry take various forms and differ in nature and intensity by country. Links between universities and business enterprises range from highly diversified relations in countries such as Canada and the United States, to growing yet unevenly developed systems in some European countries (*e.g.* France, Germany, United Kingdom), to as yet undeveloped links in other OECD countries (OECD, 1998*c*). In most countries, governments are attempting to facilitate university/industry research interactions through a variety of mechanisms, such as the removal of legal obstacles and constraints on personnel mobility, funding for collaborative research projects and the establishment of national research programmes.

The major types of university-industry research partnerships are presented in Box 2. Industry has interacted with universities traditionally by giving support for general research activities in the form of endowments and gifts. In addition, there have always been informal relationships between industry and university researchers. These links were later supplemented by contract research, where

Box 2. **Typology of university/industry research partnerships**

Type of partnership	Description	Example
General research support	Monetary gifts, endowments, equipment donations, research facilities	***Canada*** – NSERC Industrial Research Chairs programme
Informal research collaboration	Informal partnerships among individual researchers in industry and academia	***United States*** – Center for Computational Genetics and Biological Modeling
Contract research	Industry finance for specific research projects under contractual terms	
Knowledge transfer and training schemes	Advisory exchange programmes and student training placements in industry	***United Kingdom*** – Teaching Company Scheme
Government-funded collaborative research projects	Government grants to specific research projects undertaken jointly by industry and universities	***Australia*** – Collaborative Research Grants Schemes
Research consortia	Government-sponsored large-scale research programmes involving several parties	***European Union*** – Framework Programmes
Co-operative research centres	Government-supported facilities or centres for collaborative research	***Sweden*** – NUTEK Competence Centre Programme

enterprises finance a particular research project or activity in a university. Such traditional forms of interaction have now been joined by co-operative research arrangements, usually underwritten by government funding, including collaborative work on projects and participation in research consortia and specialised research centres. It should be noted, however, that the degree of university-industry links tends to vary considerably by academic discipline.

A previous US study of university-industry interactions drew attention to the differing degrees of industry control and involvement in these partnerships, which seem to be intensifying over time (National Science Foundation, 1983):

- *Relative control over outputs* – University-industry interactions can be characterised by the balance of control over outputs and benefits – from full, or close to full, control by the university within the more traditional framework of grants and endowments, through types of linkages where industry has the ''upper hand'' at least in terms of short-term financial gains from collaboration, *e.g.* contract research and research consortia.
- *Degree of industry involvement* – The level of industry involvement in such relationships may change from very little direct involvement when grants and other forms of gifts are given to universities through arrangements where the industry engagement increases until it reaches its peak in research consortia and co-operative centres.
- *Industry expectations regarding outcomes* – Industry may expect very few direct benefits when grants are provided to universities, but these expectations grow when collaborative research is undertaken and increase further when companies become involved in various types of interaction to profit from technology transfer from universities.

General research support. The most traditional form of industry research interaction with universities in most OECD countries is support for general research activities in the form of monetary gifts, endowments of chairs or professorships, donations of equipment and contributions to research facilities. In many cases, such donations are not tied to any particular professor, researcher or research project, but are to be used by the university to fill gaps in financing, human resources, facilities or equipment wherever they are deemed necessary. Increasingly, industry is being asked to help universities improve and upgrade the general research infrastructure in universities, including maintaining and enhancing databases and networks. In other cases, industry donations may be tied to a particular research field or person with the intent of advancing knowledge in certain technological areas or furthering specific areas of investigation. For example, industry has helped Canadian universities establish more than 200 Natural Sciences and Engineering Research Council (NSERC) Industrial Research Chairs to assist in the intensification of research efforts in technical fields that have not yet been developed in universities, but for which there is an important industrial need.

Informal research collaboration. Informal partnerships among individual researchers in universities and enterprises are often the most fruitful form of collaboration and are on an upward trend. In knowledge-based economies, individuals are less and less likely to have all the skills, equipment and material required for scientific research. The increased breadth of knowledge essential to scientific discoveries and the need to combine skills and labour have led to growing intra-sectoral and inter-sectoral R&D collaboration among individuals. This is reflected in the increase in co-authored papers and studies across the OECD area, particularly bringing together researchers from universities and industry (OECD, 1997). This trend is most evident in certain science-based sectors such as pharmaceuticals, aerospace and environmental technology.

Studies show that informal communication channels between industry and universities far exceed the number of formal linkages and are often essential to success in more formal research partnerships. Increasingly, the transfer of tacit knowledge among individuals is a multidirectional flow and can lead to spinoffs for both enterprises and universities. For example, in California, informal collaboration among researchers has led to a new academic research centre based on industrial technology. Interval Research Co. in California is spinning off technology it developed to Stanford University as the basis for the Center for Computational Genetics and Biological Modeling. This centre, which will use advanced computer modelling techniques to address complex questions in the areas of populations and human genetics, is the extension of a research project begun by two senior researchers in the company and the university. It is moving to the university to gain the participation of university scientists in other disciplines.

Contract research. It is an increasing practice in many OECD countries for companies to finance specific research projects in universities which are governed by detailed financial contracts. A number of factors have contributed to this trend towards contract research. Companies are finding it necessary to reduce their own budgets for basic research and thus are outsourcing their more generic research requirements to the public sector. At the same time, firms are moving away from donations and grants to support general research towards more specific projects which allow access to research results more quickly and easily. Contract research provides a good opportunity for companies to be directly involved in the research contracted out to the university and to define their expectations precisely. In addition, it offers clearly identifiable, direct benefits to the company, which might be more difficult to obtain within a multi-partner framework such as a research consortium or centre.

Knowledge transfer and training schemes. Advisory exchange programmes and student training schemes are a common form of university-industry interaction emphasizing knowledge transfers. For example, academics might spend time as consultants in industry to advise on the direction of corporate research and development programmes, while industrial advisory boards might review university curricula, research programmes and facilities development. Co-operative training programmes include using industrial scientists and engineers as faculty, assigning graduate students to industrial mentors, using industrial laboratories to conduct dissertation research, and placing students in industry on temporary research and training assignments. There are many programmes which place young academics and scientists in industry with the aim of teaching them how to work in the private sector in cross-functional research teams, to develop technical and managerial skills, to take an interdisciplinary approach to problem solving and to develop informal contacts for knowledge and technology transfer. These schemes are often financed by governments and increasingly are also intended to enhance research and development undertaken by smaller firms.

For example, the Teaching Company Scheme (TCS) was set up in the United Kingdom in 1975 by the Science Research Council to train students and to support research which had economic, industrial or social relevance. Each TCS programme involves academic participation with company managers in the joint supervision and direction of the work of a group of young graduates, known as Teaching Company Associates (TCAs). These TCAs are recruited by the university but work in the company. The Scheme makes a grant towards the basic salaries of the TCAs and provides the academic department with the costs of a Senior Assistant, who takes over a proportion of the normal workload of the academics so they can spend time at the company. The Finnish Government funds four-year doctoral training positions in companies at the postgraduate level, with 22 per cent of the 1 300 positions in 1999 devoted to the information technology area.

In other countries, there are schemes which pay the costs of companies, primarily small and medium-sized enterprises, to take on young academics to conduct specific research projects; examples are the *Promotie* Programme in the Netherlands and the *Scientists for the Economy* scheme in Austria. Another approach is to support doctoral research on projects jointly devised and supervised by the university and a company, such as the Industrial Research Fellowships in Canada and the CASE Research Studentships in the United Kingdom. In Germany, the Chemical Industry Fund supports not only basic chemistry research in universities, but also gives performance-related incentives to professors/ teachers and students/pupils at universities and in secondary schools.

Government-funded collaborative research projects. In order to encourage research partnerships between industry and universities, while reducing the competitive and financial pressures on academia and small firms, OECD governments have implemented programmes to finance specific collaborative research projects. Most often, government support is directed to research which is competitive but application-oriented. These arrangements may be bilateral research conducted in company or university laboratories; university researchers as contractors or subcontractors of enterprises; or industry subcontracting in joint research projects. These schemes often have many objectives: to foster industry-science linkages and networks; to speed technology transfer and commercialisation of research; to leverage industry research funding; to enhance the innovative capacities of smaller firms; and to orient university research programmes to industrial and market needs.

For example, Australia's Collaborative Research Grants Schemes were recently launched as a three-year programme (at a funding level of A$ 146 million) for enhancing research collaboration between industry and universities. Similarly, the German Ministry for Education, Science, Research and Technology (BMBF) supports application-oriented co-operation between SMEs and universities through the German Federation of Industrial Co-operative Research Associations (AIF); in 1996, 1 650 AIF projects were carried out in universities (45 per cent) and institutes of AIF members (43 per cent) with partial public funding. In Japan, university-industry co-operative research projects have increased thirty-fold since their launching in 1973 and tend to be directed to product development supported by academia for the benefit of companies. In Korea, university-industry collaborative research grants are funded for three-year periods by the Korean Science and Engineering Foundation (KOSEF). Other examples are the NSERC Research Partnership Program in Canada, which had a budget of C$ 118.5 million in 1997/98, and the LINK programme launched in the United Kingdom in 1986. The latter involves firms working together with one or more research base partners on a particular project of strategic importance. By 1997, the UK government had spent £183 million on the LINK programme and committed another £344 million to ongoing projects; there has been similar expenditure by industry.

Research consortia. Governments also sponsor larger-scale collaborative research projects which often involve several firms and universities, as well as government laboratories or research institutes, in programmes to develop certain technologies or carry out a specific piece of research. In most cases, firms, universities and institutes must band together in research consortia to submit proposals in order to win government funding. Most of these programmes are addressed to the development of advanced technologies and are often intended to augment national capabilities in strategic technical fields, with the side-effect of enhancing linkages among actors in innovation systems.

Prominent examples of this type of university-industry partnership include the European Union schemes developed through the successive Framework Programmes. These have created more than 150 000 public/private links throughout Western Europe, benefiting above all universities and to a lesser extent government laboratories; on the industry side, large firms have been the primary participants while smaller firms have experienced some difficulties. At the national level, the United Kingdom has promoted programmes such as ALVEY (in advanced information technology) and CARE (in engineering ceramics) for near-market collaborative research to bolster the academic and industrial science and technology base. In Japan, the ERATO programme was the first to promote co-operative research projects between industry, academia and government, while the United States has fostered the development of collaborative research consortia through the Advanced Technology Program. Other countries have used competitions to stimulate multi-party research partnerships. Germany has boosted university-industry collaboration through its BioRegio competition which challenges regions to submit ideas for developing biotechnology, while the United Kingdom has awarded financial support to collaborative projects selected as winners in its Foresight Challenge competition, based on priorities identified through the Technology Foresight programme.

Co-operative research centres. Another method by which governments have sought to encourage university-industry partnerships is through support to certain research facilities, generally located in universities or technical institutes. In this way, governments are attempting to create ‘‘centres of excellence’’ or co-operative research centres to advance both basic and applied research, often in interdisciplinary fields. Governments generally provide funding for a set period of time (three to ten years) with matching funds from industry, while using academic premises and personnel. In some cases, universities, institutes and companies must compete on the basis of proposals to win government funding. Research centres are generally conducive to a team approach and often stipulate that undergraduate and graduate students be centrally involved in the research activities. One of the earliest such schemes was founded in the United States: the Industry/University Co-operative Research Centers (IUCRC) Program of the National Science Foundation has funded the development of over 50 centres at various locations and in a range of technical fields. The US Government has also supported the development of the Engineering Research Centers and the Science and Technology Centers, to which industrial firms subscribe as members for an annual fee and are in return allowed to influence the R&D portfolio and share in the results.

Sweden’s National Board for Industrial and Technical Development (NUTEK) has sought to build bridges between universities and science by funding Competence Centres at universities or institutes in which industrial companies participate actively in order to derive long-term benefits. Following a competitive process based on a call for proposals, there are now over 30 NUTEK Competence Centres at eight universities and institutes of technology (NUTEK, 1997). Similarly, Finland has established 11 centres of expertise which foster collaborative research among small firms, local governments, science parks, universities and research institutes. In Austria, the Kplus Programme is establishing 10-20 competence centres, funded 60 per cent by the government, to bridge the gap between fundamental research at universities and short-term R&D projects in industry.

Australia established the Co-operative Research Centre (CRC) programme in 1990 to bring government research centres (principally the CSIRO) and universities closer together and for both to link more closely with industrial users. Each CRC is funded for seven years with research providers and users required to commit resources. There are now 66 CRCs in Australia in sectors including manufacturing, mining, energy, environment, agriculture, health and information technology. In Japan, centres for co-operative research have been established in 49 universities to promote university-industry collaboration at the local level. Similarly, the Netherlands has launched an initiative for four Technological Top Institutes to foster co-operative high-quality research. In Korea, the Industrial Technology Research Consortium Promotion Act was adopted to facilitate co-operative research by providing the funds, staff, facilities and information necessary for research collaboration.

V. MAJOR ISSUES

Funding

The increasing number and diversity of university-industry research partnerships raises new types of funding issues – for industry, for universities and for governments. Traditionally, corporations have established links with academic institutions for help with long-term research. Many new partnerships, however, have shorter-term goals, such as getting a specific product to market. Company decisions to outsource research are usually made on the basis of finding the right partner. Corporations do not generally have a preference for whether the R&D provider is another company, research institute or university. What matters from their perspective is the provider's ability to deliver high-quality research results. Industry thus views universities as one of many players operating in the global environment and competing with other research providers for a limited amount of private sector funding. While government support for collaborative university-industry research is welcomed, it cannot be expected to provide enough incentive to influence a corporate decision if the university cannot deliver the highest quality of research.

However, some level of government financing is involved in all university-industry research partnerships in that governments are the primary funders of research in universities in OECD countries. In supporting the research function and overhead costs of universities, the government's role is often an indirect one.

For example, increasing levels of contract research present dilemmas for universities which normally undertake long-term research and training, but are not necessarily particularly effective institutions for short-term tactical research. The university structures and mechanisms set up to develop interaction, provide training and ensure accountability lead to high and expensive overheads, which may not be covered by the industry research contracts for which universities compete with other research bodies. While there are clear benefits to university research from industrial partnerships, there is a limit on the financial resources which universities can obtain from industry or other non-government sources. While industrial financing can complement government funds, it cannot replace the core funding provided by the government sector.

More and more, universities are having to confront the reality of industry as a permanent partner in their research activities. There is a need to ensure that the industrial partnerships fit into, and hopefully strengthen, a broader, long-term programme of research and teaching excellence. If industry funding – particularly for short-term contract research – grows substantially in relative importance, individual researchers, departments and whole universities must guard against a ‘‘job-shop’’ mode of operations. A preponderance of short-term industrial support may lead to the loss of competitive pressure for world-class excellence in scholarship. It may be detrimental to development of faculty careers, teaching excellence and any special non-profit status. In contrast, government-funded partnerships usually hold participants to international standards of research excellence. For universities, a portfolio of different types of industry research partnerships is the best model (GUIRR, 1991).

Many OECD governments are seeking to stimulate university-industry research partnerships of all types. In countries such as the United States, the greatest driver has been changes to intellectual property rules which allow universities to capitalise on research and provide a monetary incentive to universities to pursue partnerships with industry. Fiscal incentives are another indirect tool for encouraging partnerships. One approach is to offer tax credits to companies involved in sponsoring university research – a tool used in some states of the United States and in two Canadian provinces: Ontario and Quebec. In Ontario, the Business-Research Institute Tax Credit (BRITC), effective in 1997, is a fully refundable 20 per cent investment tax credit available to companies for research expenditures incurred under approved contracts with eligible universities and research institutes. Quebec provides a fully refundable 40 per cent tax credit for research performed by an eligible university on behalf of both large and small firms located in the province. Similarly, in Korea, industry expenditures on university contract research are fully tax deductible.

Governments are playing a more direct role in providing monetary incentives for the formation of university-industry partnerships by financing collaborative research projects. Increasingly, government research support may be coupled to requirements for industrial participation or co-funding or both. Funding may be provided through competition or seed grants and generally requires some level of matching funds from industrial partners. In the case of collaborative research projects, while financially attractive for both the university researcher and the company involved, matching fund programmes are sometime criticised as too bureaucratic. They may impose a heavy reporting burden on the principal university researchers without contributing to the effectiveness or the quality of the research. Consequently, companies are willing to invest in collaborative programmes as long as they are convinced that the researcher's time is used in the most productive way, *i.e.* doing research.

With regard to larger-scale research consortia and co-operative centres, big companies with substantial financial, human and organisational resources may remain relatively insensitive to government stimuli to facilitate partnerships. The situation may be somewhat different with medium-sized companies whose resources are more limited, but which nevertheless see benefits in collaborating with universities. For such companies, financial support from the government may have a significant impact on their research decisions. For smaller companies, especially in low- and medium-technology industries with limited resources and little inclination to be involved in research and development, special schemes targeted to involving SMEs in partnerships with universities may be needed and are being mounted by a number of countries.

In an era of budget constraints, governments are seeking greater returns from their research investments. Providing seed money to university-industry partnerships is seen as one means of increasing the commercialisation of government-funded research and raising income for public coffers. Alternative funding options are being sought, including government equity investments in collaborative research, for which governments receive a share of the royalties from licensing intellectual property and income from spin-offs. Government funding arrangements are becoming more innovative and include revolving funds and capital participations. This, however, has made the design and contractual requirements for partnerships more complicated and poses new issues regarding commercialisation of research.

Implementation

One of the problems in fostering successful university-industry research partnerships is the cultural differences between the academic and industrial participants. Universities have a distinctive set of values, procedures and objectives which are not well aligned with the typical characteristics of the business culture. The term university-industry research collaboration implies that organisations rather than individuals are the partners in the collaboration. While from the legal point of view this may be the case, the relationship between the company representatives and university researchers is at the core of a successful collaboration. The corporate objective of many partnerships is to gain access to the expertise of university researchers. Universities as employers of researchers are fundamentally the environment within which corporations have to operate.

If they wish to foster partnering, universities must provide the environment that facilitates collaboration between their researchers and the private sector. Researchers involved in partnerships need the institutional support of the university, access to facilities, access to graduate students and time to undertake the collaborative research. Reward and promotion systems employed by the university also need to be prepared to support collaboration. Explicit policies taking into account collaborative efforts as one of the criteria for promotion and reward might be put in place. This, however, may encounter resistance from opponents of university researchers' involvement with private sector companies as detrimental to other obligations which academics have, namely publication and training of students.

Similarly, if partnerships are the aim, governments and universities need to remove institutional and regulatory barriers which may inhibit professors and researchers from entering into research co-operation with industry. Strict regulations in some European countries and Japan concerning remuneration of researchers, promotion and reward systems, and transferability of pension schemes have created a number of obstacles to collaboration between academics and industry. Japan has recently relaxed regulations to increase flexibility concerning rules on joint research and to eliminate disadvantages in calculating retirement allowances for university researchers who take a leave of absence for co-operative research activities with the business sector (Hashimoto, 1998). In general, climates favourable to public/private partnerships are characterised by the absence of regulatory obstacles regarding financial earnings, pension schemes, teaching obligations as well as autonomy for developing interdisciplinary faculty structures.

For the university participants, a clear understanding of company needs is a necessary precondition for a successful collaboration. Research collaboration is bound to fail without a firm grasp of what precisely the company expects to derive from the partnership, who will be responsible for what, what the measurable outputs will be, what will constitute the success or the failure of the project and how and by whom this will be measured (Box 3). Experienced universities have standard approaches covering intellectual property rights, publication, student participation, access to related research and other matters. When well executed, these serve both to allow the company sponsors to gain commercial benefit from their support of the university research and still preserve the open intellectual

Box 3. **Characteristics of successful partnerships**

- Well-defined objectives, roles and expectations of parties involved.
- Identification of key personnel in the project, including duties and restrictions.
- Clear funding arrangements, including when and how funding is transferred to university.
- Stable support (labs, staff, students) and flexibility (acknowledgement, pensions) provided by the university for the researcher.
- Uniqueness of researcher's expertise and its applicability to the problem at hand.
- Intellectual property and publication issues resolved early on.
- Relationship based on mutual trust, respect and flexibility.
- Projects run in professional manner – deliverables, timelines, financial management.
- Continuous communication between principal players from both sides.
- Inclusion of dispute resolution methods.

climate of the university. Frequent and predominantly informal communication between the university research team and the company sponsoring the research also plays a key role in ensuring that any problems with implementation are dealt with promptly.

These points were confirmed by the Higher Education Winning with Business (HEWB) project in the United Kingdom. This enquiry has shown that academics need to understand and learn the behaviour of the business world, without necessarily adopting the same values. Successful university-industry partnerships are based on a clear recognition by each partner of the other's values and the exchange of benefits which fits in with those values. The central function of a higher education institute should be to help its people forge these partnerships with industry by recognising their worth, providing the means by which those involved can learn the different behavioural skills to help them succeed, and ensuring that internal processes provide the necessary assistance.

Intellectual property rights

With regard to the intellectual property developed in partnerships, several areas of friction may appear between universities and industry due to sometimes conflicting interests (Fraunhofer Institute, 1997). There are issues relating to differing traditional roles, attitudes towards publication and flows of information, and orientations towards developing patents and pursuing commercialisation of research results. Universities are often opposed to restrictions on flows of information, as they need to have their research published and require some degree of academic freedom. In addition, in most countries outside the United States and Canada, patenting research results is still regarded as an unusual activity for university scientists (ESRC, 1997). As university-industry partnerships increase, there are fears that traditional academic roles with regard to publishing and disseminating information may be jeopardised by corporate confidentiality requirements.

Many believe that potential conflicts of interest between the university obligation to train and to disseminate knowledge through publications, on the one hand, and the industrial need to protect the results of the research they sponsor, on the other, are generally resolvable. If a company provides a significant share of the funding for a university research project, it should be assured of intellectual property protection. If a university has done a considerable amount of research on a project before the company enters into a partnership, the university can ask for royalties. In addition, all sponsored research agreements can include mutually beneficial licensing agreements and due diligence clauses. It is important that universities define and openly inform enterprises about their policies on intellectual property rights, including publication of research results and ownership of patents, licence fees and royalties. University researchers may also need professional help in understanding and protecting their property rights.

One study of research partnerships found that companies may be willing to cede intellectual property ownership to the university as long as they are guaranteed a meaningful time advantage over their competitors. Typically, six months may be enough. However, an inflexible demand that the company resigns all the intellectual property rights to inventions, both expected and unexpected, resulting from the research it has sponsored is almost sure to prevent the establishment or continuation of a good relationship. In addition, successful partnerships do not prevent publication of research findings – they encourage them. In practical terms, researchers should be free to publish the general findings of the research after a reasonable delay and after the company has a chance to review the manuscript to ensure that no proprietary information or patentable findings are disclosed (Conference Board of Canada, 1998).

There is concern, however, that an emphasis on intellectual property ownership as an incentive to research collaboration with industry may have adverse effects on universities and academic research. This could lead to changes in internal norms and behaviour which could impair the research and training roles of these institutions. The United States has moved further than many other OECD countries in extending formal intellectual property protection to publicly funded research. The Bayh-Dole Patent and Trademark Amendments Act of 1980 first permitted performers of federally funded research to file for patents on the results of such research and to grant licences for these patents. While this has stimulated an increase in university-industry research partnerships, there has also emerged a new willingness on the part of some US universities to accept significant restrictions on the publication of the results of research undertaken with industry sponsorship. These new restrictions may represent a major shift from the relatively ''open'' norms of university research to one of ''excludability'' of certain research results. The higher level of restrictions on publication before patent applications are filed could limit the diffusion of important scientific and technological knowledge. In addition, knowledge diffusion could be further limited by restrictive licensing terms or exclusive licensing that cover a broad array of possible fields of use (Mowery, 1998).

Commercialisation

The increasing involvement of universities with industry partners focuses attention on the need to commercialise the results of joint research and to move the technology into the marketplace. In some countries, particularly the United States, universities are becoming increasingly sophisticated in valuing technology development opportunities, marketing, packaging and other aspects of commercialisation. In the new partnering paradigm, institutions are recognising that patents and licences are tools which can be used in the short term to obtain industry-sponsored research support and in the long term to generate income from fees, royalties and equity. But again, there are concerns that an emphasis on commercialisation activities will jeopardise traditional university functions.

The changes to patent laws in the United States led to the creation of new ''bridging'' institutions between universities and industry. Universities are setting up special commercialisation, licensing or technology transfer units which guide research partnerships with industry from their initial contract negotiations through their final licensing and royalty arrangements. The US Association of University Technology Managers (AUTM) reports that the number of universities with technology licensing and transfer offices in the United States increased from 25 in 1980 to well over 200 currently and a cumulative total of active licences, signifying that the industry partner is pursuing commercialisation, of almost 13 000 in 1996 (AUTM, 1998).

Similarly, higher education institutions in other countries are attempting to commercialise a greater share of research and establishing external structures to manage their increasingly complex links with firms. In Europe, Finland was ranked first in 1996 and 1997 with regard to the framework in place for commercial exploitation of publicly funded research, including that from universities. The key factors cited were cultural factors enabling close university-industry links, active marketing by the university staff including professors, organised training courses attuned to the needs of industry, proximity of customers, simple contractual procedures and dynamic technology parks. At the Tampere University of Technology, 65 per cent of research is funded by firms, of which almost half are small and medium-sized enterprises (ESTA, 1997).

There is also an increasing desire on the part of many governments to emulate US and Canadian performance in encouraging spin-off firms from university-industry partnerships. These may be small, technology-based businesses founded by industry researchers or university professors on the basis of licensed research results. In 1995 in Canada, it was estimated that there were about 500 university spin-off firms providing 9 560 jobs and company sales of over C$ 1.3 billion (Conference Board of Canada, 1997). Universities may accept an equity position in start-ups partially in lieu of licensing fees to permit firms to direct the cash conserved towards faster commercialisation. In 1996 in the United States, 167 licences, or about 6 per cent, included equity participation in spin-off firms for the universities (AUTM, 1998).

Some countries have attempted to support financially the creation of firms by scientists from universities and by those involved in university-industry partnerships. In Austria, for example, the *Scientists Found Their Own Firm* scheme offers a non-repayable grant plus additional subsidies for investments in special equipment for scientists who leave the university to start their own firms. To date, over 80 per cent of these firms have been in the services sector, operating generally as providers of technology services, consulting or computer software. In general, to foster such start-ups, there is a need for institutional flexibility on the part of governments and universities, a culture which fosters the propensity for individual risk-taking and entrepreneurship and an adequate supply of venture capital.

These orientations have raised concern about the role of universities and how that role might be undermined by commercialisation activities, particularly where universities are trying to capture material benefits for themselves rather than emphasizing technology transfer through people to industry, their traditional function. In addition, in countries such as the United States and the United Kingdom, there has been controversy regarding the university's role in encouraging spin-off firms. These include disagreements between different segments of universities on when spin-outs should take place, the establishment of ''shell'' spin-offs by academics as a means of attracting venture capital for academic research but with no intention of actually spinning off, as well as hostility among some independent firms for what is seen as unfair government subsidisation of competing ventures.

Evaluation

University-industry partnerships need to be evaluated from many different viewpoints – including that of the university and the science base, the company and industry, and local and national economies – and may require new evaluation methodologies. In general, successful partnerships are characterised by a flexible approach to evaluation in which the research process, in addition to its outcomes for the different partners, forms part of the evaluation. Inevitably, there may be tension between the different parties in joint research as to which evaluation criteria should be used and what are perceived as valuable outputs and outcomes.

Universities generally evaluate the benefits of research in terms of peer assessment on the basis of pure scientific criteria as well as publications. For research partnerships, university evaluation methods may need to be redefined. First, partnering arrangements raise questions about the traditional practice of university peer review, which is based on the assumption that in any speciality there will be a group of scientists knowledgeable but independent. In a highly collaborative system of overlapping networks, may become too interdependent scientists to provide effective peer review. However, participation in collaborative networks or in partnerships with industry could itself be taken as a standard of research excellence. For example, the United Kingdom set up the Realising Our Potential Awards Scheme in 1995 to reward academic researchers who receive financial support from industry through the award of grants with which researchers can carry out curiosity-driven, speculative research of their own choosing. The scheme uses industrial funding of academic research as an indicator both of the fields which industry considers strategically important and of researchers carrying out high-quality research.

University technology managers tend to evaluate the results of partnerships in terms of the number of patents rather than the number of publications. University technology licensing and transfer offices, such as those in the United States, may come under pressure from their administrations to generate royalty income. For example, the US AUTM tends to gauge its progress by measuring patent activity and gross royalties received by its member universities. In 1996, US research universities received 10 178 disclosures of inventions from their researchers, resulting in 3 261 new patent applications (AUTM, 1998). However, for all but a few universities, selling the results of university research to industry is not a money-making enterprise. Even in most US universities, the total gross royalties collected from licensing average less than 1 per cent of their research budgets. The payoff to the university may be more in terms of increased support from industry for research, than in income from royalties *per se*.

Evaluations of the impact of university-industry partnerships on the university research environment, on the direction and quality of basic science or on the scientists themselves are relatively rare. One study done in the United States of the impact of university/industry research co-operation on graduate student outcomes found there is little difference between industry and government funding and the form of the partnership (*e.g.* contract, consortia) in terms of how research is conducted, the nature of the research, the climate for academic freedom, scientific publication rates or creation of intellectual property. The most significant differences in these variables were between sponsored (either government or industry) research and unsponsored research (Behrens and Gray, 1998). However, another study by the Carnegie Foundation found that undergraduates at research universities were being short-changed by not receiving as much instruction from professors as students at other colleges and universities in the United States.

With regard to the company involved in collaborative research, corporations generally seek access to expert researchers, state-of-the-art knowledge and unique facilities. Their goals are to leverage research and development, enhance productivity and develop or improve products. For industry generally, the value to be gained from interaction with the academic research enterprise is constituted by insights, contacts and early access to new information in science and technology (Industrial Research Institute, 1995). Sometimes a firm or a small business will seek a specific technology or solution to a problem from a university and occasionally the search will succeed. But research outcomes are unpredictable and research partnerships should not be evaluated according to whether the final outcome exactly matches company expectations. In some cases, companies may consider a partnership to be a success even though the research project failed entirely to develop what the company expected. Instead, the project may have proven the impracticality of a particular concept, thus saving the company 's time, resources and effort for a more productive line of investigation. On the other hand, an engineering professor may solve a technical problem for a company as part of a partnership and in the process learn something that allows him to start a new business. Here, the company shared the cost of developing something from which it may receive no benefit.

Governments are interested in the more general contributions to the economy and to competitiveness of the partnerships which they fund. They may wish to evaluate the impact on industrial performance in terms of the contributions to particular companies, industries and to society in general. In some cases, entire industries may benefit from close relationships with university-based centres of research excellence. In a few industries, the connection may actually yield commercial products and services that can be readily traced back to a particular body of research. According to the US AUTM, the sales of products developed from inventions made in the course of academic research and licensed to industry amounted to US$ 20.6 billion in 1996 and supported 212 500 primarily high-wage, high-skill jobs. A large share of this income was related to research in the biotechnology, biomedical and other life science fields (AUTM, 1998).

Often, regional or local governments which support university-industry partnerships may stress the job creation aspects and the contribution to regional economic development. For example, the State of New York established the Centers for Advanced Technology in 1982 to facilitate and support university-industry collaboration for the development and application of technologies that are relevant to industry and the state. A cost-benefit analysis of the programme conducted in 1992 measured benefits in terms of external income attracted to the state, cost savings to companies and new companies formed, new jobs created and jobs retained, and improved workforce training. Benefits such as job creation and retention may be used, particularly by local governments, to justify government expenditures for research partnerships.

In general, evaluations tend to be circumspect about the capacity of partnership programmes to generate real breakthrough discoveries or enhance overall industrial performance. For example, evaluations of research consortia show that apart from fostering closer ties between industry and the science base, the programmes did not greatly enhance the general competitiveness of industry. Support for R&D partnerships may be a necessary but insufficient means of enhancing industrial innovation capacity. Their true value may be in networking, constituting more of a complementary support for the academic communities involved, while enterprises see such schemes as opportunities to keep an eye on evolving scientific disciplines or technology areas. Industry support for the education of graduate students can be of great value from a national perspective, and partnerships can orient groups of researchers towards fields of importance for the future and for industrial competitiveness. But such outcomes are difficult to quantify, highlighting the general difficulties in evaluation of research partnerships.

VI. CONCLUSIONS

Increasing partnerships among universities, companies and research institutes are transforming the research system in OECD countries into a highly collaborative one. Policy makers may find their role shifting away from one of supporting individual institutions to one of building the infrastructure needed to support communication and collaboration among researchers. Scientific research funding will need to accommodate more widespread collaboration rather than a few programmes targeting and attempting to increase university-industry joint research. This paradigm will also challenge policy makers to rethink the structure of research funding, management of research universities, assignment of intellectual property rights, the peer-review process and the basis for evaluation.

University-industry research partnerships, which are changing in their nature and intensity, bring into conflict the differing norms of the parties and may necessitate some compromise over future research agendas. Partnerships must overcome the problem that industry needs research results more quickly than universities habitually produce research. Universities will need to become more permeable, more flexible with regard to researchers and more equipped in terms of communication infrastructures. In the future, how to fund, manage, facilitate, conduct and evaluate collaborative research will become a more significant core competency for university personnel. Universities are confronting the question of what their optimal profile should be to fulfil all their varied functions.

However, increased collaboration between universities and industry must consider the effects of these partnerships on the process of academic research and teaching. Evaluations show that both the public and private sectors can enjoy substantial benefits from partnerships, but should avoid unrealistic expectations and inappropriate measures of desired outputs and outcomes. Excessive attention to monetary returns to the university from the research it performs can undermine the university-based resources that industry values most. A misplaced emphasis on economic contributions and job creation can prematurely doom the success of partnering efforts. Assessments of the effects of research partnerships are still quite limited in number and scope, partly because their impacts are subtle and indirect. Academic research and training can contribute to the technical and economic success of companies, who can in turn provide financial resources and practical experience to researchers and universities. A better understanding of such collaborations will aid policy makers, companies and universities to make more informed decisions regarding the allocation of research funding and the design of policies aimed at facilitating and supporting university/industry partnerships.

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FINANCING AND LEVERAGING PUBLIC/PRIVATE PARTNERSHIPS: THE HURDLE-LOWERING AUCTION

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This article was written by John T. Scott of the Department of Economics at Dartmouth College, Hanover, New Hampshire, United States. The author would like to thank Jean Guinet, Robert G. Hansen, Meir G. Kohn, Albert Link, Stephen Martin, F.M. Scherer, Gregory Tassey and the participants at the OECD Workshop for advice on the issues addressed in this article.

I. INTRODUCTION

The purpose of this article is to propose a mechanism – the *hurdle-lowering auction* – for leveraging the public funds invested in public/private partnerships to promote technology. The article addresses *financial engineering* – the optimal amount and design of public funding of privately performed investments in technology and innovation carried out by *public/private partnerships*. Public/private partnerships are joint research ventures combining public and private resources to invest in the research and development of technology and innovations.[1] Thus, financial engineering concerns the design of mechanisms for public funding of public/private partnerships that generate the maximum *leverage* of the public funds on the private investment and performance. By maximum leverage of public funding, is meant maximum effectiveness of the funds in ensuring the use of the least amount of public funds to get the desired results and ensuring the necessary incentives to get those results given the appropriate amount of public funding.

Obviously ''desired results'' can mean different things in different circumstances, but in the context of this study good results mean correcting the under-investment that would result in the absence of the public funding. The social objective of the public funding is to correct market failure which results in under-investment in technology and innovation. Martin and Scott (1998) develop a taxonomy of innovation modes and associated market failures and appropriate policy responses, and in that context suggest circumstances where the mechanism discussed in this article might usefully be developed and reduced to practice. The aim of this brief article is simply to sketch the idea of the proposed mechanism.

Changes in the nature of technological competition compel the development of a new approach to leverage public investments in public/private partnerships. The review of the literature in Martin and Scott (1998) points to the following observations:

- There is an important role for public support of R&D, and there is support for two very different views of the appropriate use of public funding of R&D.
- One is a very cautious view that technology policy should foster ongoing institutional arrangements, either at or in connection with universities, that will encourage innovation and dissemination of new knowledge over the long run. Broadly, such arrangements would be focused on the basic and generic end of the spectrum of research and not on the applied research that is closer to the commercialisation of innovations.

- The other view is an aggressive view that a revolution in the nature of technological change combined with a revolution in the extent of global competition and transformations of financial markets dealing with technology and innovation investments have reinforced one another to create a new technology and policy regime in which public funding of public/private partnerships is more important, and more feasible than ever before, to correct market failures that extend beyond the basic and generic end of the research spectrum and into the development and commercialisation of innovations.

The revolution in technological change is centred on information technology, which is fraught with appropriability difficulties and risks that cause market failure and underinvestment.[2] Broadly speaking, the technological networking issues to be addressed with R&D investments must be solved in a global economy that is increasingly ''networked'' with regard to complex and interdependent information technology, and in this new technological and competitive environment, public/private partnerships are more important than ever. At the same time, new developments in venture capital markets make old-style public funding of technology investments obsolete; in the current high-technology environment, the selection of investment projects will need interactive involvement with evolving technologies that will be difficult for governments to provide, and the investments themselves will need a type of ''hands-on'' monitoring that will be difficult for governments to provide directly.

In this new policy regime, lessons from the past about not using public funds for development work that is close to the commercialisation stage may be challenged for three reasons. First, past difficulties may have reflected circumstances where the legitimacy of public funding was not as compelling as it is in the new policy regime. Second, new developments in venture capital markets and new understanding of those markets place new demands on public funding of ventures dealing with the new regime of technological change. Third, past difficulties may have resulted because insufficient attention was paid to the design of the mechanisms for public funding.

- Attention must be paid, in the implementation of public funding for R&D, to the appropriate design of mechanisms to stimulate desirable investment responses from the private partners in public/private partnerships.
- Given the new reasons to believe that public funding to overcome market failure and underinvestment in R&D is needed more than ever before, and given that the past difficulties for public/private partnerships may be attributable to inadequate design of the public funding mechanisms, the hurdle-lowering auction is proposed as a mechanism for delivering public funding to public/private partnerships more effectively.

The new technological and competitive environment makes public/private partnerships compelling; poor performance for some earlier public/private partnerships suggests the need for new approaches to public funding of the partnerships, and the case for new approaches is especially compelling now that venture capital markets are developing rapidly to deal with investments in emerging technologies. If one accepts the argument that public funding should extend beyond basic and generic research, government needs to do something better than simply pick the technology area where commercial results are to be supported and then throw money at the chosen projects. That leads to the next question:

– How can government *ensure* that such support exert a maximum leverage on private investment?

The leverage question has been focused to get beyond the prescription of ''do the socially optimal amount of funding to correct the underinvestment that resulted from the market failure''. Technology policy must do more than offer the theoretically correct, but operationally empty, prescription that says to provide enough public funds to bring investment up to the point where social marginal benefit and marginal cost of investment coincide. How does the government optimise such public funding? What is the form and the optimal amount of public support, and how can the government ensure that such support exerts maximum leverage on private investment? The extent of market failure and underinvestment varies by type of innovative investment done by the project and by type of industrial setting. The mechanisms for the delivery of public funding for public/private partnerships must be flexible enough to work well in different technological and economic environments.

Further, because venture capital markets require a hands-on, ongoing relationship between investors and entrepreneurs that is expected to be difficult and costly for public agencies to conduct successfully, the mechanisms should rely on private markets and to the extent possible not supplant private market decision making. To provide more reliance on private decision making to answer key questions about the incidence of public funding and about the form of the funding and its optimal amount, this article proposes a flexible bidding process to determine the extent of public funding at the various stages of the investment projects. Certainly it is beyond the scope of this initial paper to develop complete details of the bidding process, but it is sketched in sufficient detail to justify and explain the approach and introduce its essential ideas; Martin and Scott (1998) place the idea in the context of the literature and propose further development of the idea for future research.[3]

II. PUBLIC/PRIVATE PARTNERSHIPS TO CORRECT MARKET FAILURE

Market failure in general refers to situations where the divergence of private and public benefits or costs cause market solutions to differ from socially optimal ones. This article focuses on market failures that result in underinvestment in technology and innovation. Although there are market failures that can cause too much R&D investment (Baldwin and Scott, 1987), those are obviously not the market failures addressed with public funding to counter a shortfall of private R&D investment.

Two broad and interrelated sources of the market failures cause underinvestment in technology and innovation: appropriability difficulties – private firms typically do not appropriate all of the social returns from their innovative investments; and risk and uncertainty – private firms typically are concerned about the downside risk of their innovative investment because of bankruptcy costs and the firm-specific human capital of the managers and employees of the firms.

These two sources of market failure and underinvestment are related because appropriability difficulties make unacceptable downside outcomes for an investment project more likely. Thus, if appropriability differences imply that two projects with the same variance in return have different expected returns, the one with lower appropriation of returns and hence lower expected outcome creates a greater risk for the firm because the probability of an outcome below a minimal acceptable level is greater. The appropriability difficulties and the uncertainty stem from spillovers of knowledge, from ‘‘the paradox of information’’, from unappropriated consumer surplus with even monopoly pricing, from the competition that drives price towards marginal costs in a post-innovation market, and from technological risks and market risks facing firms doing R&D.

Public funding through public/private partnerships for R&D investment corrects underinvestment by increasing the rate of return on the private firm’s R&D investment, thereby giving the private firm the incentive to carry out the investment project. The public funding directly eliminates the problems of appropriability difficulties and risk by changing the probability distribution over the outcomes for the private firm’s investment in the project. The public funding would typically shift the distribution of rate of return on the private firm’s own investment in the project to the right, increasing the company’s expected return while lowering the downside probability of bankruptcy. The increase in expected value directly improves the incentive for investment that appropriability difficulties had reduced.[4]

III. CHALLENGES TO THE EFFECTIVENESS OF PUBLIC FUNDING: HOW THE REQUIREMENTS OF THE VENTURE CAPITAL MARKET CREATE DIFFICULTIES FOR EFFECTIVE PUBLIC FINANCING OF PUBLIC/PRIVATE PARTNERSHIPS

Debt financing will not work for financing risky R&D investments of the sort that may require public funding. There is no up-side to the return to such instruments, and they are suitable for investors who do not want much risk at all. When used to finance risky investment, lenders are exposed to opportunistic behaviour by borrowers because the returns to the lender and to the borrower are asymmetric. The borrower will have an incentive to take big risks, since only the borrower participates in any up-side returns, but both the borrower and the creditor share the downside risk, and the possibility of bankruptcy means that the lender may bear even more downside risk than the borrower. Equity financing then, is the suitable means for financing such risky investment; the investor shares in the up-side profits of the risky venture.

However, equity financing requires a hands-on approach to managing the investment, because if absentee owners place the equity funds in the control of the company investing in R&D, there is an agency problem. The active owners in the firm now must share any gains realised from the upside potential with the absentee owners, and other things being equal will have less incentive to do the best job for the other investors. Whether those who have operating control are entrepreneurs who have obtained venture capital or simply the company 's managers, not gaining all of the investment's upside returns, those with operational control have an incentive to undertake less risk than the outside equity owners would prefer; more generally they do not, without some sort of extra incentive mechanism, have an incentive to work in the best interests of the absentee equity investors.

''Venture Capital in OECD Countries'' (OECD, 1996) emphasizes the ''hands-on'' aspect of venture capital for investments in companies in the early stages of development.[5] The survey also emphasizes that venture capital is the key source of long-term funds to small and medium-sized enterprises (SMEs), and it provides a description of the venture capital market and how it works. The extent and success of venture capital markets vary across countries, and there are many government programmes to stimulate venture capital provision. The survey observes that there are differences of opinion about the benefits of government involvement. Some believe that excessive public intervention will lower returns on the early-stage investments to the point where venture capitalists will no longer be attracted. In the context of a limited number of such projects, the public/private partnerships might take the more attractive projects, crowding out private investors. These critics then argue that government should limit its role to assistance in setting up the market infrastructure and in creating an environment conducive to entrepreneurship. However, new technologically intensive firms may not receive sufficient capital, and such capital constraints limit R&D investment especially for small firms (Lerner, 1996).

Lerner (1996) and Gompers and Lerner (1997) observe that the pool of funds committed to venture capital investments has recently grown rapidly. Along with the rapid increase in the venture capital funds, there is the pervasive belief that private venture capital firms will do a better job than the government in monitoring the ventured equity positions in risky companies making R&D investments. The dilemma, however, is that despite a surge in private funds for the venture capital market, and despite the capability of the private market for managing the investment of such funds, because of the appropriability problems and the risk the private sector on its own will typically underinvest in technology and R&D.

For example, the *Financial Times* (Campbell, 1997) reports that there is currently great momentum gathering behind private equity across Europe, observing that: ‘‘Private equity encompasses everything from large leveraged buy-out deals to the more traditional venture capital channelled into start-up or early-stage businesses. While there are some signs of a revival of interest in emerging businesses, particularly in the technology sector, today’s flood of money is directed primarily towards buy-out opportunities.’’ Detailed evidence on the new interest in venture capital for technology investments emphasizes that the pick-up in interest in providing venture capital to the high-tech sector is starting from a low base because of poor performance in the last decade for venture funds and because of the difficulties of successfully managing such funds (Houlder, 1997; Price, 1997).

Lerner (1996) observes that if the capital constraints literature is correct, then public funding of early-stage high-technology firms would stimulate significant growth for the firms because they would be able to invest in high-return projects that they could not have accepted without the government funding. The question, then, is how to deliver the necessary public funding to provide sufficient investment funds in such a risky environment without losing the monitoring ability of a private venture capital firm and without having to ensure such monitoring with clumsy and costly contracts. Support for the view that public provision of venture capital will not work well is provided by the work of Dyck and Wruck (1996) which studies German government-owned privatisation agencies that own portfolios of eight to ten eastern German firms. Dyck and Wruck hypothesise that private companies are more reliable contracting partners than a government. As a result, governments must use more intricate and hence more costly contracts than private firms would use. The reason that Dyck and Wruck expect governments to be less reliable partners and to require more costly contracts spelling out contingencies and responsibilities is their hypothesis that government organisations as political organisations need to please their diverse constituencies and therefore will be reluctant to make economically painful or controversial decisions.

In his study of the impact of public provision of venture capital in the US Small Business Innovation Research (SBIR) Programme, Lerner (1996) provides evidence in support of a positive view of the prospects for public funding of public/private partnerships. Thus, he tests the hypotheses that the private sector provides too little capital to new firms and that the government can identify companies where investments will yield high social and private returns, and his evidence supports the hypotheses. However, Wallsten (1997) re-examines the SBIR Programme and finds that the SBIR grants crowd out private-firm R&D dollar for dollar. He hypothesises the grants fund research that would have been funded privately because politicians judge the success of technology programmes by the commercial success of the projects they fund, and then of course the managers of the grant programmes choose promising, commercially viable projects that would have been funded privately and needed no subsidy. Wallsten observes (1997, p. 10) that although ''Lerner included a control group, he did not deal with the issue of 'picking winners' – the possibility that agencies fund commercially attractive projects that could have been funded privately''.

The mechanism for delivering public funding proposed below actually solves this problem, to the extent that it does exist, because for such projects the mechanism results in the private sector completely reimbursing the government for the cost of the publicly funded project. Some transaction costs would remain unreimbursed, but over time, as experience with choosing projects and use of the new financing principle grew, the mechanism would allow identification and weeding out of projects that should not be publicly funded.

Another observation about the venture capital market is also important for the proposal below for a new mechanism for delivering public funds to public/private partnerships. Gompers and Lerner (1997) find a very robust relationship between the valuation of early-stage firms and the volume of venture capital funds that are bidding for the equity of companies seeking venture capital. In particular, a greater volume of commitments of venture capital funds increases the valuation of new investments. Apparently, a larger volume of venture fund commitments translates into more competition for, and hence higher prices for, the type of risky asset provided by entrepreneurs seeking venture funds. There are implications of their finding for the proposed bidding mechanism introduced below. First, evidently, the most propitious time to invite bidding from private venture funds that would bid for the right to manage funds for public/private partnerships would be when outstanding venture capital commitments are high. Second, the need for public funds may be greatest when such commitments are relatively low.

The venture capital literature also emphasizes the importance of a means of ''exit'' from the venture capital stage. Although exit can be provided by acquisition or merger, anticipated rewards can be increased by the capability of successfully trading the company on an exchange such as the NASDAQ. Several new stock markets for small, fast-growing firms have emerged in Europe recently (*The Economist,* 1997). Gilson and Black (1996) and MacIntosh (1996) emphasize the importance of stock markets as a means for venture capitalists to dispose of their investments. One simple recommendation for technology and innovation policy is then for governments to take steps to increase the availability and ease of use of stock markets for small, rapidly growing firms. Such markets make investment in start-up firms more attractive and, in the context of the mechanism proposed in the next section, reduce the gap between project cost and what firms will bid to be the private partner in the public/private partnerships.

IV. ENSURING OPTIMAL DESIGN OF PUBLIC FUNDING: A MECHANISM FOR LEVERAGING THE PUBLIC FUNDING

Improving the design of public partnerships raises three fundamental questions: How can the public get the best private partner for each public/private partnership? How to obtain the optimal amount of public funding – not too much, but enough to overcome the underinvestment resulting from market failure? How to overcome the potential for opportunistic behaviour to which both the government and the private partner are exposed?

Premise: the private sector knows more than the government about the investment characteristics of the technology projects – or at least has the resources to take the best guess at the streams of returns and the risk.

Implication: policy should design a mechanism for setting up a public/private partnership that provides the incentive for private parties to determine who is best suited to be the private partner in a public/private partnership.

Premise: the government wants to overcome the underinvestment resulting from market failure and to do so at the least cost to the public.

Implication: policy should design a mechanism that gives the selected private partner for the public/private partnership the incentive to carry out the desired level of investment while providing a proportion of the project's funding that is consistent with a normal expected rate of return for the private firm given the appropriability and risk characteristics of the project.

Premise: both parties want to overcome the potential for opportunistic behaviour by the other party.

Implication: policy should design a mechanism that gives both the public and the private partners the incentive to participate in the project in a way that maximises the total value of the project's outcome rather than the value to the individual partner who could of course use opportunistic behaviour to benefit at the expense of the overall results of the project.

General characteristics of the mechanism: what are the general characteristics of the optimal mechanism for public/private partnerships that will achieve the desired incentives for the private sector to choose the best private partner, for the private partner to carry out the desired amount of investment at the least cost to the public, and for avoiding opportunistic behaviour by either the public or the private partner?

Consideration of the questions suggests that the optimal mechanism would have the private parties use a contingent valuation method to bid for the right to be the private partner. In particular, the bidding could be a hybrid bidding mechanism that combines an up-front bid, a periodic payment bid, and finally a royalty bid: private firms would bid for the right to be the private partner in the public/private partnership project that the government would fund. Or, instead of bids being accepted directly from the companies that will be performing the R&D, private venture capital companies that would manage the public investments might bid for the rights to manage the projects.

As a simple example of how a bidding process would deliver the public funding to a public/private partnership, consider the following. Suppose that from society's perspective, an R&D investment project would cost 100 now and generate the expectation of 130 in one year and nothing thereafter. Suppose further that the threshold rate of return justifying public funding – society's hurdle rate – is 10 per cent. Thus, the R&D project yields a social rate of return of 30 per cent, which exceeds the hurdle rate of 10 per cent, and of course the net present value of [130/(1.1)] – 100 is greater than zero. Suppose that from a private perspective the project costs 100 and because of incomplete appropriation of returns yields the expectation of just 105 in a year. Suppose further that, given the private risk, the private hurdle rate is 15 per cent. Thus, the private sector would not undertake the project which has an internal rate of return of 5 per cent which is less than the hurdle rate of 15 per cent; and, of course, net present value is then negative.

In the context of the foregoing example, the bidding process would work as follows. The government announces that it will ''buy'' the R&D project, paying the 100 investment cost.[6] The government then opens the bidding for the right to be the private partner in the public/private partnership. Private firms will bid the amount X such that X (1.15) = 105, implying that X = 91.30. The cost to the public of the project would then be 8.70. With great uncertainty about the future returns, the use of royalty bidding rather than the up-front bidding can yield more to the government. Also, private firms with better capabilities for doing the project would be expected to bid higher than those firms that are less well suited to the project.

There is a large literature describing bidding mechanisms in great detail. McAfee and McMillan (1987) provide a review, and they set out the general hybrid mechanism with the up-front bid as well as the royalty bid. Hansen (1985) and Samuelson (1986) provide analyses of the royalty bidding and bidding for the up-front fee and the royalty rate simultaneously. Just a general overview of a more general bidding mechanism and the bidding mechanism's potential in the context of public/private partnership is provided here.

Broadly, suppose that the government wants to use a public/private partnership to develop a project. The government would announce that it would provide an up-front payment of F to support the R&D investment project to be conducted by the winning bidder in an auction to determine the private partner for the public/private partnership. Further, the government pledges to provide a periodic flow of funds c throughout the project's life to support the flow costs of the R&D project. The fixed cost F and the flow cost c correspond to the typical abstraction of the structure of costs for R&D investment projects (Lee and Wilde, 1980). Bidders then bid for the right to be the private partner in the project by submitting a three-part bid: first, a bid for how much the private firm will pay the government up-front; second, a bid on the periodic flow payment during the life of the R&D project; and, finally, a bid on the royalty rate that it would pay the government on the innovation produced by the public/private partnership and licensed (perhaps exclusively) to the private partner.

As McAfee and McMillan (1987) make clear, in the context of the appropriate combinations of assumptions about the characteristics of the asset being auctioned and the participants in the auction and their beliefs about the value of the asset, there are non-trivial choices to be made about the exact nature of the auction. Apart from the usual choices for auctions in general, there would be choices specific to the new institutional use of auctions to determine the private partner for the public/private partnership. For example, institutional arrangements must be designed to insure that the government's payments of F and c go solely for the purchase of R&D investments; the private partner's profits from the R&D investment project will come after the innovation is introduced. However, for this article, full details of the ideal auction in different circumstances will not be developed. Instead, the article presents the basic idea and observes that the three-part bidding mechanism proposed has the potential for leveraging public funding optimally.

– First, with a well-designed auction, a viable private partner is likely to be chosen. Intuitively, the company that can (or at least *thinks* it can) produce the best results at the least cost will gain more value from winning the bid to be the private partner in the public/private partnership; therefore, it will bid higher and win.

- Second, the government's investment cost will be minimised. Intuitively, that cost is the present value of *i)* the up-front investment *F* minus the up-front bid and *ii)* the flow cost *c* minus the periodic flow payment, and the firm with the best capabilities for producing the research at lowest cost will submit the highest bid for the up-front payment and the periodic flow payment. The government's net costs are reduced further by the royalty payments it will receive. Those royalty payments, however, serve other specific roles in the mechanism design.
- Third, the royalty payments are the contingent payment option that mitigates the effects of uncertainty by tying the actual payment by the private firm to the government to the actual performance of the R&D investment and the innovation it produces. The contingent payment mechanism then increases the willingness of private firms to bid and increases the winning bid and reduces the expected cost to the government. Greater uncertainty about value implies lower expected price at the auction, and using royalty bidding as a type of contingent pricing mechanism gets around that problem, giving in effect *ex post* pricing, whereas without contingency pricing less is bid because no one knows what to pay for the right to be the private partner in the public/private partnership. However, as noted subsequently, with royalties, there is an agency problem that changes the way the winning bidder will exploit the innovation resulting from the public/private partnership, and that issue is addressed below.
- Fourth, the royalty payments give the government an equity stake in the project and reduce the likelihood of opportunistic behaviour on the part of the government.[7] Suppose that the project is one for which public support – funds of course, but also the energy and talents of the government's employees such as those in public laboratories and technology policy departments – will be needed for many fiscal years. The government's equity position in the project may be a way to ensure the credibility of the public's support throughout those early investment years despite changes in administration or changes in public sentiment. The equity position could help to ensure that the government did not abandon a project midstream, and thus make private participation and investment more attractive.
- Fifth, the likelihood of opportunistic behaviour by the private investors is lessened because the private firm or firms will have invested in the project with both up-front and periodic payments, and good faith behaviour would be required to keep the public funds *c* for the flow costs arriving on schedule to protect and sustain the private investment and keep the prospect of the private share of the project's expected earnings.

– Clearly, though, the royalties to the government in return for use of the technology must be low enough so that the problem of reduced incentives for the private firm to promote the innovation does not outweigh the gains because the royalty mechanism mitigates risks and ensures continued public support. With diminishing returns, and hence rising marginal costs of exploiting the innovation, the royalty payments to the government will reduce the private company's use of the innovation below the optimal amount.

The proposed hurdle-lowering auction mechanism, broadly, is that private firms bid for a public/private partnership using a three-part bid reflecting the up-front, fixed costs of the R&D project, its flow costs, and the stream of profits from the resulting innovation. Government wants the right firms to win the bid, and it wants to pay the optimal amount, but not too much, to get the innovations. The three-part bidding mechanism proposed would potentially provide the desired properties. By having private venture capital companies, as contrasted with the early-stage companies performing the government-supported research and technology investment, bid for the contract, the bidding mechanism could even incorporate private venture capital market supervision of the public investments in early-stage firms or joint ventures.[8]

V. CONCLUSIONS

This article has introduced a simple idea that may be of use for leveraging public funding of investments in technology and innovation. The simple idea is to develop appropriate bidding mechanisms to allow private-market decisions to flexibly tailor the amount and timing and delivery of public funding of public/private partnerships. The article has sketched a prototype three-part bidding mechanism – a hurdle-lowering auction – and explained why it can potentially provide the desired traits for delivering the public funds to public/private partnerships. The approach need not be a radical departure from current practice. The public funding authority can still exercise judgement about which bid to accept, and the process could be seen as an extension of the negotiation process over the exact details and extent of public and private contributions to the project.

Of course, the bidding mechanism, in whatever form it takes, should be evaluated and compared with other mechanisms to ensure that it performed well, especially given the problems of ''government failure'' that can be just as difficult as problems of ''market failure''.[9] A good mechanism would have not only the desirable traits – choosing a good private partner, achieving desired investment while minimising the expenditure of public funds, and so forth – that have been associated with the bidding mechanism, but additionally it would have relatively low administrative costs.[10] Bidding mechanisms have the potential to return far more than they cost administratively because they will minimise the public funds needed to support the public/private partnership projects, but that expectation must be tested. Governments should engage in ongoing evaluation and development of the mechanisms for identifying projects for public funding and for delivering the public funds to the public/private partnership.

NOTES

1. Note that public/private partnership more generally need not necessarily involve public and private parties doing research. For example, the public/private partnership could be focused on the provision of appropriate legal infrastructure such as the laws concerning intellectual property, or on the co-ordination of appropriate standards for technologies.
2. Antonelli (1994) provides an overview and details about the economics and policy issues for networked information technology.
3. Scherer (1997) provided a helpful suggestion when asked for his opinion on the question of financing public/private partnerships. He observed: ''You might profitably study the experience of the United States in awarding offshore oil tracks by royalty bidding rather than front-end bonus bidding.'' Following up on his suggestion led to the proposal for the three-part bidding process sketched in this article.
4. Scott (1980) discusses the coefficient of variation as a natural hybrid measure of both return and risk. Tassey (1997) defines risk in terms of the downside potential for project failure; variance in return *per se* is not the key, but the probability of the downside deviations from expected value placing the return so low that the project is deemed a failure. Hence, he implicitly uses a hybrid measure of risk that combines expected return and the variance in the return. Given the variance, a higher expected return can – using the hybrid view of risk – lower risk, because it lowers the probability of failure.
5. Harris and Bovaird (1996, p. 197) also emphasize the need for hands-on management of venture capital investments by studying the successful investments of companies offering funds to young businesses. Rather than simply providing capital, investors need to ensure that early-stage companies address other capability gaps – inadequate management skills, inadequate understanding of the market, inadequate relations with suppliers, and inadequate financial control.
6. Martin and Scott (1998) provide detailed discussion of the circumstances in which market failure and underinvestment would be expected to occur; the discussion is needed to inform the identification of projects that would be funded.
7. Of course, the government is not a profit-maximising firm, and one must be concerned then, that incentive problems will occur because a bureaucrat will be deciding what to do based on his or her own preferences. However, governments do have constituencies to satisfy which can potentially play a role analogous to that of stockholders in a

for-profit firm if a good mechanism for delivering the public funding to the public/private partnership is in place.

8. Clearly the discussion here has only sketched the idea of designing a bidding mechanism to leverage the public financing of public/private partnership projects. Details remain to be developed for actual public/private partnership projects. Such details include the type of auction (for example, English, Dutch, sealed first-bid, or sealed second-bid auctions), the use of a reservation price, and so forth, for various circumstances such as independent or correlated private values, common values or hybrid cases where technological and market uncertainties are subject to different valuation characteristics.
9. Problems with incentives, unintended consequences, interest groups lobbying for concentrated benefits that have diffuse costs, and inconsistencies of group decision making suggest that the makers of technology policy should continually look for ways to remove government-induced obstacles to R&D investment, and ways to make private investment more effective even while implementing new mechanisms to make the government's actions more effective.
10. In the context of their evaluation of alternative tax incentives for R&D, Bozeman and Link (1983) list and critically discuss several criteria by which alternative mechanisms should be evaluated.

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MANUFACTURING PARTNERSHIPS: CO-ORDINATING INDUSTRIAL MODERNISATION SERVICES IN THE UNITED STATES

TABLE OF CONTENTS

This article was written by Philip Shapira and Jan Youtie of the Georgia Institute of Technology, United States. It is based on an earlier paper, ''Co-ordinating Industrial Modernisation Services: Impacts and Insights from the Manufacturing Extension Partnership'', published in the *Journal of Technology Transfer,* Vol. 22, No. 1, 1997, pp. 5-10. Permission from the publisher is gratefully acknowledged.

I. INTRODUCTION

Partnerships involving private and public organisations are increasingly important for policy implementation and programme provision in the United States (Gore, 1993; Osborne and Gaebler, 1993; Shapira, Kingsley and Youtie, 1997). In the field of technology policy and technology transfer, there are now many co-operative programmes involving a wide range of public and private participants. By the mid-1990s, it was reported that ten federal agencies had joined with states, industry and other organisations to spend US$3.1 billion a year on hundreds of partnered technology programmes (Berglund and Coburn, 1995).

The Manufacturing Extension Partnership (MEP) exemplifies this partnership trend. The MEP is a network of technology assistance and business service providers that aims to upgrade the performance and competitiveness of US small and medium-sized manufacturing enterprises (SMEs).[1] The programme is a collaborative initiative between federal and state governments which also involves non-profit organisations, academic institutions, and industry groups. The National Institute of Standards and Technology (NIST), within the US Department of Commerce, is the MEP's federal sponsor. From three Manufacturing Technology Centres (MTCs) in 1989, the MEP has now grown to a network of more than 70 centres in all 50 states (National Institute of Standards and Technology, 1998*a*; Shapira, 1998). Most of the growth in the programme has occurred since 1992, with support initially from Department of Defense funds through the federal Technology Reinvestment Project (Advanced Research Projects Agency, 1993) and subsequently from the civilian budget of the Department of Commerce, through NIST. In fiscal year 1998, federal funding for the MEP of $113 million was matched by at least a further $100 million in (mostly) state and (some) private funds.

MEP centres usually operate either as separate non-profit corporations or as part of other organisations, such as universities, state agencies, technology centres or economic development groups. The MEP programme is decentralised and flexible: each centre develops strategies and services appropriate to state and local conditions. The individual centres typically employ field personnel with industrial experience who work directly with firms to identify needs, broker resources and develop appropriate assistance projects. Other services include information provision, technology demonstration, training and referrals. At the federal level, NIST not only provides matching funds but also co-ordinates the system, reviews the quality of member centres, sponsors common services such as staff training, tools and information exchange, and supports national and cross-cutting initiatives in such areas as supply-chain management, environmentally conscious manufacturing or workforce training. With the growth of the MEP system, almost 30 000 manufacturing firms are being assisted annually through assessments, technical assistance projects, workshops and other services. Some two-thirds of assisted companies have fewer than 100 employees.

In addition to deploying in-house resources, the MEP centres work with several thousand affiliated public and private organisations across the United States. These service partnerships allow MEP centres to offer an array of resources, capabilities and tools to their SME customers (National Institute of Standards and Technology, 1998*b*). Through co-ordinated partnerships with other technology and business service providers, the MEP seeks to leverage limited public funds, avoid the duplication of services, tap specialised skills, extend awareness and outreach, and promote flexibility in the delivery of services.

This article reports on an ongoing study that is tracking the development, operation and impacts of efforts to promote service co-ordination by the MEP system.[2] After an overview of the extent of MEP's service partnerships, the ''additionality'' generated by the federal government through the MEP, by promoting partnerships that otherwise might not have existed is examined. The article then considers the consequences of efforts to promote partnership and co-ordination among industrial service providers. The costs and drawbacks associated with partnered services are discussed, along with the benefits and advantages. Finally, the article identifies a set of best practices in service partnerships, with the aim of offering guidance to programme managers as they seek to optimise the gains from partnered service co-ordination.

The findings reported in this article draw on indepth case studies of six MEP centres with exemplary service co-ordination features. The case study centres were selected with the help of an expert advisory panel. The centres (with their service areas in parentheses) are: the Chicago Manufacturing Centre (Chicago, Illinois area); the Georgia Manufacturing Extension Alliance (the state of Georgia); the Great Lakes Manufacturing Technology Centre (Cleveland, Ohio area); the Manufacturing Extension Partnership of Southwest Pennsylvania (Pittsburgh, Pennsylvania area); the Minnesota Manufacturing Technology Centre (the state of Minnesota), and the Oklahoma Alliance for Manufacturing Excellence (the state of Oklahoma).[3] At the case study sites, structured interviews were conducted with MEP programme managers, field staff, partner organisations, small business customers and state programme sponsors. Reviews of programme documents from each centre and its affiliates and an analysis of information from the MEP national reporting system augmented the case studies.

II. PARTNERED SERVICE CO-ORDINATION IN THE MEP

Across the United States, MEP centres have established relationships with many other providers of technology and business services, as well as with organisations that have an interest in upgrading SMEs. In mid-1997, more than 2 600 organisations were associated in some way with 68 of the MEP centres reporting this data into NIST's national reporting system.[4] Although there are issues of data comparability, this number is more than three times greater than the 750 affiliated organisations reported by 40 centres at the end of 1995. It suggests that MEP centre affiliations with third-party service providers have grown.[5] The most common relationships are with economic development organisations and universities. About 95 per cent of the centres have relationships with these types of organisations (Table 1). The next most common type of organisational relationship, for two-thirds of the centres, is with community or vocational colleges and technical institutes. Almost 60 per cent of centres have relationships with industry associations and small-business development centres, and about one-half with private consulting companies. To a lesser extent, partner relationships are also reported with federal laboratories, larger companies, utilities and training organisations.

Table 1. **US manufacturing extension partnership: affiliated organisations**

Type of organisation	Percentage of centres reporting affiliation
Economic development organisation	97
University or four-year college	95
Community or vocational college	66
Industry association	59
Small Business Development Center	59
Other non-profit business assistance organisation	57
Consulting company	48
Federal laboratory	38
Other government agency	38
Other extension service (co-operative, industrial)	31
Large company	31
Electric power or other utility	31
Training organisation	29
Other for-profit organisation	26
Vendor (of equipment or software)	10

Source: Analysis of Manufacturing Extension Partnership centre reports to the National Institute of Standards and Technology, June 1997. Based on reports from 68 centres. Results for ten centres have been excluded because they are reported as a state aggregate.

These organisational partnerships take a variety of forms. Many MEP centres have arrangements where other service providers act as programme affiliates to perform particular operating functions, such as marketing to prospective customers, or provide specialised services, for example in helping manufacturers with environmental compliance. MEP centres have also established collaborative initiatives with industry associations, large manufacturers, technology centres and other groups through which information, training, networking, technology diffusion or other special projects are targeted to SMEs in a particular locality, industry or supply chain.

Perhaps most frequently, MEP centres use other service providers on a subcontract or referral basis. About one-quarter of MEP's technical assistance projects involve outside service providers.[6] In such cases, centre staff typically conduct an assessment of a customer's needs, propose a project and then recommend qualified outside service providers or consultants to assist in implementation. Centres tend to use other service providers in fields both outside and within traditional MEP core competencies. Human resource projects, where most MEP centres do not have indepth expertise, are most likely to involve outside service providers. However, the second most common area for third-party projects – process improvement – is a central MEP core competency. Here, the involvement of outside partners to provide services presumably leverages the number of projects within their field of expertise that centre staff can manage. Other common areas for third-party projects include business systems and management, market development and quality.

Although organisational partnerships between MEP centres and other organisations are often informal, the trend is increasingly for these relationships to be structured in writing, through memoranda of understanding, performance agreements or binding contracts. Formal agreements are universal where money changes hands. But there is no single system-wide model; each centre has considerable flexibility within allowable legal, auditing and sponsor criteria. MEP centres may entirely underwrite the cost of activities or specialised services by partners, although this mode of partnership is becoming less prevalent as the centres face greater pressure to generate fee revenues. In other cases, MEP centres and partners share costs (at times with in-kind as well as cash contributions) or collectively obtain resources for a special project from NIST, the state or another funding source. With the aim of generating revenues, some centres seek management fees from outside service providers who implement referred projects with MEP customers. In other instances, vendors, corporations or large private consultants may donate cash, equipment, in-kind or *pro-bono* services in liaison with MEP centres.

III. THE FEDERAL ROLE IN INCREASED SERVICE CO-ORDINATION

The Technology Reinvestment Project (TRP), which provided the major boost for the growth of the MEP between 1993 and 1995, guided applicants to form partnerships of service providers. There was an explicit requirement that proposals for funding address a criterion entitled, ‘‘Co-ordination and Elimination of Duplication’’. This criterion required the proposer to understand and link with related service providers in the service region, to be consistent with existing state strategies and not to duplicate existing resources or services. Proposers’ partnerships were judged in terms of the number, diversity and skills of constituent service providers, geographic scope and coverage, cohesiveness, organisation and management structure (National Institute of Standards and Technology, 1994).

It is reasonable to ask what impact these guidelines have had on the partnership and service co-ordination arrangements now evident among industrial modernisation service providers in the United States. Would these partnership arrangements have come about without specific federal attention to this issue through the TRP and the MEP?

Drawing on the six detailed case studies of MEP centres, there were instances where states had sought to promote service co-ordination alongside (and occasionally prior to) federal efforts; however, mostly there was ‘‘benign neglect’’ of issues of service co-ordination at the state level. It appeared that state governments did not consistently require public providers of manufacturing assistance to co-ordinate their efforts. In those states where entirely new centres were developed under stimulus of the TRP and MEP, separate organisations were prompted to form partnerships in direct response to the federal programme design. Generally, the organisational and service co-ordination relationships embodied in these partnerships had not existed prior to the federal programme. On the other hand, the older case study centres in the study – those that were operating before the TRP programme – had developed, mostly at their own initiative, a range of informal (and in some instances, formal) alliances and linkages. But, even for these long-established programmes, it took the stimulation of additional federal TRP and MEP funding for serious attention to be paid to co-ordination (Coburn, 1994; National Institute of Standards and Technology, 1994).

Although state and local policy makers may be more disposed to encourage service partnerships today than perhaps just a few years ago, there was no substantial evidence that co-ordinated service provision would be self-sustaining in the absence of a major federal role. At the state level, maintaining an individual programme’s distinctive ‘‘turf’’ is an important and time-honoured aspect of budgetary politics. Programme managers traditionally perceive greater returns from cultivating their own particular political and business constituencies than from subsuming their activities in a greater whole. (Such programme behaviour is rational as long as elected officials continue to fund multiple business and economic development programmes each with specific functions and line-item budgets located in separate institutions.) In this context, co-ordinated service provision appears as an ''externality'' which benefits customers and regional economies more than individual programmes. Even those programmes that have pursued business-like models and tried to ''self-generate'' funds through managing external service providers do not, in the end, generate substantial revenues relative to the costs involved. In short, service co-ordination requires specific attention and resources by sponsors to become established. Some states do, of course, go further than others in encouraging co-ordination among different business service providers. But, from the point of view of establishing service co-ordination and partnership on a nation-wide scale, such efforts are most likely to be encouraged by ongoing attention to this element by federal programme sponsors.

IV. IMPROVEMENTS IN SERVICE PROVISION: BENEFITS, COSTS AND LEARNING

Without doubt, federal policy and funding has stimulated an extensive, and almost unprecedented, array of linkages and partnerships between different service providers within the manufacturing extension system in the United States. Many advantages are claimed from this effort to promote partnership and service co-ordination. As has been seen, it is suggested that these include reduced duplication, access to special skills, greater flexibility and the leveraging of scarce public (and private) dollars. Moreover, from the perspective of small and medium-sized customer firms, it is preferable to deal with one organisation that can seamlessly and objectively offer a range of needed business services from public and private sources (as opposed to numerous single-function government programmes or private vendors promoting only their own products).

To what extent are these professed benefits to service providers, firms and the overall quality and efficiency of publicly sponsored industrial modernisation initiatives actually realised? Our case studies and interviews confirm that co-ordinating networks of local industrial service providers gives real net benefits to service quality and delivery. Enhanced service co-ordination has made available a wider range of expertise to firms and, in many instances, a more systematic approach to providing assistance. Involving other partners has allowed MEP centres to maintain flexibility and particularly helped the newly established centres to ''ramp up'' their services fairly quickly by ''leveraging'' existing resources. MEP centres have been able to draw upon other well-established organisations, such as economic development organisations, to conduct marketing and outreach campaigns. Facilities at community colleges have been used for business training programmes and for demonstrating new technologies. Experts at universities and federal labs have been involved in helping firms to resolve specific technical problems. New working relationships have been forged with private consultants through which MEP centres have been able to broker a range of business-oriented services to SMEs. Centres have also used partnerships to develop new service offerings. In affiliation with third-party organisations, MEP centres have won grants to develop new tools, training and group service programmes and to extend services in critical fields, including environmentally conscious manufacturing and human resources.

In these and other ways, the emphasis on partnership has improved the scale, scope, quality and efficiency of the services delivered to SMEs through the MEP system. Yet, paradoxically, while the differential characteristics of programme partners added new capabilities to the system, efforts to promote tighter service co-ordination also revealed partner limitations. These affected how various partners performed in delivering extension services to manufacturers. For example, economic development organisations offered general referral services but typically could not provide technological or longer-term project assistance to firms. Work with federal laboratories and university researchers involved particular technical capabilities in narrow fields, but had the potential to be hampered by asynchronous time horizons and administrative barriers within these large institutions.

Small-business development centres provided needed business planning capabilities, but their lack of a manufacturing background sometimes posed problems in face-to-face dealings with manufacturers (see also the evaluation of MEP-SBDC partnerships in Yin *et al.*, 1998). Private-sector consultants had an orientation towards manufacturing needs, but their expense rates and operational styles were often geared to large-manufacturer budgets. The involvement of community colleges promised additional institutional resources for local manufacturing extension partnerships, but these sometimes proved ephemeral as college administrators (under continual funding pressure) focused on their own priorities, rather than on the MEP's.

Moreover, although MEP centres have formed partnerships and, in so doing, have leveraged resources, it is also apparent that this process has both direct (*i.e.* MEP) and indirect (*i.e.* non-MEP) costs. For example, MEP programmes actively engaged in service co-ordination incurred significant transaction costs, including the expense of identifying and qualifying outside providers, information exchange, contracting, consulting and monitoring. Also, in most instances, the other programme resources "leveraged" by MEP centres were not "free" in that they had to be paid for by other public or private sources. Additionally, the inter-organisational tensions associated with partnership promotion efforts has required the expenditure of ‘‘political’’ capital, for example in resolving concerns about clients being ‘‘stolen’’ or about one programme working in another’s territory.

The story about service co-ordination and partnership is thus somewhat more complex than often assumed. Complications and extra costs are involved. But it should be emphasized there are real benefits and, at every centre examined, these benefits significantly exceeded the costs. MEP partnerships have allowed specialised skills and capabilities to be engaged to better meet customer needs, the system is more flexible and responsive because it relies on a distributed network of resources rather than building up in-house staff capabilities in all fields, and reduces service overlaps. Overall, it can be said that the partnership promotion effort has led to improvements from the perspective of the efficiency and quality of services delivered for the total resources invested. But, and it is more than a footnote, the investments of money, management time and human energy that are required to build effective partnerships in complex industrial, institutional and political environments should not be overlooked.

Furthermore, it is also evident that service partnerships go through successive stages, during which not only is there change in the balance of benefits and costs but also much learning about how the partnerships can be most effectively structured and managed to accommodate developments in customer needs, technology and policy. MEP partnerships were first formed under conditions of increased federal and matching funds, with guidance to demonstrate a high level of co-ordination and service partnership. Under these conditions, MEP centres entered into a wide-ranging set of service partnerships, as the analysis of MEP-affiliated organisations illustrated. However, as MEP centres subsequently operationalised their partnerships, they have come to better understand the strengths and weaknesses of particular affiliates. This has led to changes in arrangements. In many cases, relationships have been scaled down or ended. In other situations, links have continued but important adjustments have been made. To take one example, to address the high cost of some private consultants, one centre has negotiated reduced rate structures which take into account the fact that the centre bears the marketing costs and that centre referrals often generate opportunities for follow-on work.

As they have gained more experience with partners and partnerships, many MEP centres are now undertaking a substantial restructuring of their service co-ordination arrangements. The outcome has been to focus on tighter links with a smaller set of the most capable partners, with the ability to adjust partner arrangements as customer business and technological needs change. Links with more marginal partners are being reduced, usually – although not always – in an amicable manner that maintains communication and allows collaboration on an as-needed basis. This trend has been accelerated by the reduction in the federal contribution to MEP centre costs – from about one-half of each centre's budget in the programme's early years to a planned steady-state level of one-third. As federal resources become tighter, centres have to reduce their own costs as well as generate additional revenues from customers and other sponsors. Partnerships with other service providers continue to be important. But centres have recognised that they must more exactly specify what each service provider is expected to contribute to the partnership, how partnership performance will be monitored, and under what conditions partnerships will be renewed or, if necessary, terminated.

Best practices in service co-ordination

In the final aspect of this study, the insights and experiences gleaned through field interviews with centres, service partners and customers are used to identify a set of best practices in service co-ordination. The MEP system is maturing from an initial stage of rapid start-up, through which service partnerships helped to quickly establish a nation-wide system, to one of programme optimisation, where service partnerships will be judged by how they contribute to system performance and impact. The practices outlined in this section aim to offer guidance to MEP centres as they consider the management of their service relationships and how these relationships can best contribute to centres' overall effectiveness.

Differences in local industrial and geographic circumstances, institutional histories and capabilities, funding arrangements and modernisation strategies affect particular details of how these practices have been, and can be, applied. Nonetheless, these practices could have broad applicability across a variety of organisational conditions (including at least some applicability to partnership arrangements in programmes other than the MEP). These practices are as follows (see also Table 2):

– *Shared system-wide partnership vision*. Partnerships are a means to an end rather than an end in themselves. Partnerships are thus best constructed in the context of a clear definition of strategic goals; within this, centres should select partners and arrangements that contribute to and, at least in broad terms, share the programme's vision of its aims and mission. Different programme visions may lead to different partnership co-ordination styles. In some cases, partnership arrangements involve other organisations in core programme management and delivery roles. In other situations, partnership arrangements can be structured to fill relatively narrow roles, such as providing key services or access to certain segments of new customers.

Table 2. **Summary of best practices in industrial modernisation service co-ordination**

Practice	Description	Observations	Examples
System-wide partnership vision	Partnerships fit into the goals and vision of the programme. Partners may take on central management functions or play specific roles in providing service or access to new customer segments.	Because programmes have different strategies and local conditions, their partnership arrangements are likely to differ.	The Chicago MTC has multi-organisational team management. Georgia has a lead organisation using partners to provide specific services.
Structured flexibility	Strategic and operating plans recognise phases of change in partnership arrangements.	In practice, external changes (*e.g.* customer needs, budgetary or political factors) often drive modifications in partner relationships.	Oklahoma and Chicago both used NIST planning grants to evolve their multi-organisational programmes.
Joint marketing efforts	Collaborative activities for increasing outreach to customers, involving marketing materials, jointly sponsored seminars and workshops, and co-locations.	The cost of outreach to new types of potential customers or those in a broader geographic area is shared. In practice, the partner that gets the first call may keep the project.	Southwest Pennsylvania has a uniform brochure which all partner organisations use.
Collaborative service delivery	For assessments and projects, teams involve staff from more than one organisation.	May be more objective, leading to new observations and recommendations, but can cause delays.	Chicago uses multi-organisational teams to deliver assessments.
Co-ordinated, programme-wide system for making referrals	Programme-wide mechanisms for accessing common information about external service providers for making referrals.	Provides consistency in quality of referrals throughout the programme and lowers the cost of finding referrals; quality control a possible problem for referrals.	Minnesota has a system-wide shared database of external service providers and bulletin for posting project proposal requests.
Development and sharing of tools	Collaborative development of assessment tools, customer tracking systems, or benchmarking methods for use by multiple service providers or centres.	Promotes cohesion, standardizes methods, shares development costs and can promote objectivity. Staff training is required. Can be hard to develop tools to address multiple requirements.	Cleveland has participated with several other MEP centres in the development of assessment tools and an electronic reporting system.

Table 2. **Summary of best practices in industrial modernisation service co-ordination** *(cont.)*

Practice	Description	Observations	Examples
Partner communication and information sharing	Regular communication among organisations can occur through periodic meetings, electronic systems and informal mechanisms. The institutionalisation of personal relationships is particularly important.	Implementing shared electronic information systems can be difficult and expensive. Personal links may be weakened as staff turnover occurs.	Southwest Pennsylvania has an electronic information system used by more than 15 partner organisations.
Cross-training	Shared or cross-cutting training of staff to learn skills and capabilities from one another as well as improve inter-organisational understanding.	Some centres provide little training for in-house staff or partners.	Georgia's partners have held training sessions in financial analysis, working with the federal laboratories, and other areas.
Designated responsibilities and mechanisms to promote partnership	Specific functions for promoting and monitoring partnerships are designated with lead organisation.	Prevents service co-ordination from taking a lower priority to daily operational issues; facilitates paperwork.	Oklahoma's Regional Coordination Councils organise existing resources to help broker/agents effectively identify service providers. Georgia's Technology Linkages Office facilitates relationships with federal laboratory and university departments.
Partnership performance review	Systematic evaluation of partnerships against contractual goals or manufacturing needs.	Helps to assess partnership performance, changes in partner capabilities and requirements.	Chicago and Pennsylvania have modified contractual relationships with partners after review.

– *Structured flexibility.* Partnerships need to combine ''structure'' – which is crucial to defining relationships and effective operating frameworks – with ''flexibility'' to evolve those relationships over time to meet changing conditions and reflect learning about capabilities and limitations. Linkages between MEP centres and other service providers change as centres increase, reduce or modify their relationships in response to new conditions or judgements about partner performance. Contractual instruments should reflect this, specifying not only objectives but also the way in which performance can be tracked and relationships modified or terminated. Yet, even though partnerships inevitably grow and change over time, external events or short-term factors alone should not dictate this process. The most effective relationships take time and resources to develop. Mutual trust and a realistic appreciation of strengths, weaknesses and opportunities have to be established. Methods have to be devised to open up critical resources even if contained in institutions with known problems. Best practice thus involves the conscious consideration and anticipation of how partner capabilities and links can evolve. Strategies, plans and organisational mechanisms should address partnership development over time.

– *Joint marketing*. Co-ordinated marketing practices include uniform marketing materials, jointly sponsored seminars and workshops, and co-located offices. The co-ordination of such outreach mechanisms is an efficient use of resources, particularly given the high cost of marketing to large numbers of dispersed SMEs. It can also make it easier for SMEs to understand what services are available and present a more consistent customer image. The ability of the partners to agree on and adopt uniform marketing materials is a reflection of a shared system-wide partnership vision. Joint seminars leverage resources among organisations to cover the costs of reaching many manufacturing customers with a single group event. Co-locations share the cost of placing centre staff throughout the state or region, make it easier for SMEs to access several services in one location, and facilitate subsequent project collaboration and cross-organisation referrals.
– *Co-ordinated referral procedures*. After an initial assessment, MEP customers are frequently referred to other service providers for specific project assistance. To ensure quality, centres and their partnered service providers need to develop effective procedures for qualifying customer needs and making appropriate referrals to one another and to other outside service providers. This requires an awareness of what specific services other providers and consultants offer, as well as systems to track and manage referrals and to monitor actual performance on a project-by-project basis.
– *Collaborative service delivery*. Partnered organisations should take advantage of opportunities to collaborate in service delivery to SMEs. This goes beyond referrals, to the development of projects and services that are jointly designed and offered by multi-organisational teams. Examples include structured assessments, where staff with different skills from more than one organisation work together in diagnosing company needs, offer recommendations and implement projects. Inter-organisational team assessments and projects can offer a wider array of expertise to industrial

customers, although they can be time-consuming and relatively costly to implement.

- *Development and sharing of common tools*. Federal funding has encouraged several MEP centres to collaborate with one another and with service partners to develop common tools, such as assessment protocols, benchmarking instruments or database systems. The sharing of tools saves development costs, allows smaller service providers access to tools they would not otherwise have, and can lead to more consistent operating methods.
- *Partner communication and information sharing.* Regular communication and information sharing among partners is an essential practice. Many methods are available, ranging from regular partnership meetings and newsletters to system-wide electronic information systems. Most important is the establishment of strong personal working relationships among individuals in different organisations who perform similar or complementary tasks.
- *Cross-training.* This allows organisations to learn skills and capabilities from one another. It also can impart the lead centre's approach and processes for delivering services across a partnership so that manufacturers receive consistent services regardless of the organisation managing the project. Cross-training may involve running internal seminars and workshops to promote awareness of different partner capabilities and skills. Training may also be provided in a particular set of skills, technologies or procedures to promote consistent levels of quality and delivery by staff from multiple organisations.
- *Designated responsibilities and mechanisms to promote the partnership*. For all partnerships, but especially those that involve multiple or large organisations, it is best practice to designate responsibilities and establish specific mechanisms to promote the partnership. At an administrative level, effective methods have to be found to contract with partners and to manage funds, with an eye to minimising paperwork, contracting delays and other barriers as well as tracking partner performance. At a strategic level, responsibilities for partnership promotion need to be designated, so that opportunities for linking customer needs with special skills or facilities in other organisations are systematically exploited.
- *Partnership performance review*. For service partnerships to be structured towards meeting overall strategic goals and specific performance objectives, methods need to be instituted for partnership assessment. Reviews of partnerships need to occur at the level of individual service providers, which may then lead to specific changes in individual service relationships and contracts. In addition, it is an essential best practice for centres (and programme sponsors) to conduct regular comprehensive reviews across

the complete portfolio of service relationships, to consider if strategic changes are necessary in the management, orientation and composition of partners.

There is much tacit knowledge about the effective operation and management of service partnerships that individual programmes typically learn the hard way – through their own experience, by making mistakes as well as producing successes. Statements of best practice try to make this tacit knowledge more explicit, but brief written statements cannot easily communicate all aspects, even if backed up by weighty reports. For this reason, it would be valuable for NIST, as an essential MEP system-wide function, to promote the exchange of information and experience on managing service partnerships. The methods to achieve this would include forums, training events and the exchange of personnel. Such exchanges would be complemented by the ongoing benchmarking and assessment of MEP partnerships and by the development and dissemination of case studies where firms have been assisted through co-ordinated services (for several examples of successful engagements involving co-ordinated services, see Cosmos, 1996). Continued attention to issues of service co-ordination in guidance to programme managers, NIST external programme reviews and evaluations, and re-funding decisions is also recommended.

V. CONCLUSIONS

Our study of organisational and service delivery arrangements in MEP centres and their affiliates highlighted the critical role played by the federal government in stimulating a greater degree of service co-ordination and inter-organisational partnership at the state and local level. The MEP case studies found real benefits associated with service co-ordination. These included avoiding the duplication of services, tapping specialised skills, spreading development costs of new tools, broader marketing to new industrial customers, improving access to particular industries and areas, flexibility in staffing and the delivery of services, improving service quality, enhancing visibility in the locality, and strengthening state and local support.

At the same time, while service co-ordination had significant advantages, attention was drawn to the fact that there are costs and potential tensions. These drawbacks include increased transaction costs (including the expense of identifying service providers, information sharing, contract management and monitoring projects), difficulties in maintaining quality across partner organisations, delays in timely service delivery and inter-organisational tensions through unresolved conflicts over client and service territories. The dispersion of technical expertise and learning from the central organisation to affiliated partners may also be an issue.

With increased attention being paid to promoting the co-ordination of services in industrial modernisation and other areas of technology transfer, there should be a careful assessment of the benefits and costs of co-ordination. In the MEP examples, new partnership arrangements have resulted in significant advantages, but this should not lead policy makers and programme managers to overlook the reality that there are expenses and tensions associated with greater service co-ordination. Investments of resources, time, people, technology and political capital are needed to make service partnerships work well.

The series of best practices identified in this study can help MEP centres, and probably also other organisations involved in collaboratively delivered programmes, to gauge their performance in co-ordinating services. Applied appropriately, these practices may also help programmes to increase the effectiveness of their service co-ordination, reducing associated drawbacks and optimising the quantity, quality, flexibility and comprehensiveness of services delivered for total resources expended across multiple organisations in a locality. Moreover, such practices – when combined in ways appropriate to local conditions and coupled with a complementary funding, professional staffing and policy environment – are likely to result in what is most important to industrial customers: ensuring that industrial modernisation services and other technology and business assistance services delivered through multi-organisational arrangements are effective, consistent and strategic.

NOTES

1. Small and medium-sized manufacturing enterprises (SMEs) are generally defined as those with 500 or fewer employees. There are about 415 000 SMEs in the United States, representing 99 per cent of all manufacturing enterprises and almost two-fifths of manufacturing jobs. Evidence about the technology and business challenges facing SMEs can be found in several recent studies, for example: Office of Technology Assessment, 1990; National Research Council, 1993; and Kane, 1998.
2. The first phase of this study examined the extent of partnered service co-ordination in the MEP and service co-ordination impacts and best practices (for the full report, see Shapira and Youtie, with Kingsley and Cummings, 1996). The second phase, to be completed in mid-1998, focuses on how MEP service partnerships evolve over time. The research is supported by the US Department of Commerce, National Institute of Standards and Technology. The views expressed in this article and in project reports are the authors' and do not necessarily reflect those of the research sponsor. Further information, including electronic copies of project reports and associated publications, can be located through the World Wide Web site of the Georgia Tech Policy Project on Industrial Modernisation at <http://www.cherry.gatech.edu/mod>.
3. Details of these case studies are not reported here, but can be found in the first-phase report (see Shapira and Youtie, with Kingsley and Cummings, 1996).
4. Analysis of MEP center reports to NIST, June 1997, with removal of duplicative information. There are variations in how different centers define and report their affiliates. Some centers do not report information about organisations that staff used informally to provide assistance to manufacturers. In addition, data from seven mostly newer MEP centers is not included in this analysis.
5. In mid-1997, the average MEP center reported 38 organisational affiliates, compared to 19 such relationships at the end of 1995. One center reported 280 relationships and an additional five centers reported more than 100 relationships. At the other end of the spectrum, four centers reported only one or two organisational affiliates. To account for this variation, we note that the median number of organisational affiliates in mid-1997 was 26.
6. Analysis of 8 443 technical assistance projects of eight hours or more with companies completed by 59 MEP centers in 1996 shows that outside service providers were involved in 24 per cent of projects.

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PUBLIC/PRIVATE PARTNERSHIPS FOR DEVELOPING ENVIRONMENTAL TECHNOLOGY

TABLE OF CONTENTS

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I. INTRODUCTION

Inducing appropriate innovations in environmental technology, especially cleaner products and cleaner production processes, is a growing concern of technology policy in the OECD area. With the exception of the energy area, technology and environmental policies were for a long time inadequately integrated, partly since technology was not regarded as a tool with the potential for solving environmental problems. In fact, technology has sometimes been viewed as the villain generating noxious pollution, ecological disasters and deadly health hazards. For this reason, solutions for improving the environment and contributing to sustainable development goals were not sought in technological innovations.

This perception, however, has changed, as a range of techniques – largely end-of-pipe technologies such as desulphurisation equipment and catalytic converters – have significantly contributed to pollution abatement. Advances in energy conversion and end-use technologies have also made positive contributions to environmental amelioration. Technology is increasingly regarded as the source of solutions to many environmental problems, particularly as the nature of environment technology has shifted away from end-of-pipe solutions to cleaner processes and products. These developments have given rise to a growing industrial sub-sector producing environmental goods and services (OECD, 1996). Some recent studies present evidence of the positive impact of environmental technologies on competitiveness and productivity (Repetto *et al.,* 1996; Porter and van der Linde, 199*5).* Technology foresight exercises in OECD countries list environmental technology as a critical area for the next century (OECD, 1998*a*).

Environmental protection is normally considered as an externality, *i.e.* existing outside the economic system; therefore, it is an area typically prone to *market failure*. In many cases, public benefit can be gained only at considerable cost to the industrial sector, resulting in insufficient investments and inadequate technological innovation. This underlines the importance of the role of public policy in stressing environmental protection and in implementing policy measures to induce adequate and appropriate technological innovation geared towards solving environmental problems.

Environmental regulations have constituted the most important tool of public policy in stimulating industrial innovations in environmental technology. In the past, the imperative to comply with regulations forced the industrial sector to develop and adopt various pollution control technologies and equipment. Through a few decades of experience in environmental regulation, it has become clear that the kind of regulatory measures adopted by the government influence the type and extent of innovative efforts by the industrial sector (OECD, 1997*a*). Designing regulatory measures that maximise innovative efforts to generate suitable environmental technologies is of fundamental importance. In this context, recent experience in OECD countries indicates that innovations in environmental technologies are best stimulated when various regulatory measures and economic (market) instruments are flexibly combined in a manner that takes into account the industry-specific and, in some cases, firm-specific context. Well-designed technology policy can play a key role here to combine and direct various mechanisms to induce cost-effective cleaner process and product innovations. Also, on a sectoral basis, long-term strategies for ‘‘sustainability’’ and co-operative efforts, including public/private partnerships in research and development, are considered important tools in stimulating environmental innovation.

The science-based nature, as well as the interdisciplinary, intersectoral nature of environmental technology, implies that this is a domain prone also to *systemic failure*. In order to optimise environmental innovation, there is a need to integrate insights from advances in various basic and applied sciences and engineering disciplines. Interaction between research in domains related to the environment ranging from basic sciences to more interdisciplinary fields such as ecology, climatology and toxicology, as well as technical areas such as environment monitoring and engineering, will be needed to generate breakthroughs as well as to progress incrementally. However, the breadth and depth of required interaction is at present inadequate in most OECD research communities. This highlights the government’s role in enhancing co-operation among the necessary actors and linking the university, industry and government research sectors to address important environmental problems.

This article is a survey of public/private partnerships in developing environmental technologies in some OECD countries, including some sectoral technology partnerships which have environmental objectives. It is by no means comprehensive. A selection of country programmes were examined and compared for the purpose of gaining insight as to how they evolved, their characteristics, and for assessing whether public/private partnership is in fact a useful tool for developing environmental technologies.

II. COMPARISON OF PROGRAMMES

Rationale

The aspects of developing environmental technologies discussed above point to the importance of the public role in stimulating suitable research and innovative activities. Public budget allocations for research and development in the environmental area have been small, increasing from 1-2 per cent of total government research investments in the 1980s to about 3 per cent at present. Total government expenditures on environmental R&D in the OECD area are estimated as US$2.5 billion per year. Moreover, most such research in government laboratories or universities has been directed to fundamental science and ecological concerns and relatively little to technology. On the other hand, it should be noted that publicly funded R&D devoted to some other sectors includes R&D for environmental objectives. For example, it may be estimated that a significant part of publicly funded energy R&D, with an annual budget allocation totalling about US$10 billion[1] for the OECD area, is in fact directed to developing cleaner and more efficient energy conversion and end-use technologies. However, few statistics exist on R&D spending on energy technologies with environmental objectives. Governments have turned to industry for technological innovation related to the environment and relied on other mechanisms, particularly regulatory regimes, to stimulate such technological development by the private sector.

More attention is now being given to using public funds to leverage private spending on research and development, particularly through partnership schemes. Public/private partnerships, or joint government/industry efforts in funding and/or executing research and development, are one useful mechanism for addressing both market and systemic failures in science and technology (OECD, 1997*b*). They can address industrial underinvestment in environmental technologies by lowering the cost burden of research investments and providing the incentive to undertake long-term R&D projects to develop cleaner processes and products. In this way, they can direct industry's innovative efforts towards fields and technologies deemed most promising for sustainable development and other social policy objectives, such as energy security and health. Partnerships can also address systemic failures by bringing together different research sectors (government laboratories, enterprises and universities) and different scientific and engineering disciplines, thus strengthening the necessary linkages in fostering innovation for sustainable development.

The public/private partnership programmes in developing environmental technologies in the selection of OECD countries examined in this article were shaped out of the different historical paths along which government technology programmes evolved. In Japan, government technology programmes have always had the objective of increasing the competitiveness of Japanese industry, and industry-government co-operation in technology development has a fairly long history. To increase competitiveness, collaboration between government research institutes, universities and enterprises was regarded as vital, and the technology programmes of the Ministry of International Trade and Industry (MITI) were designed to enhance links between these actors in research and development. In this sense, without explicitly being such, most MITI technology programmes have been, in effect, government-funded partnership programmes.

Over the last few decades, MITI has sponsored projects that pioneered industrial technology essential for developing the national economy and which required substantial funds, long lead times and high risk, and were therefore difficult for the private sector to undertake alone. For example, the Very Large Scale Integrated Circuit project is considered to have played a role in fostering the Japanese semiconductor industry.

Research and development projects on environmental (and energy) technologies have accounted for a growing share of MITI technology programmes. Some of the first projects under the Large Scale Projects Programme initiated in 1966 were the flue-gas and the heavy oil desulphurisation projects, which played a role in enabling the Japanese industrial sector to control SO_x emissions, while at the same time fostering the sub-sector of the machinery industry engaged in the production of pollution control equipment (Fukasaku, 1992). Energy technologies became a main focus in the 1970s, with the launching of the renewable energy technology development programme, the Sunshine Programme, in 1974 and the energy conservation technology programme, the Moonlight Programme, in 1978. The main rationale behind these programmes was to develop alternative energy technologies in the wake of the petroleum crisis for the purpose of energy security with environmental objectives being only secondary; however, since then, the latter objective has grown in importance. The programmes involved a wide range of technologies, including cleaner coal technologies. In 1990, the Global Environment Industrial Technology Research and Development Programme was launched. In 1993, these three programmes, as well as elements from other programmes, such as the new chemical processing project and diesel and learn burn engine NO_x catalyst development project, were merged to form the New Sunshine Programme, in which environmental technologies, especially those related to protection of the global environment, such as CO_2 fixation technologies, constitute a major part.

In the United States, the concept and the term ‘‘partnership’’ reflects the reorientation of publicly supported research and development over the last two decades. Initially after the Second World War, it was assumed that US government research to fulfil government agency missions such as defence and space, would automatically, and in fact did, ‘‘spin off’’ to the industrial sector to enhance its technological development. This paradigm worked well while America enjoyed undisputed leadership in science and technology. However, in the 1970s and 1980s, the increasing industrial competitiveness of other advanced countries started to erode US technological supremacy, causing economic decline and job losses. By then, the new technologies created by the spin-off process and which underpinned American technological superiority, *e.g.* computers, software, semiconductors, advanced materials and manufacturing technologies, were increasingly driven not by military but by commercial demand and the spin-off process no longer functioned effectively (Brody, 1996).

Under these circumstances, a new paradigm emerged, in which the government is a partner with the private sector in developing technologies for the objective of enhancing the competitiveness of American industries and creating jobs. The US government started to launch partnership programmes in the 1980s which were designed directly to enhance US competitiveness, *e.g.* the Advanced Technology Program and the Manufacturing Extension Partnership. In energy technology, partnership programmes such as the Clean Coal Technology Program operated by the Department of Energy since 1986 have brought innovative power generation technologies based on coal and natural gas such as fluidised bed combustion, gasification-combined cycle and fuel cells closer to commercialisation. These new programmes all sought to correct underinvestment by the private sector in technological development. More recently, the US government has extended such partnerships to the environmental area.

Similarly, the European Union started research and development partnership programmes in the mid-1980s under the Framework Programmes, with the Fifth Framework Programme (1998-2002) now being initiated. In addition to promoting scientific advance and industrial competitiveness in areas such as the environment, partnership programmes in Europe have largely been aimed at enhancing European integration by involving enterprises and research bodies from different countries in joint projects. Sectoral programmes such as the Thermie Programme have sponsored energy technology demonstration projects on a shared cost basis (with a maximum Community support of 40 per cent) since the 1970s. In the current phase, the Programme seeks to improve energy efficiency in both demand and supply, to promote the utilisation of renewable energy and to encourage cleaner use of coal and other solid fuels, and funds projects in these sectors. Through these projects, the Programme also aims to contribute to other EU objectives which include reinforcing the competitiveness of the EU industry (especially SMEs) with benefits for the economy, and promoting employment and export potential.

If there is diversity in the historical evolution of public/private partnerships, a certain convergence seems to be emerging as OECD governments take the initiative in launching partnership programmes to develop environmental technologies. Many governments are starting to view environmental technologies as able to contribute not only to the achievement of social goals, but also to the enhancement of industrial competitiveness and job creation; hence the integration of these policy objectives. Therefore, policy thinking is evolving, based on a growing awareness of the importance of environmental technology for sustainable growth. Governments now believe that technology can and should, wherever possible, provide solutions to environmental problems, and that this can be done while enhancing industrial competitiveness and creating jobs. Thus, the rationale for government programmes for developing environmental technologies in partnership with industry derives from a mixture of economic and environmental motives and a recognition of the need to address both market and systemic failures in the innovation area.

Structure

There are broadly two types of public/private partnerships in the environmental area. Environmental technologies can constitute a part of existing research partnership programmes or can be created as special schemes directed to environmental concerns. Thus, one category includes public/private research partnership programmes for promoting technological innovation in general or with a broader scope than environmental technologies alone. Examples include Technology Partnerships Canada, where environmental technologies constitute one of the three areas, along with enabling technologies and defence and space technologies, promoted by the programme. Similarly, the LINK programme in the United Kingdom is directed to promoting partnerships in several technology fields, of which environment is only one, while the European Union's Framework Programmes cover a wide range of science and technology areas. In Sweden, the Competence Centre Programme has created joint industry/university research centres to develop a number of new technologies, including some directed to environmental innovation. The integration of environmental technology into broader government schemes shows the heightened attention being given to environment-related innovation and can also bring environmental research more stability and funding over the long term; however, environmental technology schemes still constitute a very small part of these larger programmes.

In the second category are those partnership programmes which are devoted exclusively to environmental/energy research topics. Examples include Japan's New Sunshine Programme, the Finnish Research Programme of the Environment Cluster, Germany's Research for the Environment programme and the US Technology for Sustainable Environment scheme. These programmes are relatively new and their durability and continued funding will primarily depend on their results and impacts from an environmental and economic perspective. Also in this group are partnership schemes directed to the development of a specific environmental technology, such as the US Department of Commerce 's Partnership for a New Generation of Vehicles (PNGV). The fact that there are specialised environment/energy technology development schemes as well as environmental technology programmes in general technology development partnership schemes underlines the growing importance of environmental technology in government research agendas.

Most public/private partnerships to develop environmental technologies aim to push forward the state of the art in technical areas of potential relevance to both competitiveness and sustainable development. As opposed to more basic scientific investigation, they are usually concerned with the development of technology – products, processes and systems of potential commercial use. They are also usually focused on enabling technologies, or those whose underlying importance could spawn a host of spin-offs and have applicability beyond the competitive situation of individual firms. The types of technologies that the partnership programmes aim to develop thus range from pre-competitive, breakthrough technologies – as in the case of the MITI programmes – to those that target technologies closer to commercialisation, as in the case of Technology Partnerships Canada. In some programmes, such as the UK LINK programme, research and development priorities are directly related to the government's Technology Foresight exercise, which identifies important technical areas in need of further research.

The wide spectrum of technologies promoted through these programmes explains the variations in project duration which, depending on the type of programme, range from long-term projects continuing over five to ten years to short-term ones that last less than a year. The development of pre-competitive, breakthrough technologies naturally takes longer to produce results, whereas near-commercialisation research may need only a few months. Also, the funding for partnership programmes is sometimes dependent on independent evaluations and assessments which are becoming more widespread for all government-funded research and development.

Technology focus

In general, environmental technology partnership programmes have evidenced a similar broad shift in their research priorities. Many government programmes of a decade or two ago aimed to develop end-of-pipe technologies in order to assist industry compliance with environmental regulations. In recent years, the partnership programmes have focused on cleaner process and product technologies. For example, in Germany, the acknowledged cost-effectiveness of cleaner technology and the potential to enhance resource productivity have spurred this trend (BMBF, 1998). In the effort to focus on cleaner processes and products, some programmes, such as the US Technology for Sustainable Development, even explicitly exclude end-of-pipe technologies. Focus is also shifting away from specific local pollution control techniques to technologies that address energy efficiency and more diffuse environmental issues such as waste treatment and climate change.

Despite considerable variety in the focus of these partnerships, the ubiquity of certain technologies reflects the existence of international consensus on innovations which are, in the immediate future, crucial for enhancing industrial competitiveness and achieving social objectives. Thus, despite a range of subjects for research, a few technologies are found in several countries. One is the development of pre-competitive technologies associated with a radically more fuel-efficient car. These include the US Partnership for a New Generation of Vehicles, the UK LINK Foresight Vehicle Programme, the clean car project of Technology Partnerships Canada, and Japan's New Sunshine Programme project on lean-burn engine technology. The US PNGV is a classical R&D partnership scheme and ''probably the best US example of an environmentally integrated technology programme'' (Oldenburg, 1998). It involves the joint efforts of the ''big three'' American car manufacturers and a number of federal government agencies and their affiliated research institutes as well as universities and supplier companies in funding and executing the research to develop a more fuel-efficient car.

Another common theme is the integration of the energy efficiency dimension into environmental partnership programmes. In Japan, energy efficiency has for some time been a key element of environmental technology development efforts and energy policies have addressed environmental goals through the promotion of energy conservation (Fukasaku, 1995). The rationale behind the merging of MITI energy and global environmental technology programmes in 1993 was the integration of energy and environmental dimensions in technology development. Similarly, the US Department of Energy launched programmes in the early 1990s, such as the Industries of the Future Initiative and National Industrial Competitiveness through Energy, Environment and Economics, to develop technologies that integrate energy efficiency and cleaner processes. The European Union's Framework Programmes are also moving towards better integration of environmental and energy research on enabling technologies. More recently, the pursuit of broader *eco-efficiency*, *i.e.* increasing the efficiency of both materials and energy as inputs and reducing wastes and emissions as outputs, is increasingly integrated, as in the Finnish Research Programme of the Environment Cluster.

Greener design, especially for products, is attracting special attention in programmes such as the US Design for the Environment and the Swedish Design for Environment in SMEs. The US project, sponsored by the Environmental Protection Agency, aims to help businesses incorporate environmental considerations into the design of products and processes through co-operative projects. The Swedish programme is based on the prediction that product development and design is becoming more important to achieving environmental goals, and that new technologies and approaches are needed to decrease or prevent product impact on the environment from a life cycle perspective.

Biotechnology is also the subject of several public/private partnerships in environmental technologies. The use of biotechnology or micro-organisms can contribute to soil remediation and improved water quality as well as to a reduction of energy and materials consumption and a diminution of emissions and wastes in manufacturing (OECD, 1994; 1998*b*). Canada's Technology Development and Demonstration Programme includes research projects on biological treatment methods for soil and sediment management. Germany's Research for Environment Programme is closely linked to other government programmes including the Biotechnology 2000 Programme, and the interlinkage is expected to lead to the development, for example, of higher-yielding plants which substantially reduce the application of chemical pesticides, or of lower cost (than chemical) and more environmentally acceptable biological water purification processes. In Japan, the environmental technology part of the New Sunshine Programme includes a project on fixation of carbon dioxide through biological techniques using bacteria and micro-algae, as well as a range of projects for developing a new generation of industrial processing and product technologies based on biotechnology, such as the development of bio-reactors and biodegradable plastics. The Research Institute of Innovative Technology for the Earth (RITE), which participates in many of the New Sunshine projects, focuses its research efforts on developing innovative industrial processes based on new biological or chemical processes which would contribute to the protection of the global environment.

Another frequently found theme is waste management and recycling, as in the case of the German Research for the Environment programme. Recycling, specifically the conversion of post-consumption and industry waste into building materials, is one of the targets of the environmental projects of Technology Partnerships Canada. Recycling of non-ferrous metals using liquid natural gas is under study in Japan's New Sunshine Programme, and recycling of ozone-depleting substances is being examined in Japan's RITE. In addition, MITI organises a range of waste management and recycling technology research programmes. Several projects are directed to developing closed-loop production processes, as in the case of the UK LINK Waste Minimisation through Recycling, Re-use and Recovery in Industry programme.

Funding

Although some classical programmes exist in which the government agency assumes the funding while the private partners undertake the research, public/private partnerships in environmental technology research are generally based on cost-sharing among the partners involved. The costs are shared by the public and private partners, and the R&D activities are undertaken by companies as well as universities and research institutes affiliated to government agencies. Part of the value of public/private partnerships is the leverage effect obtained from a small government investment. The focus, therefore, has been on broad-impact R&D, where a small amount of funding can have large payoffs for the economy and the environment, as well as on challenging industry to take on higher-risk projects.

Cost-sharing ratios differ from programme to programme or even from project to project within a programme, depending on the number and the kind of research actors involved and the stage of the research and development effort. In many schemes, industry provides 50 per cent or more of matching finance. In the case of Technology Partnerships Canada, which is perhaps aimed at innovations closest to the market, industry provides 70-75 per cent of finance with the remainder provided by government. The general trend is greater public funding for activities closer to the basic end of the research spectrum and increased private participation as the commercialisation stage nears. Cost-sharing by government and industry, although taking different forms, seems to encourage effective participation by the private sector in public/private partnerships. Public funds are normally given as grants, but in some cases, such as Technology Partnerships Canada, funds are provided as repayable investments. Here, the government and industry share the costs, risks and returns on investment. The government share of investment is repaid through royalties on successful projects, and these repayments are recycled back into the fund for future investments in research partnerships. In order to increase returns, some environmental technology R&D programmes include mechanisms for promoting the commercialisation of developed technologies as well as wider dissemination. Examples are the various Design for Environment schemes directed at environmentally sound product development. Technological spin-offs from research partnership programmes are one of the broad goals, so all schemes might give greater attention to means for more broadly disseminating the results of the R&D conducted.

In relation to this, mention should be made of programmes which more specifically aim to facilitate commercialisation and diffusion. The US Rapid Commercialisation Initiative aims exclusively to facilitate commercialisation of developed technologies through joint national, state and private sector efforts to lower barriers to commercialisation by providing assistance in finding appropriate sites for demonstrating/testing near-commercial environmental technologies, in verifying the performance and the cost of technologies and in facilitating and expediting the issuance of permits. Related to commercialisation are domestic diffusion and technical assistance programmes, which include the range of voluntary partnership programmes of the US Department of Energy and the Environmental Protection Agency and the Manufacturing Extension Partnership of the Department of Commerce. Many governments operate programmes to promote the commercialisation of environmental technologies beyond national borders through business-to-business initiatives such as the UK Technology Partnership Initiative, export promotion or the international transfer of environmental technologies such as the US-Asia Environmental Partnership programme of USAID. The International Centre for Environmental Technology Transfer in Japan undertakes R&D and diffusion of environmental technologies appropriate for use in developing countries through international R&D co-operation programmes.

Partners

The trend in environmental technology partnership programmes is towards involving more public and private research performers and enhancing collaboration among them. Networking between these actors for the purpose of promoting interdisciplinary research is one aim of partnership programmes. Personnel mobility and collaboration is enhanced through project teams that cut across institutional and public/private boundaries. Such mobility also provides opportunities for specialised training for researchers. Thus, a preference may be expressed for co-operative endeavours that cross sectoral, institutional and/or national boundaries. This stems from the desire to promote technical cross-fertilisation, ensure dissemination of results across a range of potential users and/or enhance regional integration, particularly in the case of European Union programmes.

Partnership programmes usually provide funding for research to single firms or to consortia of industrial enterprises. The general technical areas may be outlined in advance, with industrial consortia or firms submitting relevant project proposals. This is particularly the case for the larger partnership programmes aimed at several technical fields, of which environment is only one. Here, as for all projects, programme awards may be based on the technical excellence of the recipients and their proposals as well as their ability to contribute to the development of the innovation in question. Another general benefit of these schemes is that, even in the proposal stage, they tend to bring together disparate groups to pursue common technology development opportunities through the establishment of horizontal consortia, vertical producer-supplier relationships and linkages between large and small companies.

Except for the Swedish Design for Environment in SMEs, most programmes target firms of all sizes; however, there is involvement of smaller firms in most of the programmes examined and many include special provisions to attract SMEs. In the case of the UK LINK programme, out of the more than 1 300 companies presently involved, some 700 are SMEs, and the programme ‘‘actively encourages’’ the involvement of SMEs. Technology Partnerships Canada, being an investment programme, targets near-commercialisation environmental technologies, which are often developed by innovative smaller firms. An important characteristic of partnership programmes is that they can help SMEs realise their innovative potential by leveraging investments for developing environmental technologies.

Many programmes aim to involve not only government agencies and industrial firms but also universities and other research bodies. Academic institutions and other research groups tend to participate in co-operative relationships with firms. Some programmes – such as the US Environmental Technology programme and the German Research for Environment scheme – explicitly stress the promotion of interdisciplinary research to involve researchers and research approaches from a number of differing scientific and engineering disciplines and institutions. In cases such as the European Union 's Framework Programmes, environmental research has been carried out primarily by consortia of universities and research institutes, and there is now stress on involving more industrial enterprises.

Programmes also differ in the number and type of government agencies involved. Some programmes are run by only one government agency, such as the Japanese MITI programmes, while many others involve a number of government agencies, such as the US PNGV and the German Research for the Environment scheme. There seems to be a trend to involve more government agencies as well as research bodies and companies in funding and execution so as to promote networking and linkages in research endeavours. The recent trend is for increased involvement of universities. In some cases, regional or sub-national government bodies are also included, particularly when partnership programmes address regional environmental issues, as in the case of Environment Canada's Technology Development and Demonstration Programme.

III. CONCLUSION

Governments are increasingly entering into partnerships with industry to develop environmental technologies in the interest of both sustainable development and industrial competitiveness. Although the origins of national partnership programmes for developing environmental technology vary, the fact that they have increasingly been used in recent years indicates that partnerships are an effective tool for developing environmental technologies and, in view of the constraints on R&D budgets confronting most governments, they do provide a means of doing more with less. They correct for market failure by leveraging and complementing private investments in environmental objectives which otherwise suffer from underinvestment. This is demonstrated by the extensive involvement of SMEs in environmental technology partnership programmes. Partnerships are also an effective tool for facilitating interdisciplinary research, enhancing networking among various national and international research actors, and introducing personnel mobility on an *ad hoc* basis. This indicates that partnership schemes are also effective for correcting systemic failures. For the most part, the growing number of these programmes reflects a commonly shared perception that environmental technologies can play a key role not only in contributing to sustainable development but also in enhancing industrial competitiveness and creating jobs.

In recent years there has been a clear trend for convergence in the types of environmental technology that are promoted through public/private partnership schemes. In many government programmes, focus has shifted from end-of-pipe to cleaner technologies. Also, the energy efficiency or broader eco-efficiency dimension is increasingly integrated in environmental technology development programmes. The fact that pre-competitive clean car technology development is included in most government programmes is probably not a coincidence, but rather a reflection of the international consensus on the technologies that will form the basis of industrial competitiveness in the near future. Related to this is the frequent recourse to the use or development of biotechnology for addressing environmental problems in many of these programmes. Other shared themes include recycling and greening of product (and process) design through design for environment projects.

While there is convergence in the content of the technology, there exists considerable diversity in the structure of environmental technology partnership programmes. This is probably a reflection of the different contexts in which government partnership schemes are placed which, in turn, is a reflection of the particular historical development paths along which government technology programmes have evolved as well as of the need for these programmes to be adapted to specific national innovation systems. This implies that governments should take into account the specific historical and national contexts in designing effective partnerships. It should nonetheless be stressed that partnerships, by virtue of their ability to cut across institutions and sectors, are a flexible mechanism that can be designed to generate a wide range of technological innovations from pre-competitive, breakthrough environmental technologies to near-commercialisation research. It is the role of technology policy to design partnership schemes that are well adapted to particular innovation systems and tailored to achieve both social and economic objectives for the creation of a sustainable developing world.

NOTE

1. The figure is based on IEA statistics which include budgets for demonstration projects in addition to research and development (IEA, 1997).

Annex

SELECTED OECD PROGRAMMES

Canada

Technology Partnerships Canada. Created in 1996 as a part of Jobs and Growth Strategy, this is an investment partnership programme, in which partners share the costs, risks and returns on investment for projects that foster international competitiveness and innovation. The government funds 25-30 per cent of the project cost. Environmental technology is one of the three categories of technology supported by this programme, along with enabling technologies and aerospace and defence technologies. The projects selected are usually near-commercialisation technologies being developed by SMEs (Industry Canada, 1998).

Technology Development and Demonstration Program. This programme promotes regional development and job creation while developing environmental technologies for the purpose of protecting the St. Lawrence River environment. Launched in 1988, the programme supports private sector initiatives in the development and demonstration of new environmental technologies at the pre-commercialisation stage. Priority is placed on pollution prevention, development of monitoring tools and the promotion of environmental efficiency and international technology transfer, mainly in areas of industrial discharges, soil and sediment management. Project duration and funding shares between partners have differed from project to project. The programme has been evaluated as having improved the quality of the St. Lawrence river environment, having acted as a catalyst among scientific, technical and financial stakeholders and having promoted the development of the environment industry in Canada.

European Union

European Framework Programmes. Since the mid-1980s these programmes have included environmental and energy partnership projects. The *Environment and Climate Programme* of the Fourth Framework Programme (1994-98), with a budget of ECU 567 million, has aimed to contribute to research into global change, improve the cohesion of European universities, research institutes and industry, strengthen the European scientific base, help develop the scientific knowledge and technical competence needed to fulfil environmental policy mandates and contribute to growth, competitiveness and employment. However, activities to date have been primarily directed to basic research, and R&D on environmental technology has been limited. The *Energy Programme* has included research for the development of technologies for clean production and use of conventional energy sources. Participants are largely consortia, usually consisting of at least two entities from two different member countries and thereby promoting research co-operation among member states. Special provisions exist to stimulate participation by small firms. Projects are co-funded, with EU funding not normally exceeding 50 per cent; EU participation is progressively lower the nearer the project is to the market. Although, in general, industrial participation in the environmental programmes has been relatively weak, the EU Five-year Assessment Report concluded that important contributions had been made in forging a European research community via the formation of new research partnerships and networks. In the Fifth Framework Programme (1998-2002), the research programmes are concentrated under four themes: *i)* quality of life and management of living resources; *ii)* creating a user-friendly information society; *iii)* promoting competitive and sustainable growth; and *iv)* preserving the ecosystem. The latter theme has three subprogrammes of environmental and sustainable development, energy and EURATOM activities. Greater emphasis is placed on involving industry in these environment-related activities and on innovation. ''Innovation units'' will be established within each of the programmes to provide support and advice to innovation-related aspects of programme management.

THERMIE programme. This programme is the demonstration component of the non-nuclear RTD Programme JOUL-THERMIE. The current phase runs for four years (1995-98) with a budget of ECU 577 million. Among other goals, it has the environmental objectives of reducing energy consumption and reducing the environmental impact of the production and use of energy, particularly CO_2 emissions. THERMIE 3 also aims to contribute to the achievement of other EU objectives such as reinforcing the competitiveness of

EU industry, especially SMEs. The programme provides financial support on a cost-share basis for demonstration projects implementing innovative energy technologies in the sectors of rational use of energy, renewable energies and fossil fuels including clean technologies for solid fuels. Community support covers a maximum of 40 per cent of the total eligible costs of the projects. Proposals for projects are initiated by consortia involving at least two non-affiliated legal entities from different member states.

Finland

Research Programme of the Environment Cluster. This programme, which involves enterprises and the public authorities as well as research and education sectors, enhances the competitive edge of Finnish industry and facilitates the emergence of innovations through collaborative projects that cross disciplinary boundaries and stimulate researcher and research/user networking. Implemented between 1997 and 2000, the initial projects are directed at increasing knowledge of eco-efficiency through applying the tools of life cycle analysis and material flow assessment in agriculture, forestry, the basic metals industry and water management. The Ministry of the Environment co-ordinates the programme with funding and implementation shared also by the Ministry of Trade and Industry, Technology Development Centre (TEKES) and the Academy of Finland.

Germany

Research for the Environment. As in other countries, the emphasis in environmental technology research in Germany has been shifting from end-of-pipe solutions to developing cleaner products and processes. This is made explicit in this new programme which is a comprehensive research programme intended to ‘‘support scientific initiatives aimed at developing, together with partners from industry, new environmental technologies and/or new concepts of environmental engineering and use’’. Co-ordinated by the Federal Ministry of Education, Science, Research and Technology (BMBF), the new programme aims to explore more environmentally acceptable paths for technology and product development, with due consideration for increasing resource productivity and developing cost-effective measures so as to secure jobs and strengthen competitiveness. The programme stresses an interdisciplinary approach and is interlinked with other government programmes such as the Biotechnology 2000 Programme. It is a joint undertaking of all participating federal departments with co-ordination by BMBF. Funding also comes from other public and private sector sources and the EU. Research focuses on: *i)* regional and global engineering of the environment; *ii)* approaches to a sustainable economy; and *iii)* environmental education. The second area includes the development of environmental technologies with an emphasis on energy-efficient cleaner products and processes, replacement of ecologically critical substances and recycling. Ecological design of products, cleaner production, closed-loop production processes, waste management, soil remediation and water treatment are the areas on which co-operative research efforts are to focus.

Japan

The majority of Japanese environmental technology development programmes are run by the Ministry of International Trade and Industry (MITI) and managed by its affiliated agency, the New Energy and Industrial Technology Development Organisation (NEDO). MITI entrusts (*itaku)* projects with funding to NEDO which, as the project implementing entity, commissions research to private firms and universities and research institutes who normally organise themselves into research associations. MITI usually funds the initial stages of the projects and, as the project nears commercialisation, the participating industrial firms fund a portion of the research expenses. MITI programmes aim to develop risky innovative technologies that take five to ten years to develop.

New Sunshine Programme. This was created in 1993 by merging the Sunshine (renewable energy), Moonlight (energy conservation) and the Global Environment Industrial Technology R&D programmes, for the purpose of facilitating innovations which would simultaneously address energy and environmental issues. The environmental technology component focuses in particular on those technologies which protect the global environment. Many also address energy efficiency. A number of projects in the renewable energy and energy conservation components have environmental objectives such as cleaner coal technology. The environment technology projects include: *i)* New Generation Chemical Processing Technology Projects aimed at developing energy and resource efficient chemical processes using new catalysts; *ii)* development of de-NO_x catalysts for lean-burn and diesel engine emissions; *iii)* projects for fixation and recycling of CO_2; *iv)* environmentally friendly industrial processes and reduction of hazardous wastes.

Research Institute of Innovative Technology for the Earth. This was set up as a foundation (*zaidanhojin)* in 1990 as the implementing body of New Earth 21, a scheme to rejuvenate the planet over the next century through the development of innovative energy-environment technologies. It is a research entity, funded by the private sector (more than half) and MITI. Private firms participate directly in RITE's research projects; in addition, some national research institutes and universities usually collaborate. International co-operation is promoted through co-operative research grant schemes. While the majority of projects undertaken address long-term, breakthrough technologies, many of which belong to the New Sunshine Programme, its *Joint Research Programme of Technological Development in the Private Sector* promotes the development of closer-to-commercialisation environmental technologies through a cost-sharing (50-50) arrangement for a period of three to five years. Project themes include: *i)* greenhouse gas reduction, recovery, fixation and re-use technologies; *ii)* energy-efficient production processes; *iii)* treatment, recovery or recycling of ozone layer depleting substances; and *iv)* air, water and soil pollution monitoring techniques.

New Industry Creative Technology Research and Development Promotion Programme. Launched in 1995 by NEDO after a broad call for proposals for innovative projects to be undertaken by collaborating research teams involving universities, national research institutes and industrial firms with the objective of creating new industries to promote economic growth and energy security. Energy conservation related environmental technology is one of the three areas being promoted under this programme.

Waste Management and Recycling Technology R&D. This programme, also managed by NEDO, comprises projects to develop technologies for treating and/or recycling a wide range of wastes from CFCs to municipal sludge.

International Centre for Environmental Technology Transfer. Founded in 1990 under joint sponsorship of the central and local governments and the industrial sector, the Centre aims to facilitate the transfer to developing countries of environmental technologies developed by Japanese industrial firms, by conducting international co-operative R&D involving both domestic and foreign government, industrial and university research sectors on appropriate technologies adapted to the specific needs of the recipient countries.

Sweden

NUTEK Competence Centre Programme. Launched in 1993 to promote university-industry interaction in research for the purpose of enhancing industrial productivity, the programme aims to develop industry-related competence centres conducting co-operative research in specific technical areas. There are now approximately 30 competence centres, where the universities administer the activities and contribute to their financing by providing a base organisation and other resources. Four of these centres focus on research related to environmental technology. About 160 industrial companies now participate in the programme.

Design for Environment in SMEs. Exclusively targeted at smaller firms and implemented in 1998, this programme aims to promote design for environment (DFE), *i.e.* ''development of measures which decrease or prevent product impact on the environment in a life-cycle perspective'' (NUTEK, 1998), based on the understanding that the driving force behind industrial environmental activity is shifting from environmental regulation to enhancing competitiveness through the adoption of environmentally sound products and processes. The programme aims to develop tools and DFE methodology based on those developed in other SME-oriented activities of the Swedish government as well as EU and EUREKA programmes. The tools and methodology are to be tested and demonstrated through product development in pilot companies. Projects are organised by networks of firms involving research institutes, universities and in some cases customers of the participating SMEs, based on industry-specific supply chains or on specific product development.

United Kingdom

LINK Programme. Launched in 1986, this is the UK government's principal mechanism for supporting collaborative research between industry and the public sector. It aims to enhance the competitiveness of UK industry and improve the quality of life through support for pre-competitive research to encourage industry to further invest in R&D leading to commercially successful products, processes, systems and services. More than 1 300 companies, including some 700 SMEs (whose involvement is actively encouraged) and 195 research institutions are involved. LINK covers a wide range of technology and generic product areas from food and bio-sciences, through engineering to electronics and communications. Typically, a number of government departments and research councils collaborate to fund each LINK programme, and each programme supports a number of collaborative research projects which last for two to three years. Public partners provide up to 50 per cent of the eligible cost of a LINK project, with the balance coming from industrial partners. The programme has been positively assessed as providing mutual benefits to both industrial and academic partners by promoting industrial relevance and commercial exploitation of public research and industrial access to the knowledge and skills of the research base. On balance, it has enhanced networking and the sharing of information. There are currently 58 programmes, including in sustainable agriculture, health, and bio-sciences and bio-engineering, in addition to the following two programmes related to environmental technology.

Waste Minimisation through Recycling, Re-use and Recovery in Industry Programme. Jointly sponsored by the Engineering and Physical Sciences Research Council and the Department of Trade and Industry, the programme aims to develop and implement cost-effective technologies for recycling, re-use and recovery of materials within manufacturing, *i.e.* closed-loop production processes.

Foresight Vehicle Programme. This aims to implement the vision of the Foresight Transport Panel by stimulating the UK automobile supplier base to develop and demonstrate a clean, efficient, lightweight, telematic, intelligent, lean vehicle which will satisfy increasingly stringent environmental requirements while meeting mass market expectations for safety, performance, cost and desirability. Jointly sponsored by the DTI and the Economic and Social Research Council with additional support from the Ministry of Defence and the Department of Environment, Transport and the Regions, the programme is a collaborative effort involving UK industry, academia, research and technology organisations, user groups and public sector bodies.

UK Technology Partnership Initiative. Launched in 1993, this is a business-to-business initiative to enable successful international partnerships linking companies and organisations in industrialising and developing countries with UK companies to provide technologies and services for dealing with environmental problems. It works in partnership with local business organisations and organises local training seminars and senior business training missions to the United Kingdom.

United States

Clean Coal Technology Program. This Department of Energy (DOE) partnership programme started in 1986 with the objective of expanding the menu of innovative pollution control options to curb the release of acid rain pollutants following the recommendation of the US-Canada Envoys on Acid Rain to launch a government-industry programme to demonstrate new innovative environmental technologies on a matching funding basis. The programme's five rounds of competition have now been completed, and the leveraging effect has resulted in two-thirds of the programme's total costs coming from non-federal sources. The first projects were more cost-effective environmental retrofit technologies which have now moved into commercial application. In the more recent phase, a broader spectrum of projects that could meet longer-term emission requirements and increased energy efficiency have been sought, such as integrated coal gasification combined cycles and pressurised fluidised bed combustors.

Industries of the Future Initiative. This is a collaborative effort between DOE and seven energy-intensive industries (steel, aluminium, metal casting, glass, chemicals, petroleum refining and forest products) to identify and develop high-risk, high payoff technologies to enhance their competitiveness while fully integrating energy and environmental considerations. DOE provides cost-sharing to many R&D projects identified through this process.

Partnership for a New Generation of Vehicles (PNGV). Sponsored by the Department of Commerce (DOC), the programme aims to develop technologies for a new generation of vehicles with up to triple the fuel efficiency of today's mid-size cars without sacrificing affordability, performance or safety, and which would be designed to comply with emission regulations and improved recyclability. It was launched in 1993, based on the recognition that the development of a new generation vehicle required efforts at the national level, and that its success is important to maintaining the competitiveness of the American automobile manufacturing sector and to preserving jobs in the industry. The programme involves a number of federal agencies and their affiliated research institutes. The private partners are the United States Council for Automotive Research (USCAR), a research consortium consisting of the ''big three'' American automobile manufacturers, and a number of suppliers and universities. Research is conducted on a cost-share basis. The federal government funds a proportionately larger share of fundamental research, but as R&D moves closer to commercialisation, industry provides an increasing share of the costs. Research efforts are focused on hybrid-electric vehicle drive (HEV), direct-injection (DI) engines, fuel cells and lightweight materials. By 2004, prototypes would be produced by each firm. The programme is assessed to be making steady progress; however, meeting cost goals within the proposed time frame of the programme is considered to be an enormous challenge.

Manufacturing Extension Partnership (MEP). Designed in the late 1980s, the programme started to create a nation-wide network of Manufacturing Extension Centers in 1989 through partnerships between federal/state/local government and industry to provide technical and business services to SMEs for the purpose of improving their competitiveness. The range of services includes the introduction of environmental management and technologies and energy audits. The centers are independent, non-profit organisations which offer services that meet the specific needs of the region's local manufacturers. A survey of over 2 000 firms served by MEP centers in 1996 showed that the firms did indeed increase sales and made substantial savings in inventory, labour and material. The companies attributed these benefits to MEP services.

Rapid Commercialisation Initiative. This is a federal/state/private co-operative effort to expedite the application of new environmental technologies involving DOC and several other departments. Based on the understanding that environmental technologies face a set of unique barriers that make commercialisation difficult, the programme addresses three key barriers: finding demonstration sites for near-commercialisation technologies, verification of performance and cost of technologies; and expediting permits. These barriers are lowered through the provision of information, testing and through inter-state collaboration in issuance of permits. Launched in 1995, ten projects ready for commercialisation, covering the areas of monitoring and assessment, emission control, avoidance and remediation and restoration, have been selected on the basis of technical readiness, innovation, and remediation and restoration.

National Industrial Competitiveness through Energy, Environment and Economics. This is a joint DOE/EPA programme to fund state/industry partnership projects that will demonstrate and commercialise innovative processes and/or equipment to improve competitiveness, foster energy efficiency and prevent pollution in the manufacturing sector. Funds are given for three years with 45 per cent federal cost-sharing.

Design for the Environment. Launched in 1992, this programme helps businesses incorporate environmental considerations into the design and redesign of products, processes and technical and management systems while improving performance and product quality by forming voluntary partnerships with universities, research institutions, public interest groups and government agencies.

Green Chemistry. Initially established in 1990, the scheme promotes the design, manufacture and use of environmentally benign chemical products and processes that prevent pollution and reduce environmental and human-health risks. It gives grants and awards through a broad consortium of partnerships involving federal agencies, the chemical industry, trade associations, scientific organisations and representatives from academia.

Technology for Sustainable Environment. A joint EPA/NSF programme to fund fundamental and applied research in physical sciences and engineering that leads to the development of advanced and novel environmentally benign methods of industrial processing and manufacturing, excluding waste monitoring and end-of-pipe technologies.

National Science Foundation Environmental Technology Program. A new programme directed towards supporting a portfolio of research in the area of pollution prevention and sustainable development technologies, the programme aims to fund interdisciplinary research and co-operative research with industries in the areas of industrial ecology, pollution prevention, monitoring equipment and modelling.

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CHARACTERISING PARTICIPATION IN EUROPEAN ADVANCED TECHNOLOGY PROGRAMMES

TABLE OF CONTENTS

This article was written by Ken Guy, John Clark and James Stroyan, Technopolis Ltd., United Kingdom.

I. INTRODUCTION

This article was written to augment and take forward the discussion of Advanced Technology Programmes (ATPs) given in the Background Report to the OECD Working Group on Innovation and Technology Policy for its meeting on 23-24 June 1997 (OECD, 1997 – henceforth termed the OECD ATP Background Report). In that Report, ATPs in the United States, Japan and the European Union were described, together with a discussion of their characteristics and the rationale for their existence.

The OECD ATP Background Report noted that ATPs are conventionally associated with:

– ***pre-competitive,*** ''basic'', ''enabling'' or ''generic'' technologies, *i.e.* long-term developments too far removed from the market and too general to be of direct immediate value in enhancing the competitive position of individual firms;
– ***high-risk*** projects, with potentially high but uncertain returns;
– ***collaboration*** between firms, and/or between firms and academic institutions or other research groups, to encourage the sharing of costs, risks and expertise;
– ***cost-sharing*** between industry and government, with industry typically providing 50 per cent or so of the total finance.

As also discussed in the OECD ATP Background Report, public funding support for ATPs can be justified on the grounds of:

– market failure, where the inability of firms to appropriate fully the results of their work can lead to socially sub-optimal levels of investment in R&D risk-aversion may also lead to an understandable reluctance to invest in costly and risky projects which show great promise but which might threaten the future of the organisation if unsuccessful;
– systemic failure, where the structure of the overall R&D system may be such that bottlenecks exist in relationships between the various actors, leading to, for example, poor information flows and unnecessary constraints to the sharing of know-how and expertise;
– enhancing international competitiveness, in the face of perceived weaknesses relative to trading partners.

This article seeks to develop the earlier report via an analysis of data from a number of evaluation studies of major programmes, with a view to providing an improved understanding of the nature and practical value of ATPs. No attempt at comprehensive coverage of ATPs in OECD countries is made. Indeed, several of the programmes analysed are at first sight difficult to classify as ATPs in terms of the characteristics described above. They are included in order to compare and contrast programmes, to pinpoint underlying similarities and distinctive differentiating features, and to help clarify the characteristics and purposes of ATPs. The programmes included should therefore be considered only as examples of large-scale publicly funded research and technological development (RTD) initiatives.

The article draws on empirical data collected over the last decade to identify and assess the characteristics of participation in ATPs in Europe. Survey questionnaires were circulated to participants in several programmes during the course of evaluations conducted by Technopolis Ltd., a consultancy company specialising in innovation policy. Although the questionnaires were tailored to individual programmes, they had a number of questions in common. Comparable data on the nature and aims of ATP projects, together with their associated costs and benefits, are thus used to re-examine the ‘‘conventional’’ definition of ATPs contained in the OECD ATP Background Report. More specifically, the results of the surveys are used to:

- highlight similarities and differences between programmes;
- compare the characteristics of specific programmes with the generic description of ATPs;
- identify the existence of a ‘‘deep structure’’ capable of providing an improved description of ATPs;
- develop suggestions for good programme design and project selection.

The programmes covered in this analysis are the Alvey Programme of Research into Advanced Information Technology in the United Kingdom (290 questionnaire responses), the equivalent Swedish national programme, the IT4 Programme (135 responses), the Finnish Electronics Design and Manufacturing Programme (EDM) and Electronic Publishing and Printing Programme (EPP) (102 and 31 responses, respectively). Also, for the purpose of comparison, data from the five-year assessment of the Environment and Climate Programmes (ENV) of the European Union (402 responses) were analysed. Whereas the UK Alvey Programme and the Swedish IT4 Programme do seem to correspond to a conventional stereotype, the relatively low involvement of industry in the EU’s Environment RTD Programme would seem to mark it out as a rather different type of programme. Similarly the Finnish EPP and EDM Programmes are included even though they contained some R&D projects which were very ‘‘near-market’’ and others more akin to technology transfer and demonstration projects.

Data included in the analysis refer to the nature of the R&D, the aims of the organisations involved in carrying out projects, and the perceived balance of costs and benefits associated with involvement in the programme. For the full results of the individual evaluations of all the above programmes, readers are referred to the appropriate reports in the Bibliography.

II. SIMILARITIES AND DIFFERENCES IN PROGRAMMES

Nature

Concerning the nature of programmes, participants were asked to assess their projects in terms of the ''semantic differentials'' shown in Table 1, providing a score of 1 for one end of the spectrum and 5 for its semantic opposite, utilising all ordinal values in between.

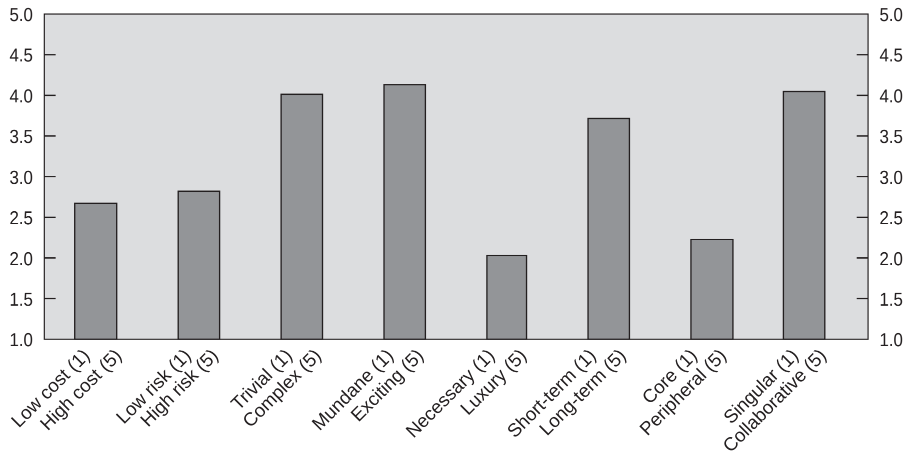
Table 1. **Semantic differentials describing the nature of programmes**

Low-cost	1	2	3	4	5	High-cost
Low-risk	1	2	3	4	5	High-risk
Technically trivial	1	2	3	4	5	Technically complex
Mundane	1	2	3	4	5	Exciting
Necessary	1	2	3	4	5	A luxury
Short-term	1	2	3	4	5	Long-term
In core technology area	1	2	3	4	5	In peripheral area
Feasible without collaborators (singular)	1	2	3	4	5	Only feasible with collaborators (collaborative)

Figure 1 shows the average values for the various ''nature'' attributes for the five programmes combined. Although, strictly speaking, it is technically incorrect to think in terms of averages when using ordinal scales, their use does offer a simple way of visualising differences across the ''nature'' dimensions. For similar reasons, histograms are used to depict these differences.

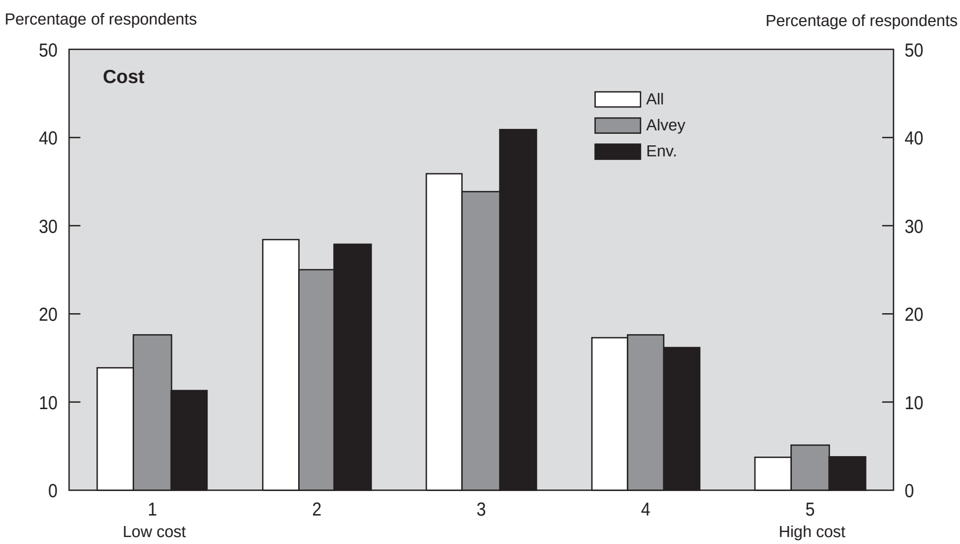
The bulk of the work within the five programmes is clearly considered exciting, complex, long-term and feasible only with collaborators. For the most part the work is also considered necessary rather than a luxury, and is largely conducted in core rather than peripheral technology areas. In terms of perceived cost and risk, however, most projects cluster round the middle of the spectrum (Figures 2 and 3).

Figure 1. **The nature of ATP programmes – combined "averages"**



Source: Technopolis.

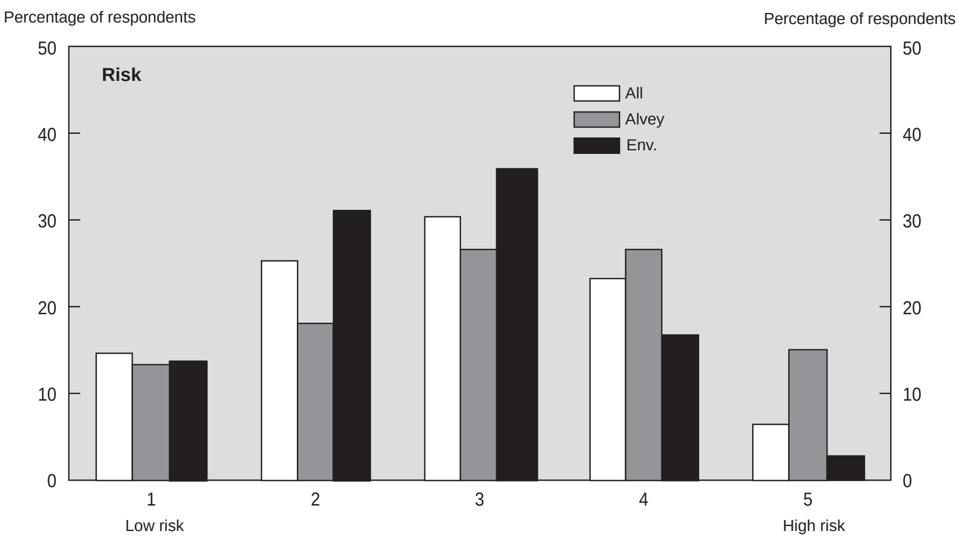
Figure 2. **Cost distributions**



Source: Technopolis.

These figures also show the comparable spreads for the UK Alvey and EU Environment Programmes, *i.e.* for a ‘‘conventional’’ ATP and a ‘‘non-conventional’’ ATP involving, for the most part, academics only. They indicate that programmes differ little in terms of average perceived cost and risk of projects,

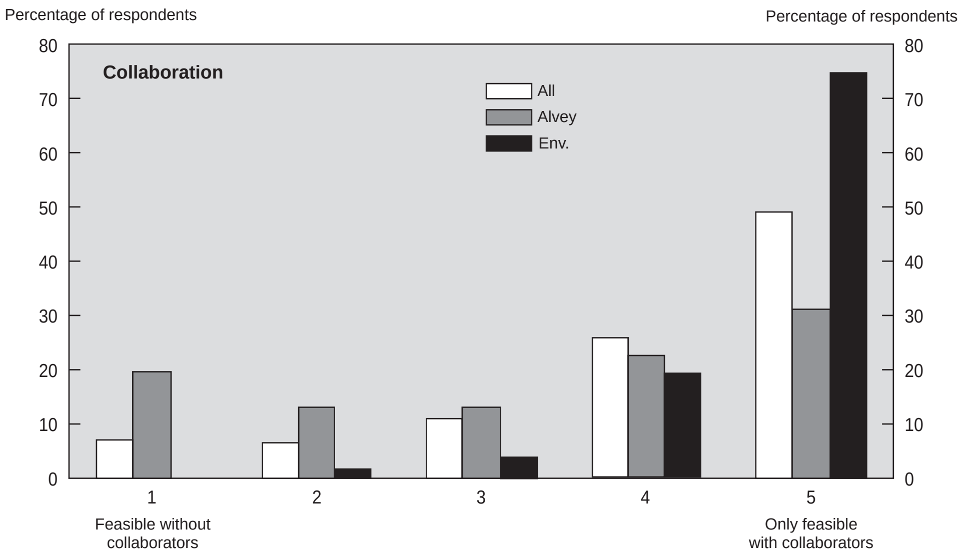
Figure 3. **Risk distributions**



Source: Technopolis.

though the Alvey Programme profile is more skewed towards riskier projects than the EU Environment Programme. In part this may be a reflection of the more commercial orientation of the programme. It may also be due to the fact that Alvey was one of the first ATPs in Europe. Lack of familiarity with the concept and practice of collaborative programmes probably enhanced overall perceptions of riskiness. This is reflected in Figure 4, which demonstrates a certain amount of scepticism amongst Alvey participants concerning collaboration, with some 30 per cent arguing that it was feasible to undertake the work without collaborators. In contrast, the vast majority of participants in the Environment Programme were

Figure 4. **Collaboration distributions**

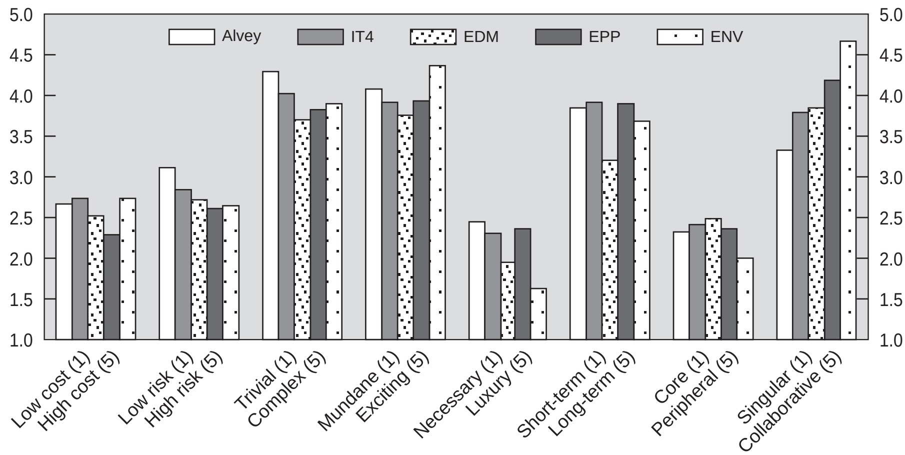


Source: Technopolis.

convinced that it was only feasible to undertake the work with collaborators, although this is hardly surprising given that one of the conditions of funding for EU programmes is that participants from more than one country have to be involved.

For all programmes, however, including Alvey, the majority of participants considered that collaboration was necessary and desirable. The average values for all the various ‘‘nature’’ attributes for each of the five programmes is shown below (Figure 5). The most important point to note is the remarkable similarity between the programme profiles across all the ‘‘nature’’ dimensions, despite the fact that the span of programmes chosen for analysis deliberately included examples lying outside the conventional definition of ATPs provided in the introduction to this article. Although for each ‘‘nature’’ attribute differences certainly exist between programmes (particularly in terms of the degree to which projects are feasible without collaboration), these differences are less remarkable than the similarities between programme profiles. This result suggests that programmes normally defined as ATPs – so-called ‘‘conventional’’ ATPs – actually form only a sub-set of a broader genus of programme sharing similar ‘‘nature’’ attributes.

Figure 5. **The nature of programmes – “averages” for individual programmes**



Source: Technopolis.

Aims

In the evaluations of each of the five programmes analysed, participants were presented with a set of motives and goals and asked to score their importance on a scale of 1 (low) to 5 (high). The sets of goals and motives participants were asked to consider were for the most part identical, with some customisation to account for contextual factors. The aims of the participants referred to such issues as the ability to enter a new R&D area, expansion of activity in an existing area, cost and risk reduction, skills upgrades, development of new tools or techniques, development of new products, entry into various kinds of collaborative ventures and the forging of links with other organisations. The ranked goals and motives for three of the programmes are shown in Tables 2 through 4.

Many of the participants’ aims reflect different aspects of four broad (and to some degree overlapping) goals usually associated with ATPs:

– *Knowledge goals.* These are goals of a technical nature concerned with the expansion and consolidation of know-how and knowledge bases. Examples include ‘‘Deepen understanding’’, ‘‘Upgrade skills’’ and ‘‘Develop new tools and techniques’’.

Table 2. **The aims of participants – Alvey Programme (UK)**

Rank	Activity	Importance rating
1	Develop new tools and techniques	4.18
2	Accelerate R&D	4.14
3	Build on R&D base	3.99
4	Maintain R&D presence	3.91
5	Deepen understanding	3.86
6	Enhance image	3.83
7	Establish new academic-industry links	3.80
8	Upgrade skills	3.77
9	Enter new R&D area	3.74
10	Use new tools and techniques	3.72
11	Develop new prototypes	3.71
12	Enter international collaborative R&D programmes	3.53
13	Enter private sector R&D ventures	3.40
14	Achieve critical mass	3.36
15	Establish new industry-industry (or academic-academic) links	3.30
16	Access industry know-how	3.26
17	Access academic know-how	3.22
18	Enter other national R&D programmes	3.20
19	Spread costs	3.18
20	Keep track of peripheral R&D	2.82
21	Spread risks	2.79
22	Enter new non-R&D collaborations	2.76
23	Develop new products	2.76
24	Use new standards	2.45
25	Influence new standards	2.27

Source: Technopolis.

- *Exploitation goals.* Some goals have a strategic or commercial orientation and are more concerned than others with the eventual exploitation of knowledge and skill bases. Examples include ‘‘Develop new products’’, ‘‘Produce patents and licences’’ and ‘‘Improve competitiveness’’.
- *Network goals.* These relate to network formation and the establishment of new links and partnerships. They have a structural or systemic nature in that they invariably refer to the relationship between an organisation and its environment. Examples include ‘‘Access academic know-how’’ and ‘‘Establish new academic-industry links’’.
- *Stewardship goals.* Goals such as ‘‘Access additional funds’’, ‘‘Reduce costs’’ and ‘‘Spread risks’’ reflect a combination of opportunistic, economical and parsimonious practices characteristic of sound R&D management and stewardship.

Table 3. **The aims of participants – Environment and Climate Programme (EU)**

Rank	Activity	Importance rating
1	Enhancement of existing knowledge base	4.33
2	Formation of new research partnerships and networks	4.25
3	Better co-operation with universities and research institutes	4.04
4	Development, evaluation or improvement of tools and techniques	3.97
5	Access to additional funds	3.87
6	Maintenance of expertise in a research area	3.81
7	Overcoming limited national funding	3.80
8	Access to complementary sources of S&T expertise	3.53
9	Follow-on entry into Framework programmes	3.31
10	Enhanced reputation and image	3.27
11	Enhanced skills of R&D staff	3.24
12	Acceleration of R&D	3.10
13	Follow-on entry into other international programmes	3.08
14	Exploration of new, alternative technology paths	3.02
15	Deeper understanding in core technology area	2.88
16	Cost-sharing between partners	2.79
17	Increased number of research staff	2.75
18	Follow-on entry into national programmes	2.70
19	Improved competitiveness	2.49
20	Reduction of in-house contribution to project	2.41
21	Development or improvement of new processes	2.32
22	Production of specifications, demonstrators, simulations, etc.	2.31
23	Reorientation of R&D portfolio towards longer-term R&D	2.31
24	Formation of new, longer-term business alliances	2.27
25	Risk reduction	2.15
26	Development or improvement of new services	2.12
27	Increased familiarity with new standards	2.12
28	Production of prototypes	1.96
29	Better co-operation with firms	1.94
30	Follow-on entry into R&D collaborations in the private sector	1.92
31	Development or improvement of new products	1.86
32	Better co-operation with customers	1.70
33	Follow-on entry into business collaborations in the private sector	1.67
34	Reorientation of R&D portfolio towards shorter-term R&D	1.56
35	Increased turnover, market share or productivity	1.55
36	Production of patents and licences	1.45
37	Monitoring of competitors' activity	1.41
38	Better co-operation with suppliers	1.39

Source: Technopolis.

Table 4. **The aims of participants – Electronic Design and Manufacturing Programme (Finland)**

Rank	Activity	Importance rating
1	Improved competitiveness	4.13
2	Development, evaluation or improvement of tools and techniques	4.12
3	Enhancement of existing knowledge base	3.95
4	Access to complementary sources of expertise	3.74
5	Development or improvement of new processes	3.62
6	Acceleration of R&D	3.61
7	Exploration of new, alternative technology paths	3.60
8	Deeper understanding in core technology area	3.51
9	Better co-operation with firms	3.47
10	Enhanced skills of R&D staff	3.45
11	Access to additional funds	3.40
12	Production of specifications, demonstrators, simulations, etc.	3.37
13	Maintenance of expertise in a research area	3.29
14	Formation of new research partnerships	3.28
15	Development or improvement of new products	3.28
16	Better co-operation with universities and research institutes	3.10
17	Production of prototypes	3.06
18	Enhanced reputation and image	2.98
19	Cost-sharing between partners	2.98
20	Better co-operation with suppliers	2.96
21	Formation of new, longer-term business alliances	2.86
22	Better co-operation with customers	2.84
23	Reduction of in-house contribution to project	2.81
24	Reorientation of R&D portfolio towards longer-term R&D	2.74
25	Development or improvement of new services	2.74
26	Follow-on entry into R&D collaborations in the private sector	2.73
27	Follow-on entry into national programmes	2.72
28	Risk-sharing between partners	2.60
29	Monitoring of competitors' activity	2.59
30	Reorientation of R&D portfolio towards shorter-term R&D	2.52
31	Increased familiarity with new standards	2.45
32	Follow-on entry into business collaborations in the private sector	2.41
33	Follow-on entry into international programmes	2.33
34	Overcome failure of international programmes to satisfy needs	2.20
35	Production of patents and licences	2.20
36	Increased number of research staff	2.17

Source: Technopolis.

The prioritisation of these four goals – *knowledge, exploitation, network* and stewardship (KENS) – by participants varies from one setting to another. Table 5 shows the results of a classification, ranking and weighting exercise based on assigning the individual goals in Tables 6-8 to the KENS categories. Individual goals were weighted according to rank and sorted according to their KENS category. An average score was then calculated for each KENS category, with low scores denoting higher prioritisation. In all programmes, *knowledge* goals are accorded the highest priority. For the other KENS categories, however, participants[1] priorities vary from one setting to another. Comparing the Finnish and UK programmes, for example, the higher priority given to *exploitation* goals in Finland reflects the programme's more overt focus on commercialisation and support for near-market rather than pre-competitive R&D. Similarly, the comparatively strong *stewardship* focus in the Environment Programme reflects the desire of academics – the dominant population – to access additional funds and overcome limited national funding, whereas the lower focus on *stewardship* in the other programmes largely reflects the low priority given to cost and risk sharing and reduction.

Table 5. **KENS goals**

Alvey (UK)	Environment and Climate (EU)	Electronic Design and Manufacturing (Finland)
Knowledge goals (10.42))	Knowledge goals (12.62)	Knowledge goals (14.00)
Network goals (14.00)	Stewardship goals (14.60)	Exploitation goals (17.50)
Exploitation goals (17.00)	Network goals (19.69)	Network goals (20.85)
Stewardship goals (20.00)	Exploitation goals (28.00)	Stewardship goals (23.00)

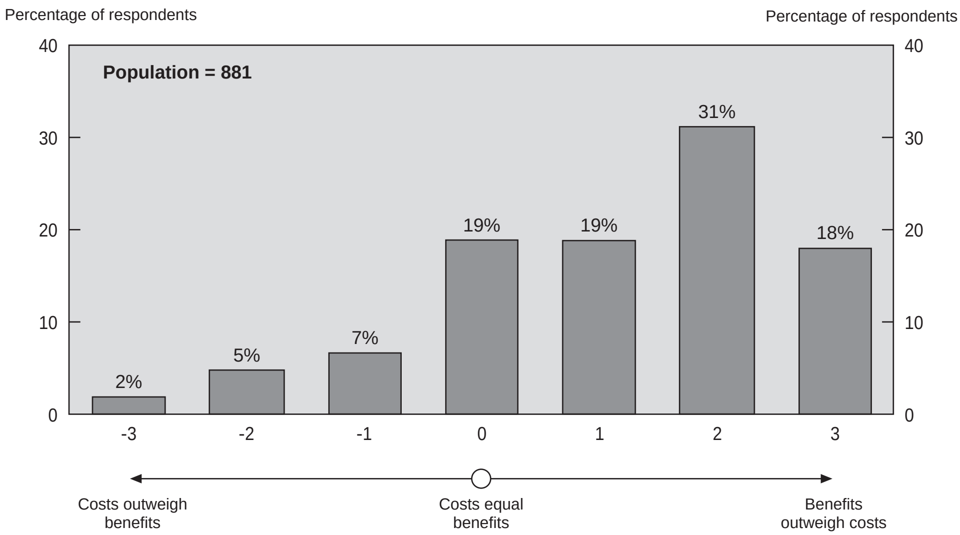
Source: Technopolis.

Costs and benefits

Participants were asked to rate their programme activities along a nine-point scale according to the extent that ''costs outweighed benefits'' or ''benefits outweighed costs''.

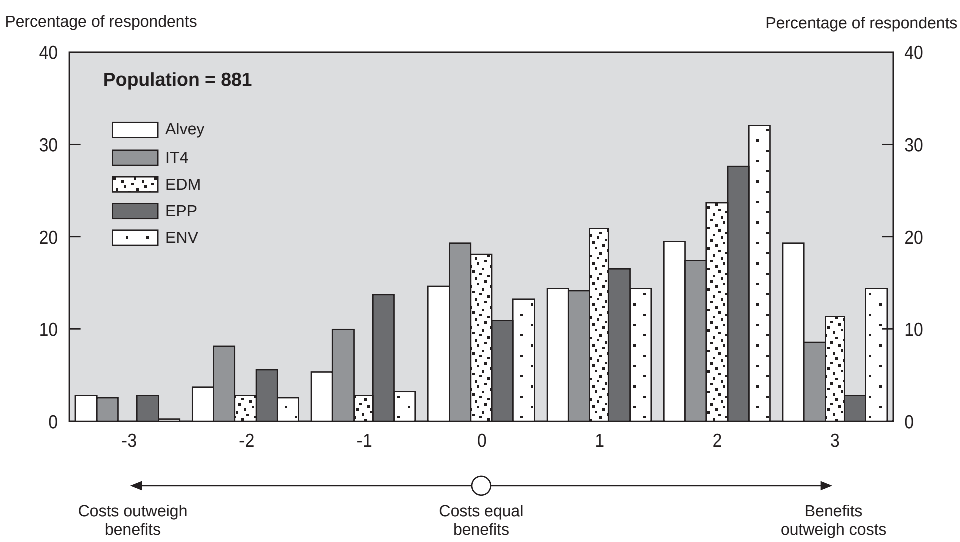
The majority of the total population of respondents considered that the benefits of involvement outweighed the costs (Figure 6). Out of a total population of 960, 881 provided an answer to this question. Very few felt that the costs outweighed the benefits, though just over 20 per cent did feel that the costs and benefits balanced each other out. Figure 7 further shows that profiles were similar

Figure 6. **Costs and benefits – combined programmes**



Source: Technopolis.

Figure 7. **Costs and benefits – individual programmes**



Source: Technopolis.

across programmes, with participants in the Environment Programme being most appreciative and those in the Finnish EPP Programme the least, although it must be noted that this was a mid-term evaluation and that most participants felt that benefits would increase over time.

III. DEFINING ADVANCED TECHNOLOGY PROGRAMMES

At the start of this article, an OECD definition of ATPs was used which characterised programmes in terms of their:

- pre-competitive nature;
- high risk;
- collaborative structure;
- cost-sharing;
- eligibility for public support in terms of market failure arguments;
- eligibility for public support in terms of system failure arguments;
- focus on enhancing international competitiveness.

The five programmes covered in the analysis are reviewed under these headings.

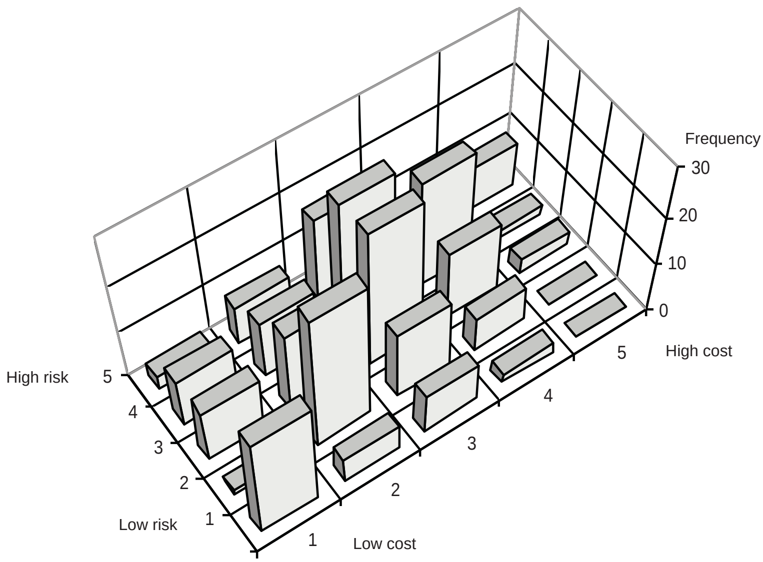
Pre-competitive nature

All the programmes had an emphasis on longer-term R&D, although the focus on nearer-market work in the Finnish EDM Programme was quite pronounced, and the Finnish EPP Programme contained an overt technology demonstration and diffusion element.

High risk

High risk was not identified as a common feature of ATP programmes, nor was risk sharing overtly prioritised by participants in any of them. One possible explanation is that participants tended to associate risk with cost (see Figure 8 for the Alvey example), and relatively few projects were thought of as high-cost projects.

Figure 8. **Cost and risk – Alvey Programme**



Source: Technopolis.

Collaborative structure

All the programmes contained collaborative projects, although the nature and extent of collaboration varied widely. In the Environment Programme, the collaboration was largely academic-academic. In the others, firm-academic and firm-firm collaborations were far more prevalent. In some programmes, however, especially the Finnish ones, ''company projects'' geared towards near-market work were largely single-company projects, with marginal inputs from other collaborators.

Cost-sharing

Across all programmes, even though collaboration did allow cost-sharing, this was rarely a prime motivation for collaboration. Main drivers tended to involve knowledge goals and the acquisition of complementary assets via networking.

Market failure

The argument that ATPs are justified in terms of market failures created by cost and risk considerations may have some theoretical legitimacy, but in practice the comparatively low attention paid to cost and risk reduction by participants diminishes its credibility as a powerful argument for public support of ATPs.

Systemic failure

In contrast, the pervasiveness and primacy of networking goals and the real perceived benefits of collaboration do suggest that ATPs help overcome systemic failures in the ability of organisations to exchange information and share know-how and expertise.

International competitiveness

Although improving international competitiveness is an understandable pre-occupation of the policy makers who frame ATPs, it is seen as a high-level and long-term consequence of participation by researchers. It therefore suffers in comparison with more tangible and pragmatic knowledge and networking goals in terms of the priority accorded to it by researchers. At a more subliminal level, however, it is widely recognised that the desire for improved competitiveness – and international competitiveness in many of the global markets spanned by ATP participants – does underpin and justify the existence of ATPs, although this is obviously not the case for programmes such as the EU Environment Programme.

ATP definitions revisited

The defining characteristics of ATPs, as presented in the OECD ATP Background Report, are limited in that they imply distinctions which are sharper than those that are actually made. They do not adequately describe any one of the five programmes included in this analysis, even though all possess, to a greater or lesser extent, some of the attributes of ‘‘conventional’’ ATPs. These conventional descriptions of ATPs seem able only to describe a very small sub-set of the programme types in existence, despite the fact that many of these do appear to share similar profiles in terms of their nature, aims and associated benefits. Rather than adhering to a restrictive definitional set, it seems more attractive to search for defining characteristics which can adequately describe real-life ATPs.

IV. THE SEARCH FOR DEEP STRUCTURE

The empirical data available from the evaluations conducted by Technopolis span many dimensions describing the aims and nature of projects. It was noted earlier how project aims could be classified into four broad KENS goals. In the search for an underpinning ‘‘deep structure’’, however, it is also possible to explore the data in more systematic ways. Correlation, cluster and principal components analysis techniques were used to this end. Associations were also sought between the underlying dimensions characterising ATPs and the costs and benefits perceived by participants. The desire here was to inform and guide policy makers and programme administrators in the difficult tasks of programme formulation and project selection by identifying elements of ‘‘good practice’’.

The main elements of the analysis comprise:

- correlations between ‘‘nature’’ attributes and perceived benefits and costs;
- cluster analysis of ‘‘nature’’ attributes and perceived benefits and costs;
- principal components analysis of ‘‘nature’’ attributes to classify and summarise relationships between them, in an attempt to detect underlying structures in the data and help develop taxonomies;
- principal components analysis of project aims, again to classify and summarise relationships between them.

The analysis of nature attributes

The correlation coefficients between all the ‘‘nature’’ variables (expressed in terms of semantic differentials) over all programmes are shown in Table 6.

The table reveals that:

- there appears to be a group of quite strongly interrelated variables spanning ‘‘cost’’, ‘‘risk’’, ‘‘complexity’’, ‘‘excitement’’ and ‘‘long-term’’ attributes;
- benefits are more likely to outweigh costs where a project is considered ‘‘exciting’’, ‘‘necessary’’, ‘‘in a core technology area’’ or ‘‘feasible only with collaborators’’;

Table 6. **Correlations between nature characteristics – Combined programmes**

	Low cost – High cost	Low risk – High risk	Trivial – Complex	Mundane – Exciting	Necessary – Luxury	Short-term – Long-term	Core – Peripheral	Singular – Collaborative	Cost – Benefit
Low cost – High cost	1.00	0.39	0.23	0.22	–0.09	0.14	–0.13	0.13	0.06
Low risk – High risk	0.39	1.00	0.40	0.26	0.12	0.19	–0.06	0.02	–0.03
Trivial – Complex	0.23	0.40	1.00	0.52	0.05	0.29	–0.06	0.06	0.07
Mundane – Exciting	0.22	0.26	0.52	1.00	–0.16	0.29	–0.14	0.23	0.17
Necessary – Luxury	–0.09	0.12	0.05	–0.16	1.00	0.12	0.27	–0.17	–0.19
Short-term – Long-term	0.14	0.19	0.29	0.29	0.12	1.00	0.01	0.07	0.03
Core – Peripheral	–0.13	–0.06	–0.06	–0.14	0.27	0.01	1.00	0.00	–0.15
Singular – Collaborative	0.13	0.02	0.06	0.23	–0.17	0.07	0.00	1.00	0.11
Cost – Benefit	0.06	–0.03	0.07	0.17	–0.19	0.03	–0.15	0.11	1.00

Source: Technopolis.

- a particularly high correlation is evident between the ‘‘complexity’’ of a project and the extent to which it is perceived as ‘‘exciting’’;
- the extent to which a project is ‘‘in a peripheral technology area’’ for the organisation is far more closely associated with a perception of it as a ‘‘luxury’’ than with any other factor.

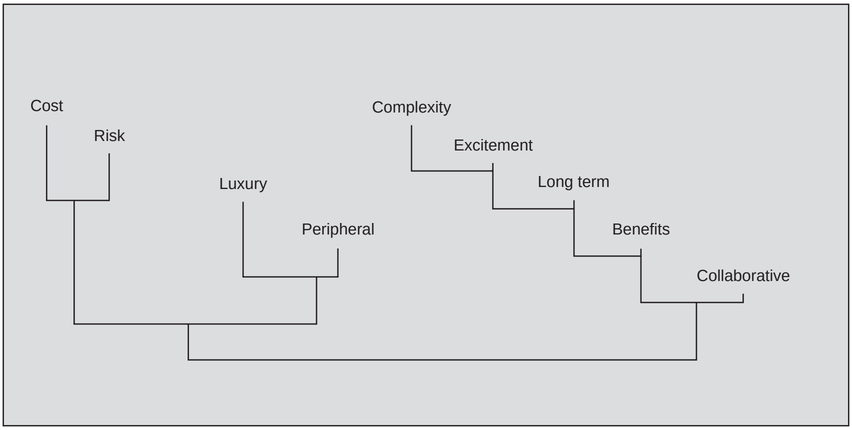
Figure 9 shows the results of a multivariate cluster analysis on these variables. This technique is designed to assign individual cases or variables into groups, according to those whose data show the greatest similarities. It thus identifies variables which might reflect similar underlying attributes of the projects, and allow us better to understand their nature.

For our set of variables, there are three distinct clusters of dimensions:

- the first links ‘‘cost’’ with ‘‘risk’’ attributes;
- the second links ‘‘luxury’’ and ‘‘peripheral’’ attributes;
- the third links ‘‘complexity’’, excitement’’, ‘‘long-term’’ and ‘‘collaborative’’ attributes with ‘‘benefits’’.

These results are in line with those obtained directly from the table of correlations. They also compare favourably with the results of a principal components analysis (see Table 7). This procedure reduced the dimensionality of the data

Figure 9. **Cluster analysis of nature characteristics – combined programmes**



Source: Technopolis.

Table 7. **Principal components analysis of nature characteristics – Combined programmes**

	Factor		
	1	2	3
Low cost – High cost	0.63	–0.30	–0.06
Low risk – High risk	0.78	0.00	–0.18
Trivial – Complex	0.72	0.11	0.25
Mundane – Exciting	0.56	–0.07	0.57
Necessary – Luxury	0.14	0.69	–0.35
Short-term – Long-term	0.45	0.35	0.33
Core – Peripheral	0.19	0.75	0.06
Singular – Collaborative	–0.01	0.00	0.71
Cost – Benefit	–0.02	–0.36	0.46

Source: Technopolis.

from nine factors (the eight ''nature'' attributes and the perceived cost/benefit) to three, which together accounted for 53 per cent of the variation in the original data. The three factors resulted from the use of the so-called ''Kaiser'' criterion of selection. The numbers shown in Table 7 are the ''factor loadings'', *i.e.* the values of the correlations between the factor itself and the original variables. High figures indicate significant contributions to factors by the corresponding variables, and if common interpretations can be put on groups of such variables for each new factor, these can be used to reclassify and reinterpret the data. The signs of the numbers in the table are important only in a relative sense within an individual column.

The factors link particular attributes, although it is important to remember that the factors suggest revealing underlying dimensions in the data and do not indicate high or low values for the variables concerned:

– factor 1 links the ''cost'' and ''risk'' attributes (compare the cluster and correlation analyses), although in this case they are also linked to the ''complexity'' and ''excitement'' attributes;
– factor 2 links the ''luxury'' and ''peripheral'' elements, as did the cluster and correlation analyses; the negative association with benefits should also be noted;
– factor 3 has ''collaborative'' and ''excitement'' attributes positively linked with ''benefits''.

Further analysis of the data for the individual programmes reveals similar factor sets for each one. Table 8 shows the results of the principal components analysis for the Alvey Programme:

– this time factor 3 links the ''cost'' and ''risk'' attributes, and also indicates a negative association with benefits;
– factor 2 again links the ''luxury'' and ''peripheral'' elements and replicates the negative association with benefits;
– factor 1 provides the link between ''complexity'' and ''excitement'', though this time these are also linked with ''long-term'' attributes as well as ''benefits''.

The results of all the correlation, cluster and principal component analyses are highly suggestive. There appear to be three dominant core attributes.

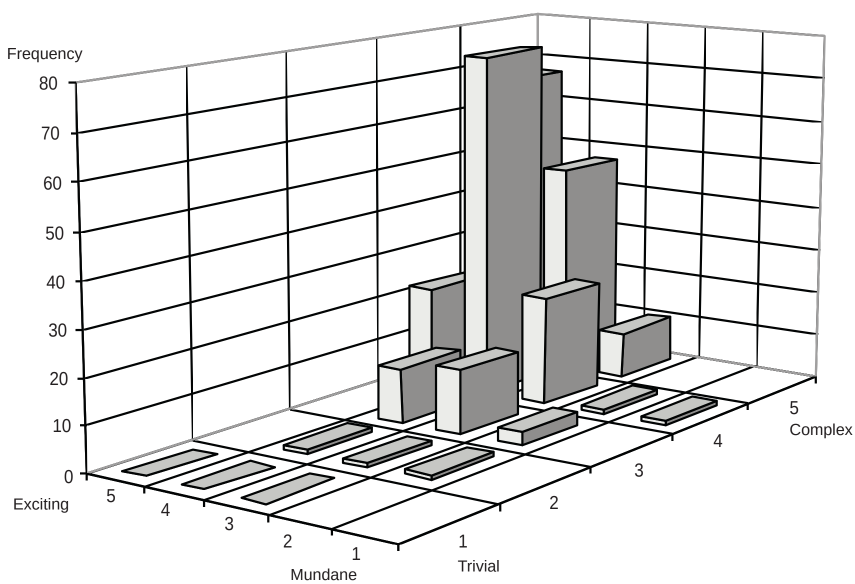
– A *stimulation* factor primarily links ''complexity'' with ''excitement'', although associations also exist with other attributes, *e.g.* ''long-term'' and ''risk'' attributes. Figure 10 demonstrates graphically the bunching of Alvey projects in the ''high-complexity''/''high-excitement'' sector.
– A second *centrality* factor links ''core'' and ''necessary'' attributes. This is illustrated by another example from the Alvey programme in Figure 11.

Table 8. **Principal components analysis of nature characteristics – Alvey Programme**

	Factor		
	1	2	3
Cost	0.02	0.11	0.82
Risk	0.24	–0.20	0.76
Complexity	0.78	0.07	0.15
Excitement	0.79	0.14	0.08
Luxury	–0.03	–0.78	–0.01
Long-term	0.59	–0.44	0.07
Peripheral	–0.09	–0.63	–0.32
Collaborative	0.08	–0.30	0.15
Cost-benefit	0.34	0.50	–0.27

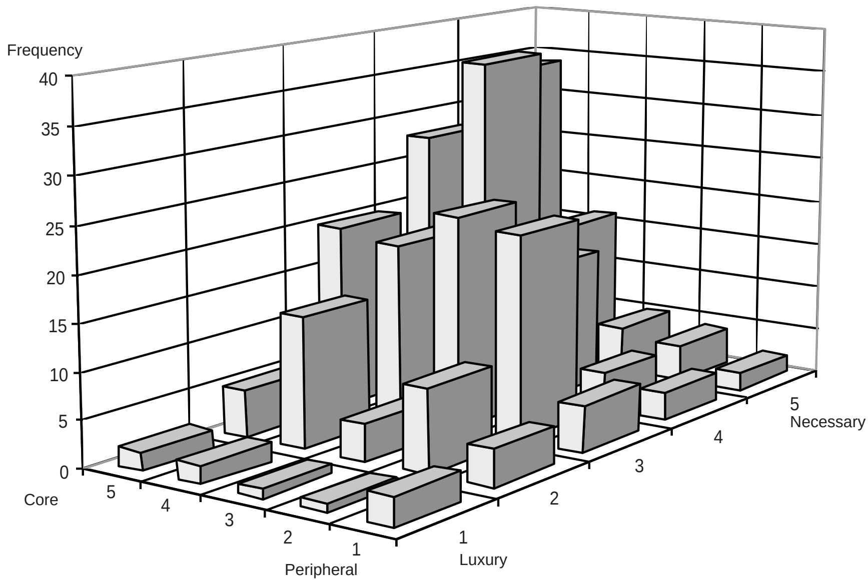
Source: Technopolis.

Figure 10. **Complexity and excitement – Alvey Programme**



Source: Technopolis.

Figure 11. **Centrality and necessity – Alvey Programme**



Source: Technopolis.

While this shows that the bulk of projects lie in the ''core-necessary'' sector, a significant number, particularly those with a higher ''luxury'' rating, are to be found towards the ''peripheral'' end of the spectrum. These latter projects might be described as low centrality or ''indulgence'' research, not necessary or a core need of the organisation, but obviously of some interest to the participating organisations. Looking at ''long-term/short-term'' and ''core/periphery'' dimensions, it has been suggested that the relatively high number of projects rated as jointly ''long-term'' and ''peripheral'' represents ''insurance'' R&D, *i.e.* R&D carried out to keep up with, and maintain expertise in, alternative technological routes, lest the organisation's ''core'' technology prove inferior in the long term (Quintas and Guy, 1995).

– The third factor of importance is a *venture* factor which strongly links ''risk'' with ''cost''. As indicated in Figure 8, projects cluster around the diagonal running from the ''low-risk/low-cost'' sector to the ''high-risk/high-cost'' sector, although many are concentrated at the mid-point of this line.

In terms of their associations with benefits, there does seem to be a consistent link across programmes with the *stimulation* and *centrality* factors. In short, highly stimulating projects are associated with high benefits, as are projects of central interest to organisations. With regard to the *venture* factor, however, there is no consistent pattern across programmes. For the Alvey Programme, for example, there was a negative association between benefits and ‘‘high-cost/high-risk’’ projects which constituted a significant venture for participating organisations, although this was not replicated either across programmes or for all programmes combined.

The analysis of project aims

It was noted earlier that the sets of aims used to characterise programmes in each programme evaluation differed slightly. It was not therefore possible to carry out multivariate analyses for a combined data set spanning all programmes. Analyses for individual programmes were possible, however, and the results are revealing. Below are the results of a principal components analysis of project aims for the UK Alvey Programme, regarded by many as one of the first stereotypical ATPs. Alvey participants scored 25 motives and goals on a 1-5 scale of importance. These scores, together with the scores for perceived costs/benefits, were included in the analysis, the results of which are shown in Table 9.

A reduced set of six factors was identified:

- Factor 1 groups together entry into follow-on R&D programmes, enhanced image and reputation, the establishment of new collaborative links, entry into new R&D areas and the development and use of new tools and techniques. It reflects an *expansion of opportunity* for an organisation, broadening its horizons through further collaboration and new areas of research. Interestingly, the perception of benefits is correlated more closely with this factor than with any other.
- Factor 2 is strongly influenced by risk and cost reduction. It is also correlated with accessing know-how and technology from academic organisations, upgrading skills and familiarity with tools and standards. Overall, it seems to represent *the leveraging of complementary assets*, *i.e.* a strategy to enhance competitiveness based on ensuring state-of-the-art know-how in core areas and cutting costs by minimising ‘‘wasteful’’ expenditures.
- Factor 3 links the expansion and maintenance of existing areas of R&D with acceleration and deepening. It represents a classic strategy of *enhancing the knowledge base* of an organisation, and there is an association with benefits.
- Factor 4, like factor 1, captures entry into new R&D areas, but this time links it with tracking developments in peripheral R&D areas, establishing a

Table 9. **Principal components analysis of participant aims – Alvey Programme**

	Factor					
	1	2	3	4	5	6
Maintain R&D presence	0.19	–0.11	0.61	0.31	0.15	–0.11
Enter new R&D area	0.44	0.29	–0.07	0.56	0.07	0.05
Build on R&D base	0.21	–0.01	0.84	–0.04	0.02	0.08
Accelerate R&D	0.02	0.28	0.65	–0.07	0.21	0.17
Deepen understanding	0.11	0.05	0.73	0.03	–0.21	0.18
Achieve critical mass	0.18	0.29	0.15	0.51	0.01	0.31
Keep track of peripheral R&D	–0.11	0.24	–0.01	0.75	0.20	0.01
Spread costs	0.13	0.84	0.17	0.13	0.02	0.10
Spread risks	0.00	0.85	0.02	0.14	0.13	0.09
Upgrade skills	0.33	0.43	0.20	0.44	–0.10	0.32
Use new standards	0.14	0.58	–0.16	0.20	0.49	0.02
Influence new standards	0.02	0.37	–0.08	0.21	0.68	0.05
Use new tools and techniques	0.42	0.43	0.07	0.13	0.33	0.23
Develop new tools and techniques	0.53	0.28	0.36	–0.13	–0.08	0.30
Develop new prototypes	0.28	0.20	0.30	–0.35	0.07	0.60
Develop new products	0.05	0.24	0.05	0.20	0.02	0.83
Enhance image	0.75	0.01	0.10	0.10	–0.24	0.26
Enter other national R&D programmes	0.74	0.17	0.03	0.01	0.21	0.18
Enter international collaborative R&D programmes	0.75	0.15	0.15	–0.01	0.22	0.01
Enter private sector R&D ventures	0.51	0.09	0.09	0.27	0.22	0.54
Enter new non-R&D collaborations	0.30	–0.05	0.13	0.12	0.38	0.71
Establish new academic-industry links	0.68	0.08	0.17	0.11	0.20	0.06
Establish new industry-industry (or acad.-acad.) links	0.42	0.02	0.15	0.23	0.52	0.28
Access academic know-how	0.20	0.45	0.02	0.36	0.19	0.24
Access industry know-how	0.44	0.03	0.21	–0.11	0.61	0.24
Cost-benefit	0.51	–0.20	0.29	0.35	0.10	0.04

Source: Technopolis

critical R&D mass and upgrading skills. Whereas factor 1 describes a positive and active grasping of new opportunities, factor 4 reflects a more cautious or *defensive exploration* of alternative technical possibilities. Again there is an association with benefits.

– Factor 5 associates the establishment of industry-industry links, and accessing technology from industrial organisations, with gaining familiarity with, and influencing, standards. It represents a strong *industrial networking* factor;

– Factor 6 links the development of new products and prototypes with entry into private sector R&D collaborations and non-R&D-based collaborative ventures. It represents an overt, commercially oriented *industrial exploitation* factor.

V. SUMMARY AND CONCLUSIONS

Descriptions of the characteristics of ATPs often make use of adjectives such as ''pre-competitive'', ''collaborative'', and ''basic technology''. As such, ATPs are often differentiated from basic scientific research initiatives, on the one hand, and ''near-market'' research and development programmes, on the other. In reality, however, although the number of programmes in existence in different countries sharing some similarities with ''conventional'' ATPs is considerable, few correspond exactly with conventional definitions.

In this article the underlying features of publicly funded research and technological development programmes are explored via an analysis of data stemming from questionnaires distributed to participants in five such programmes. The results suggest features of programmes which might usefully be borne in mind in policy decisions about objectives and selection criteria for ATPs. More specifically, it is suggested that:

– The defining characteristics of ATPs outlined in the OECD Background Report are of limited utility. In particular, it is misleading to think that ATPs primarily support high risk R&D, or that cost-sharing constitutes a strong motivation for participation. Consequently, few programmes in real life fit this ''conventional'' model of an ATP.
– A fairly small set of variables can be used to characterise the ''essential'' elements of a broader set of programmes, all of which possess some of the attributes of ATPs but differ in other respects.
– Classification of programmes in terms of some of these underlying dimensions better helps to differentiate between programme types.
– An appreciation of these dimensions should help policy makers frame programmes better suited to the realisation of policy goals.

Three dimensions characterise the underlying nature of ATPs, namely:

– a *stimulation dimension* reflecting the complexity and excitement involved in participation; academic bodies and research institutions, in particular, tend to get involved in complex, exciting projects;

– a *centrality dimension* concerned with the extent to which work is perceived as necessary in a technology area central to the main research interests of the organisation;
– a *venture dimension* denoting the degree to which projects are considered both risky and costly.

With regard to the dimensions characterising underlying aims, *i.e.* the motives and goals of participants in ATPs, inspection reveals four dimensions:

– *knowledge goals* concerned with the expansion and consolidation of knowledge bases;
– *exploitation goals* focusing on the eventual exploitation of knowledge;
– *network goals* oriented towards establishing and exploiting new links and partnerships;
– *stewardship goals* reflecting opportunistic, economical and parsimonious R&D management practices.

More systematic exploration of the data suggests six related dimensions which reflect:

– *expansion of opportunity* through new collaboration and new areas of research;
– *leveraging of complementary assets* via the parsimonious pursuit of external know-how;
– *enhancing knowledge bases* via deepening, broadening and acceleration, thus strengthening internal R&D capabilities;
– *defensive exploration* of potentially interesting new areas;
– *industrial networking* and the exploitation of these links;
– *industrial exploitation* in terms of the pursuit of commercially oriented outputs and outcomes.

Regarding the utility of these dimensions in formulating plans for future ATPs, it should be noted that the dimension covering the *costs and benefits* of participation appears to be associated with the *centrality* and *stimulation* dimensions, and with the goals related to *expansion of opportunity*, *enhancing knowledge bases* and *defensive exploration*. Phrased more simply, the benefits to participants are greatest when the projects chosen stimulate the researchers involved, help expand internal know-how and lead to further research opportunities. Benefits are also forthcoming either when the work is central to the core interests of organisations or, almost paradoxically, when the potential of new, alternative areas is explored.

In designing new ‘‘best practice’’ programmes and selecting projects, it therefore makes sense to aim for project portfolios which match these characteristics.

In particular, selection processes and criteria should be geared towards understanding:

– the potential of projects to stimulate the researchers involved;
– the centrality of projects to the technology strategies of participating organisations;
– the opportunity provided by projects to enhance the knowledge and skill bases of organisations;
– the likelihood of collaboration leading to new opportunities;
– the extent to which projects allow organisations to access and explore new areas of potential interest.

With regard to the other dimensions, it is important to realise that ATPs can legitimately include work which ranges from one polar extreme to another. It is possible, therefore, to think of a distinct range of ATPs, similar to the extent that all would ideally contain projects fulfilling the ‘‘best practice’’ criteria (stimulation, centrality, etc.), although dissimilar in that each would also contain projects spanning the other dimensions. For example, one type of ATP could be geared towards projects at the ‘‘market’’ end of the industrial exploitation spectrum, with a strong emphasis on near-market R&D and the commercialisation of project outputs. Another could be geared much more towards the basic or applied research end of the spectrum.

It is also legitimate, and often desirable, to have programmes which contain a mixture of project types. ATPs can contain ‘‘basic’’ and ‘‘near-market’’ work. Similarly, programmes can contain projects which place a strong emphasis on industrial networking together with those focusing on academic-academic interactions. There are, in fact, cogent arguments for programme constructions which comprise very different project clusters. These revolve around the general notion that policy prescriptions for complex ‘‘innovation systems’’ should comprise customised ‘‘policy packages’’ designed to support actions at various points in ‘‘innovation space’’. In jargon-free terms, this means that particular problems often require a range of actions to resolve them, rather than any one particular action, and that these remedial actions are often best implemented as part of a concerted effort rather than undertaken as quite separate serial or parallel actions.

Over the last two decades, programmatic interventions have become commonplace innovation policy instruments, but too often only a limited range of them are in place at any one time, often out of synchronisation with the real needs of regions and nations, and with each other. Participation in pre-competitive research programmes is on offer in some instances when the real problem in the affected area is the slow uptake of technology in SMEs. In other cases, industry-led programmes are promoted when the real need is for expanded support of the science base. Even when it is recognised that the needs of a particular sector are best dealt with via a mix of policy mechanisms, the individual components are often either too small to be run as independent entities or they are implemented as quite separate and often conflicting initiatives.

Programmes such as the EPP Programme in Finland combine project clusters which tackle different problems in innovation space (*e.g.* applied research projects, technology adoption projects and projects which explore new business opportunities) in technical areas which correspond with the real needs of the sectors involved. On their own, the individual clusters would probably be sub-critical. Taken together, they are not and there is even scope for synergy. For the EPP Programme this was particularly appropriate given the imperatives of the so-called ‘‘digital era’’, which call for new constellations of actors in a plethora of new business chains and clusters. Even though the applied research, business opportunity and technology adoption project clusters could have been run as separate programmes, running them together provided an opportunity for synergy where none existed previously. EPP thus constituted an appropriate package of policy prescriptions which correctly addressed systemic needs in a turbulent area of technological change and evolving business opportunities.

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INDUSTRIAL TECHNOLOGY PARTNERSHIPS IN SPAIN

TABLE OF CONTENTS

This article was written by Jose Molero and Mikel Buesa of the Universidad Complutense de Madrid, Spain.

I. INTRODUCTION

This article summarises the main findings of an evaluation of industrial technology partnerships between Spanish firms and the Industrial Technological Development Centre (CDTI) during the period 1984-94. Since 1984, the CDTI, which falls under the Ministry of Industry and Energy, is responsible for a range of measures aimed at promoting innovation in Spanish firms. The most important of these involve: managing its own funding programmes for technological development and innovation, collaborative research programmes between firms and universities or public R&D centres, international industrial R&D programmes within the framework of the European Union, EUREKA, the CYTED (Iberoeka), and Spanish participation in the European Space Agency, CERN and the European Synchrotron Radiation Facility (ESRF).

The evaluation focused on financial and technical partnerships between firms and the CDTI for developing technology in the framework of national programmes. Data for the evaluation were drawn from the CDTI databases as well as from a survey of participating firms (to which more than 500 firms responded). The evaluation also drew, albeit to a lesser extent, on the databases of the *Instituto de Comercio Exterior*, the *Dirección General de Transacciones Exteriores* and the Spanish and American Patent Offices. This article presents a summary of the main findings, beginning with a brief description of the characteristics of the firms involved in partnerships with the CDTI, followed by an analysis of the impacts of the partnerships on participating firms and the main characteristics of the CDTI as a financing agent.

II. CDTI-FINANCED FIRMS

Between 1984-94, the period considered in the evaluation, some 1 922 firms received financing or technical services from CDTI in order to develop their technological activities. However, the evaluation centred only on the 1 354 firms financed within the framework of the CDTI's national programmes. The importance of these firms in the Spanish economy is illustrated by the fact that they represent around 50 per cent of the Spanish firms that can be classified as innovative and which carry out organised R&D activities. Furthermore, these firms account for 19 per cent of exports and 13 per cent of foreign direct investment.

Aside from these figures, it is important to bear in mind the main characteristics of these firms:

- The *size of the participating firms* is predominantly small: 52 per cent employ fewer than 50 workers and a further 30 per cent employ between 51 and 200 workers.
- From the *sectoral viewpoint*, the firms are widely distributed. Nonetheless, some sectors, such as machinery and mechanical equipment, machinery and electrical material, the food and chemical industries and the business services sector are notable for their larger share.
- *Control of firms:* in 85 per cent of firms, ownership is concentrated in the hands of private nationals; foreign ownership accounts for another 12 per cent; and the public sector controls the remaining 3 per cent of firms.
- The *location* of the firms parallels the geographic distribution of R&D activities in Spain. Thus, almost 60 per cent of the firms are located in Catalonia and Madrid, while the Basque and Valencia regions account for a further 15 per cent.
- *Age* is another important factor: 38 per cent of firms started up after 1980, 17 per cent between 1970-80 and 16 per cent between 1960-70. The remainder were started prior to 1960.
- As far as *export activity* is concerned, the survey showed that nearly 80 per cent of the firms were exporters and the average *propensity to export* of exporting firms represents 21 per cent of sales.
- As regards outward *foreign direct investment,* some 28 per cent of the firms in the survey have subsidiaries abroad. Some 80 per cent of these firms have subsidiaries which are purely commercial, while only 48 per cent have production subsidiaries.
- Some 13 per cent of the firms carry out *technology transfer operations abroad* as measured by the granting of licences. Nearly 40 per cent provide technical assistance services.
- *Ownership of laboratories and R&D centres abroad* is limited. Only 4 per cent of firms have overseas R&D facilities. These are large firms controlled mainly by large private groups or foreign capital.
- Finally, 34 per cent of firms have participated in international R&D programmes.

III. THE PERFORMANCE OF THE CDTI FROM THE FIRMS' VIEWPOINT

On the basis of the survey, five main issues were examined: *i)* the concentration of CDTI financing on a group of firms that participated several times (at least four) in projects financed by the CDTI; *ii)* the clear bias observed in the allocation of financial resources by the CDTI; *iii)* a comparison of the objectives pursued by the firms with the results subsequently achieved; *iv)* the technological and economic effects on firms of CDTI-financed projects; and *v)* an analysis and evaluation of the CDTI's relationship with participating firms.

Firm size and participation

The first noteworthy observation is the close and direct relationship between the number of CDTI-financed projects and size of firm. According to the survey results, firms obtaining loans are more likely to be small: 68 per cent of firms with fewer than 50 employees had received funding for at least one project, while only 26 per cent of firms with more than 500 employees had obtained a CDTI loan over the period. At the other extreme, large firms tend to be multiple recipients: while one-third of large firms with more than 500 employees have participated in four or more CDTI-financed projects (the ''main clients''), only 4 per cent of the firms in the smallest size class participated with equal frequency.

Characteristics of CDTI financing

Survey results show that, in the absence of CDTI support, the degree of difficulty experienced by firms in financing innovation projects is greater the smaller the firm. Private firms also have more difficulty in financing projects than do state- or foreign-owned firms. This suggests that the large firms and foreign-owned firms that made sporadic use of the CDTI had access to other sources of financing (facilitated by lower interest rates, especially in 1990).

Large firms behave very differently from other firms. CDTI financing has enabled a greater percentage of large firms to reduce their own R&D costs from their initial forecasts, while a few, proportionately, increased them (Table 1). This suggests that CDTI financing may have been used by some firms as a substitute for more expensive funds, so that they are able to benefit, among other advantages (such as not requiring loan guarantees), from a substantial reduction in interest rates. Thus, CDTI financing, which may have been supplementary to other sources of finance (as was the case among the most frequent clients and, in general, among small, private Spanish firms), may in fact have been a substitute in other cases (*e.g.* among foreign-owned firms and those with a more sporadic relationship with the CDTI).

The interest rate subsidy for most CDTI-recipient firms has been between 3 and 6 per cent, although this estimate may be slightly low. According to CDTI statistics, the average interest rate for its most common loans for technological development fell from around 10 per cent to barely over 5 per cent between 1984 and 1994. During the same period, the average rate for bank loans (for periods of

Table 1. **Effects of CDT1 financing on firms' R&D expenditures**

Percentage of firms in each category

Purpose of financing	Size of firms (number of employees)				Type of company			
	< 50	51-250	251-500	> 500	Independent national	National group	Public	Foreign
Increase R&D expenditures	52	58	54	38	53	56	51.5	47.2
Reduce R&D expenditures	17	13	13	25	17	16	17.2	14.6
Maintain the same level of R&D expenditures	31	29	33	38	31	29	31.0	38.2

Source: Authors.

between one and three years) dropped to between 6 and 7 per cent, more than 6 points above the active market rate – except in 1994 when there was a substantial drop of between 15 and 18 per cent. The most frequent clients (and also the largest firms) benefited most from the lower interest rates.

It should be also be stressed that the total amount of funding obtained from the CDTI was more highly rated by firms with a single project than by those with multiple projects, and more highly by the latter than by regular clients. Private national firms rated funding higher than did public or foreign-financed firms. Overall, CDTI loans have had a greater influence on the general level of R&D than on the technological orientation of the company (Table 2).

Firms' objectives and results of CDTI-financed projects

In general, survey results showed that the firms met their objectives satisfactorily, particularly with respect to technology, and that CDTI-financed projects did not produce undesired results. The main objectives were product development, followed by the improvement, or at least maintenance, of the firm's competitive position, and market expansion. In summary, the aims of the firms – which, to a large extent, base their innovation strategies on quality and product differentiation – seem to be geared more to maintaining or improving their competitive position and the opening of new markets than to the short-term goal of cost reduction (Table 3).

Table 2. **Firms' assessment of the importance of CDTI financing**

	Size of firms (number of employees)				Type of company			
	< 50	51-250	251-500	> 500	Indepen-dent national	National group	Public	Foreign
Financing has had an impact on the quantitative level of R&D	3.2	3.1	2.9	2.7	3.1	3.1	2.7	2.8
Financing has stimulated interest for R&D	3.2	3.3	3.1	2.9	3.3	3.3	2.7	2.9
Financing determined the kind of R&D undertaken	2.5	2.4	2.2	2.0	2.5	2.5	2.0	2.0

1. Figures correspond to a valuation index from 0 (not relevant) to 5 (extremely relevant).
Source: Authors.

Table 3. **Results from CDTI-financed projects**

Purpose of financing	Size of firms (number of employees)					Type of company			
	Total firms	< 50	51-250	251-500	> 500	Indepen-dent national	National group	Public	Foreign
New products	3.5	3.6	3.6	3.3	3.0	3.6	3.5	3.0	3.2
Product improvement	2.8	2.8	2.9	2.9	2.3	2.9	2.7	2.0	2.7
New processes	2.8	2.6	3.0	3.1	2.8	2.8	2.9	2.6	2.9
Process improvement	2.5	2.4	2.7	2.7	2.5	2.5	2.6	2.3	2.6
Adaptation of technologies	1.8	1.8	1.8	1.8	1.9	1.8	1.8	1.7	1.7
Opening of new markets	2.8	2.8	3.0	2.7	2.7	2.8	2.9	2.7	2.8
Improvement in competitiveness	3.2	3.2	3.4	3.2	3.0	3.3	3.3	2.9	3.0
Reduction in costs	2.4	2.2	2.6	2.7	2.3	2.4	2.5	2.1	2.3
Other	2.0	1.9	2.0	2.1	2.3	2.0	2.0	2.1	2.0

1. Values correspond to the index used in Table 2.
Source: Authors.

Effects of CDTI financing on firms

As regards the effects of CDTI-financed projects on firms, participants particularly noted an improvement in their ''internal'' technological exploitation capacity – an increase in their knowledge base, improved staff training – rather than increased technological co-operation with other firms or public research centres. They also seemed to perceive greater positive effects on their competitive position, in relation to both domestic or foreign competitors, than on their profitability.

Table 4. **Effects of CDTI projects on the development of firms**

	Size of firms (number of employees)					Type of company			
	All firms	< 50	51-250	251-500	> 500	Independent national	National group	Public	Foreign
Technological effects									
Improvement in personnel training	3.1	3.2	3.1	3.1	3.0	3.1	3.2	2.7	3.0
Increasing the knowledge base	3.3	3.3	3.3	3.5	3.2	3.3	3.4	3.2	3.2
Improved integration of R&D department	2.7	2.6	2.8	2.8	2.5	2.7	2.8	2.3	2.6
Improved co-operation with public centres	2.7	2.7	2.7	2.8	3.0	2.6	2.9	3.2	2.7
Improved co-operation with other firms	2.0	2.0	2.1	2.1	1.9	2.0	2.1	2.4	1.9
Economic effects									
Higher profitability	2.6	2.6	2.7	2.8	2.1	2.7	2.6	1.8	2.5
Better competitive position *vs.* national competitors	3.0	3.1	3.0	2.9	2.5	3.1	3.0	2.4	2.7
Better competitive position *vs.* foreign competitors	2.9	2.9	3.0	3.1	2.6	3.1	2.9	2.5	2.7

1. Values correspond to the index used in Table 2.
Source: Authors.

Large firms (more than 500 employees) as well as firms having participated in more than three projects experienced the lowest effects (whether technological, financial or commercial), with the exception of collaboration with the CDTI. An equally differentiated picture emerges with respect to type of controlling capital: foreign- and state-owned firms noted below-average effects in the areas of staff training, increased knowledge base and integration of an R&D department. In contrast, the effects of participation on technological co-operation with public centres and private firms obtained an above-average rating (Table 4).

Firms' relations with the CDTI

According to the survey of participating firms (which excluded firms in litigation), the overall opinion of the CDTI is generally quite high, especially in terms of relations with Centre staff. The follow-up and project control procedures appear to be more highly rated than the actual granting of loans, perhaps because these tend to be subject to bureaucratic red-tape which firms find cumbersome.

IV. THE CDTI AS A FINANCING AGENT

The CDTI's performance in promoting innovation in Spanish firms can be assessed from two main perspectives: the distribution of funds, whether originating from the CDTI or not, but managed by it; and the technical and administrative aspects of support (including the financial implications). To assess the performance of the CDTI, a certain number of variables must be considered, such as the evolution of funding over time, the type and size of the projects, the industrial sector and technology field, the characteristics of participating firms (by size class and capital structure), and, finally, the regional distribution of projects. The following section reviews the results of a study of 2 268 projects carried out over the 1988-95 period, including those in various technical or financial phases, but excluding cancelled projects or those awaiting approval and special action.

The distribution of financial resources

Evolution of projects over time

First, it should be noted that there was a progressive increase in the number of CDTI-financed projects over the period studied, rising from slightly more than a hundred on average in the early years to three times that number in the early 1990s. This highlights a considerable increase in the levels of activity and, consequently, in the complexity of the projects undertaken. This increase in activity, and also in the total value of the budgets of accepted projects, which reached Ptas 422 652 million for the whole period (in 1994 pesetas), has coincided with an increase in the funds made available to firms (a total of Ptas 131 371 million over the period). This was in line with an expansionary policy up until 1990, after which the level of support stagnated or even fell, both in terms of the total budget and the financial outlays of the CDTI. Thus, the average value of the projects dropped sharply from Ptas 222 million in 1987-90 to Ptas 145 million in 1991-94. Between 1984 and the early 1990s, funding commitments dropped from 45 to 36 per cent.

Various factors underlie the increase in the number of projects financed, their increasingly smaller size and the subsequent reduction of financial commitments in relation to budgets. Among these are the fact that Spain was in an economic recession at the time, the increasing participation of very small firms – with leaner budgets – and, finally, the practice of adjusting and revising the value of the projects so as to extend financing to a larger number of firms and projects. The budget restrictions on state funds which took place during the same period must also be taken into account.

As concerns the management and distribution of projects by the CDTI, it should be borne in mind that not all projects benefited from the same degree of competence, particularly the *joint* projects (those in which a public research centre participates together with a firm) imposed, along with the corresponding budgetary allocation, from other sources, namely the Interministerial Commission for Science and Technology (CICYT). These projects accounted for one-quarter of CDTI's overall activity (in terms of both number and amount of financing). *Development* projects are the major focus of CDTI activity (1 525 projects), accounting for 67 per cent of the total budget. *Innovation projects* are more recent; there have been 83 of these, representing around 4 per cent of the total budget. *Technological promotion* projects are, in both absolute and relative terms, still barely significant (73 projects and a mere 0.2 per cent of the budget). The average value of innovation projects is higher than would have been expected (Ptas 269 million in 1994 pesetas), due to the higher allocation for technological equipment. Development projects averaged Ptas 208 million, with technological promotion projects averaging Ptas 12.5 million.

The distribution of the projects is important since many of the financial commitments undertaken by the CDTI are based on their initial acceptance. These commitments are closely related to the level of risk involved in participating in one type of project or another. Thus, on average, the joint projects have a maximum commitment/budgeted ratio of 44 per cent, while for development projects the ratio is 38 per cent and for innovation projects it is 21 per cent. Technological promotion projects have a very high ratio (69 per cent), since here it is not risk that is evaluated, but rather complementary factors which might lead to profits from the projects.

Sectoral origin and technological orientation of projects

An analysis of the distribution of the CDTI projects by industrial sector shows that they are heavily concentrated in manufacturing, which accounts for three-quarters of the projects and the amounts budgeted and spent by the CDTI (equivalent to 1 721 projects, worth Ptas 331 000 million in 1994 pesetas). Services account for 16 per cent of projects and a slightly lower share (14 per cent) in budgetary terms. Projects in the agriculture and fishing sector are not very significant (roughly 5 per cent), followed by mining and energy (1.5 per cent and 2 per cent, respectively, by number of projects and by value) and construction (0.9 per cent).

As regards the distribution of projects in manufacturing, high-and very-high-technology-intensive firms predominate, accounting for around 70 per cent of the financial resources of the CDTI; they even match the committed/budgeted ratio, particularly in the case of high-tech projects. Projects by very-high-tech firms were mainly in electronics, office equipment, and precision machinery, with more than Ptas 35 000 million committed (22 per cent of the total, including non-industrial activities), as well as the machinery and electrical materials sectors. Projects by high-tech firms were concentrated in the chemicals and pharmaceuticals sectors (Ptas 23,500 million committed, roughly 15 per cent), followed by the machinery and mechanical equipment (10 per cent committed) and transport equipment sectors (5 per cent).

Medium- and low-tech projects obtained a smaller share of support (27 per cent of the financing commitment to total manufacturing, divided almost equally and amounting to Ptas 34 000 million). Medium-tech projects tended to be in basic metallurgy, non-metallic and metallic mineral products, and worth around or slightly more than Ptas 4 000 million. Among low-technology sectors, food processing is the most heavily backed (almost Ptas 10 000 million), with textiles, clothing, paper and other manufactures amounting to Ptas 7 600 million.

Finally, concerning the technological orientation of the projects (based on the 1 730 projects for which allocation can be fairly accurately calculated), there is a clear bias towards information and microelectronics technologies (32.5 per cent of the total), followed by food and agricultural technologies (18.9 per cent), advanced technologies (16.4 per cent) and chemical and pharmaceuticals (13.8 per cent). Thus, four of the ten established categories account for more than three-quarters of the total number of projects. New materials (8.7 per cent), space research, biotechnology and environment account for between 4.6 per cent and 2 per cent.

Distribution of projects by firm size, capital structure and geographic distribution

With regard to the distribution of projects by firm size, small (less than 50 employees) and medium-sized (between 50 and 250 employees) firms predominate, accounting for almost two-thirds of the CDTI's activity, with the smallest firms receiving 30 per cent of financial commitments (nearly Ptas 50 000 million in 1994 pesetas). These firms are also favoured in terms of the backing received, as expressed by the commitment/budget ratio (although to a much lesser extent). Generally, as would be expected, the smallest firms have a low share of budget projects compared to other firms, with the share increasing with size. Interestingly, the average value of projects among firms with less than 50 workers amounts to Ptas 132 million. This figure is very high, indicating a significant economic, and undoubtedly technological, effort on the part of these firms relative to their capacity. However, as discussed below, this may also reflect other factors.

Regarding the capital structure of participating firms, three-quarters of CDTI funding was granted to national, privately owned firms whose share of public capital amounted to only 7.3 per cent, while the remainder (18 per cent) was granted to foreign-owned firms (this figure is probably underestimated since the CDTI only considers as foreign those companies with more than 50 per cent of foreign share capital). The projects of the public and foreign-owned firms tend to be larger than those of firms with private national capital (Ptas 263 million compared to 168 million). This may be explained by the fact that the larger the firm, the greater its technical, organisational and financial capacities to undertake large projects. On the other hand, there is little variation in the degree of financial support, as measured by the amounts of funds committed/budgeted, which ranges around 38 per cent.

Finally, the geographic dispersion by region more or less reflects the distribution of Spanish industry. Projects are more or less equally concentrated in the Madrid and Catalonia areas, which account for almost two-thirds of the CDTI's financial commitments, followed by the Basque region (10 per cent), Valencia, Asturias, Andalucía and Navarre, each with a share of between 4.4 and 2.9 per cent.

Priorities in project financing

The project funding process is characterised by a series of goals, ideas and routines which are difficult to articulate due to their informal nature, but which undoubtedly influence the priority setting decisions of the CDTI. These priorities are implicit both in the distribution of project budgets and the credits granted. The evaluation of the CDTI showed, however, that the size of firms and their capital structure are not related to the CDTI's allocation of resources for technology projects on a national level since R&D is carried out mainly by large firms or those with foreign capital. Second, the sectoral distribution would seem to imply that the CDTI has chosen its clients in those sectors with the greatest technological opportunities.

Third, the allocation of resources has been concentrated in the most import-dependent sectors, that is, those sectors with the lowest productive development. Fourth, the distribution follows the opposite pattern to the Spanish productive structure, although this does not mean that traditional sectors have been excluded. Thus, the CDTI's performance reflects a counterbalance to clear industrial specialisation, aimed at improving and strengthening the weakest activities in the production system. The fifth point is that there is absolutely no relationship to the export capacity of the different industrial sectors or to their level of technological dependency. Finally, and in conclusion, it seems clear that the policy pursued by the CDTI has been led by implicit priorities unlike those which have motivated the technological policy of the State and the Autonomous Communities (Table 5).

Table 5. **Priorities of CDTI activity regarding the productive and technological situation of the industry**

Correlated variables	Sectoral distribution of project budgets		Sectoral distribution of CDTI financing	
	Pearson r	Significance	Pearson r	Significance
IMC	–0.54	0.05	–0.58	0.05
EXP	–0.07	Less than 0.10	–0.05	Less than 0.10
RIE	0.63	0.05	0.62	0.05
RIC	0.47	0.10	0.53	0.05
TS	–0.52	0.05	–0.53	0.05
TD	0.12	Less than 0.10	0.12	Less than 0.10

Key: IMC = domestic market coverage;
EXP = export propensity;
RIE = relative research effort (R&D);
RIC = relative innovative effort (patents);
TS = technological specialisation in the international market;
TD = technological dependency (imports of foreign technology).
Source: Authors.

Technical and financial situation of projects: overall assessment

Having analysed the allocation of financial resources by the CDTI (as well as those from the CICYT), it is worthwhile examining how these projects have evolved over time and the extent to which the financial commitments were met. Based on the data, which only provide a picture of the technical and financial situation of the projects at a single point in time (*i.e.* 1994, the year in which the projects were approved), the projects can be classified as: *concluded* projects (where the technical and financial phase was concluded); those awaiting *payment* (where only the technical phase was concluded), whether or not overdue according to the commitments undertaken by the firm; and projects *in development,* whether overdue or not. Projects in either the follow-up or technical phase, but which failed to meet deadlines, are included in the category of *legal action.* The final situation is that of *failed* projects which occurs when, despite technical success, the firm and the CDTI mutually decide to cancel the project.

CDTI-financed projects that were concluded or in progress had a pass rate of 63 per cent and accounted for 68 per cent of CDTI outlays. Few CDTI projects failed, especially during the later part of the period covered, and those that did tended to involve projects with little funding (around Ptas 1 500 million). On the other hand, projects engaged in litigation accounted for up to 20 per cent of CDTI outlays. In other words, nearly one-quarter of the projects started before 1990 ended up in the legal department. However, the legal issues did not generally concern technical questions, but rather economic issues such as problems with payment.

Taking into account that in recent years few projects have failed or involved legal action, a comparison of the difference between the amount spent and that recovered from failed projects and those in litigation between 1984 and 1991 reveals that 22 per cent of the amounts paid out by the CDTI (*i.e.* Ptas 23 674 out of a total of Ptas 108 465 million) will be difficult or impossible to recover. To this figure should be added another 7 per cent representing outlays for ‘‘risky projects’’. The average ratio of recovery to outlays for the first two periods (66.8 per cent for 1984-86 and 58.3 per cent for 1987-90) seems to indicate a real difficulty in achieving a ratio above 70 per cent (this level was achieved only in 1984 and 1985).

These tentative results, which will have to be corroborated by further analysis, suggest that the degree of technical risk in the various projects does not appear to be positively related to the problems considered here. In principle, there does not appear to be an important risk factor for the CDTI. The joint projects, regarded as highly risky from a technical point of view, show a higher degree of fulfilment of obligations compared to other projects such as development projects. Further, few joint projects were technical failures or are in litigation over repayment. The only areas where joint projects performed poorly were in the time involved in recouping funds, probably due to the particular financial conditions of these projects, as well as to technical delays in projects under way. It is worth noting that the specific nature of the projects and their origin significantly influence the different results obtained by the two main types of CDTI project. Finally, it is not so much the technical risk as other economic and financial conditions which explain late payment and non-fulfilment.

The analysis indicates the difficulty in establishing a linear relationship between the size of the project, its technical success and the extent to which the firm's financial commitments are met. Indeed, for large projects (between Ptas 100 and 250 million), there were as many concluded projects as failed ones (139) and ones in litigation (148). Still, there are some indications that the smallest projects (less than Ptas 50 million) have greater problems in achieving positive results (concluded or in-payment), and quite frequently find themselves in litigation. However, when the consequences of such projects (either in legal action or failed) are considered, the cost for the CDTI is less for small projects than when a large-scale project fails, in both relative and absolute terms.

Performance of projects by firm size and capital structure

As regards the performance of firms according to size, small-firm projects (fewer than 50 workers) had higher rates of failure and legal actions (33 per cent of the total number of projects) and a very high amount of outlays involved in these risk categories (almost Ptas 18 000 million in 1994 pesetas); that is, 45 per cent of the amounts paid out by the CDTI for this group. The data are equally conclusive when compared to those for all firms, since they account for 72 per cent of the total number of projects and almost 65 per cent of the total amount paid out in projects which subsequently found themselves in difficulty.

This illustrates the problems encountered by small firms in achieving their technological goals or in meeting their commitments to pay back the borrowed funds. The causes of these problems cannot be discerned from the available data, but the large amount of commitments, for which the firms may not have been adequately prepared, may have played a role. Furthermore, reinforcing this trend, firms in the 50-250 employee size class present a similar picture, although to a much lesser extent; they account for a further Ptas 6 000 million (22 per cent of the total outlay involved in legal actions and failures). On the basis of the data, the performance of large firms was exceptionally positive (accounting for little more than 10 per cent of the financial resources received by one of them). Also, the joint repercussion on risk implicit in these categories is fairly low (13 per cent) with regard to their relative weight in overall funding (36 per cent).

Comparing the projects undertaken by foreign and public firms, foreign firms with CDTI funding have a higher percentage of completed projects (particularly with respect to the amount of funds paid out) and projects awaiting payment. Foreign firms are also less affected by delays in repayment (and the delays seem to have a lesser effect on projects in progress). Although they may have a couple of failed projects, recoveries are far more substantial. Likewise, although these firms do figure in the list of legal actions, both the number of cases and the amounts involved are five or six times lower than those for private national firms. Thus, CDTI-financed firms with foreign capital are, for reasons outside the scope of this analysis, a much safer credit risk than are public firms, which are otherwise very similar to foreign firms in terms of risk.

Project performance by sector and geographic distribution

In broad terms, projects in manufacturing fared best. These projects had a higher completion rate or were in the process of payment (80 per cent, approximately, by number of projects and by amount funded, excluding projects in progress), followed by mining and energy, construction, the service sector (71 per cent by value), and trailed by agriculture and fishing (47 per cent by number, 37 per cent by value). This latter group, as will be shown below, performs particularly poorly. However, the relative weight of failed projects is the lowest of the whole group. Although there is a high level of non-payment (delayed repayment), this does not seem to translate into a greater tendency to be dragged into high-risk situations; and the global recovery/outlay ratio is one of the highest (51 per cent), along with mining and energy (53 per cent). The worst ratio is that for services (40 per cent), although even this low rate is in no way comparable to the 27 per cent obtained by agriculture and fishing.

The main areas of risk for projects which failed or which involved legal action seem to be concentrated in agriculture and fishing, which accounted for 40 per cent by number of projects and 57 per cent by value of the total funding for the projects as a whole, *i.e.* roughly Ptas 4 000 million. This figure is equalled, and even partly exceeded, by service activities, although not in relative terms as part of its global performance (25 per cent and 24 per cent, respectively). The above does not mean that manufacturing industry has been overlooked; in absolute values it has 245 projects valued at slightly over Ptas 10 000 million, although its relative incidence on the profile of firms tends to be more diffused (14 per cent and 10 per cent, respectively).

An initial interpretation of the results for manufacturing industry must stress the slight differences observed between different industries according to their technological levels, which excludes any direct relationship between technical and financial performance and technological characteristics. This does not, however, mean that industries offering a more positive picture cannot be identified. As has already been pointed out, the high- and perhaps also to some extent the low-technology sectors are those that show greatest progress. This counterbalances the pitfalls (delays, failures or legal actions) into which projects may stumble. In contrast, the results for very-high-technology projects, as well as for medium-technology ones, are highly acceptable when compared with productive activities as a whole (industrial and non-industrial). However, they are at a slight disadvantage when compared to the remaining industrial activities.

Finally, it should not be inferred from the above analysis that there is a regional predisposition for projects to be successful or at risk. It could be that the lowest recovery ratios are obtained in those regions (*i.e.* Canaries, Andalucía, Asturias, Cantabria and Murcia) where the number of projects is very low, and the risks (failed/legal action) more significant in terms of outlay. Among the regions with the highest share of CDTI funding, the best performer is the Basque region (only 11 per cent of funds were in the ''risk'' category), compared to the other main regions, Madrid, Catalonia and the Valencia region (with between 20-22 per cent of ''risky'' funds).

V. CONCLUSIONS

This article analyses the performance of the main Spanish body in charge of promoting the technological development of firms over a period of eleven years. Several main conclusions emerge. First, and in general terms, the CDTI has made a positive contribution to the upgrading of the technological level of Spanish firms. In fact, at the end of the 1970s, the technological situation of firms was considerably underdeveloped with respect to other European countries and Spain lacked experience in active technological policies. Before then, imported foreign technology was the main source of technological development. Since then, and particularly in the period under consideration (1984-94), the CDTI has been able to collaborate with a considerable number of Spanish firms (around 2 000), which constitute the bulk of Spanish innovation. According to official Spanish statistics, R&D staff in these firms account for roughly 60 per cent of total R&D personnel in the Spanish business sector.

Another positive feature of the CDTI's mission is the way in which collaboration with firms is organised. Two aspects can be highlighted. First, the CDTI plays an ''active'' role in stimulating firms to undertake and evaluate innovative projects. It helps firms better define their projects, and, to a large extent, this explains the high success rate and hence the high level of returns. Second, the financing of innovation via loans has been very efficient. In fact, due to the low failure rate, the final ratio between the funds dependent on CDTI's budget and the global project budget is 1 to 11. In the absence of a well-developed supply of private venture capital, this aspect of the partnership is qualitatively very important. As noted above, firms, especially small and medium-sized ones, rate this part of the CDTI's activity very positively.

Nevertheless, the evaluation of the CDTI has revealed some less positive features. First, owing to a more risk-averse policy, there was a reduction in the size of projects over the period, and this probably reduced the level of the innovations achieved. Most resulting innovations have been gradual improvements in existing products and processes rather than radical innovations for international markets. Second, the study revealed the weak participation of foreign companies despite the fact they are a fundamental to a significant number of manufacturing sectors in Spain and that they are at the centre of the technological activities of many SMEs. Third, the sectoral priorities developed have led to the allocation of relatively less resources to branches in which Spain has revealed technological advantages, while the amounts devoted to sectors in which Spain has a less favourable international position have been comparatively higher.

CO-OPERATIVE RESEARCH CENTRES IN AUSTRALIA

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This article was written by Don Scott-Kemmis of the Department of Industry, Science and Resources (formerly Tourism), Australia. The views expressed in the article are those of the author and do not necessarily reflect those of the Australian Department of Industry, Science and Resources (formerly Tourism).

I. INTRODUCTION

The Co-operative Research Centres (CRC) Programme significantly strengthens the Australian research system. A CRC is a co-operative endeavour, under the direction of a Board, involving one or more universities and other public sector research organisations, with one or more users, to undertake focused, long-term strategic and applied research, and related postgraduate training. The Australian Commonwealth Government core funding has a vital role in the formation and development of a CRC. It is the ‘‘glue’’ that induces research organisations (which are frequently competitors) and users (which are often remote from research organisations) to collaborate in planning, managing and performing long-term research. The government support, albeit contingent on performance, provides the foundation and continuity for commitments from participants. The CRC Programme requirements regarding organisation and performance help ensure levels of professional governance and accountability that attract user involvement. The Commonwealth funding provides substantial leverage to the resources of the participants.

The Programme has introduced significant change in the organisation, governance and management of public sector research and has the potential to stimulate more far-reaching change. The participating public sector research organisations contribute largely in-kind resources to CRCs – staff time and physical facilities, but usually little cash. Hence, the Programme leads to a shift of some public sector research into managed collaborative arrangements that are likely to be in areas of national priority. This shift of resources (along with the new funds provided by the Programme) generates several benefits:

– greater co-operation among public sector research organisations enabling efficiencies;
– achievement of ‘‘critical mass’’ or at least ambitious major long-term research;
– greater involvement of government sector researchers in postgraduate training.

Users are also involved in the funding, conduct and management of research, and the supervision of postgraduates. Users include public sector agencies (*e.g.* in health, environment, agriculture) and private industry. The primary objectives in involving users are to:

– increase user funding of public sector research;
– increase user involvement in long-term research;
– raise the relevance to users of public sector research; and
– enhance the capture in Australia of the benefits of public sector research.

While the CRC Programme enjoys wide support from the public sector and industry, there has been continuing debate about some aspects of its orientation and management. There have been proposals to increase the ‘‘commercial focus’’ and the commercialisation of research outcomes. In particular, in the context of pressure to reduce government outlays, there have been calls for a greater reliance on industry funding and a greater focus on commercial outcomes. Some proponents of change from the private sector have sought both greater private sector control over the research activities of the CRCs while maintaining current levels of support from government and the public sector research organisations. Both of these approaches assume that the Programme is, or ought to be, an industry support mechanism, the primary objective of which is either to generate commercialisable technologies or to support innovation in the private sector. The most recent review of the CRC Programme, the Mercer Review, did not agree with this ‘‘positioning’’, concluding that the programme had a more systemic role in the ‘‘national innovation system’’. It believed the best elements of the Programme were nurtured through collaboration, not control.

II. CHARACTERISTICS OF THE AUSTRALIAN NATIONAL INNOVATION SYSTEM

Significant characteristics of Australia’s R&D performance are:

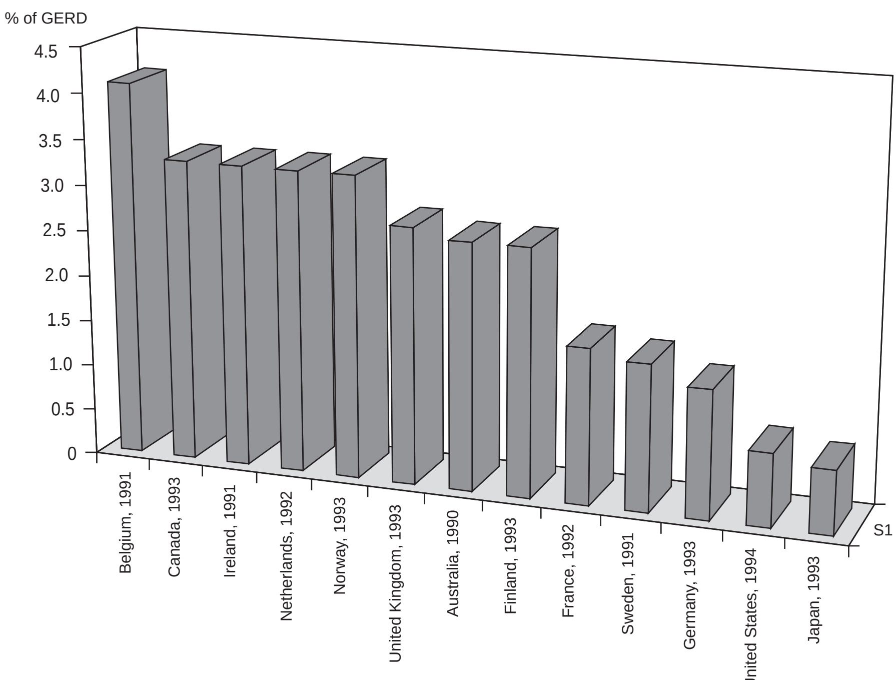
– low gross expenditure on research and development (GERD) in relation to gross domestic product (GDP) (1.61 per cent in 1994/95), reflecting relatively low business expenditure on R&D (BERD) (0.74 per cent of GDP in 1994/95);
– high public expenditure on R&D (52 per cent of GERD) relative to private expenditure on R&D;
– a relatively high ratio of basic to applied research.

In addition, the subsidiaries of foreign-owned firms have a major role in the Australian innovation system. Affiliates of foreign-owned firms account for about 45 per cent of manufacturing R&D – among countries, only in Ireland is this proportion higher (58 per cent). Among OECD countries, only in Australia, Ireland and Finland are R&D intensities in locally owned manufacturing firms lower than in foreign affiliates (Department of Industry, Science and Tourism, 1996*a*).

In the past, the domestic orientation of manufacturing, together with tariff protection and isolation, provided weak incentives for R&D (Gregory, 1993). The relatively low levels of business enterprise R&D in part reflect the continuing legacy of the past (Industry Commission, 1995). More recently, significant changes in industrial structure and in tariff policy are leading to a transformation of the national innovation system. BERD grew at 13 per cent a year over the 1981-92 period – twice the OECD average. As a result, an increasing proportion of R&D has been directed to experimental development. The increasing importance to industry of R&D and innovation is evident in the growth of the R&D-to-sales ratio in most manufacturing and in the rapid growth of Australian patent applications in the United States.

Figure 1. **Business-financed public sector R&D**

As a percentage of GERD



Source: Department of Industry, Science and Tourism.

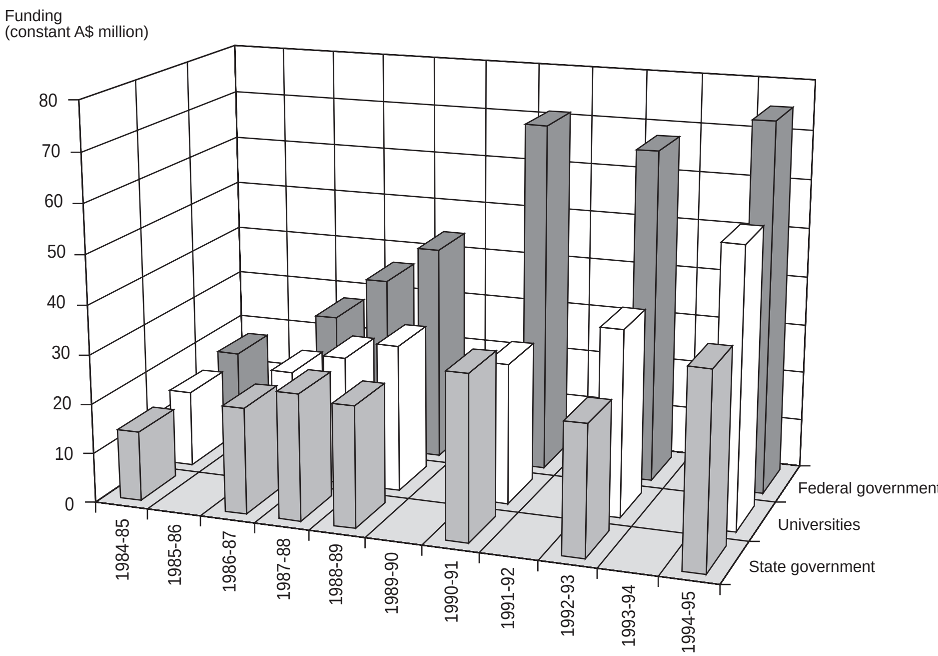
A small proportion (2.5 per cent) of BERD is performed in Australia in the higher education and government sector. This proportion is close to the average for OECD countries, and considerably higher than in the United States and Japan (Figure 1). Business funding of public sector R&D in Australia has grown significantly since the mid-1980s, slightly more rapidly than the rate of growth of BERD. Over the period from 1990 the higher education sector has shown very rapid growth in R&D support from business (Figure 2).

Despite these trends the Industry Commission (1995) expressed concerns about the linkage mechanisms in Australia:

> ... it is likely that potentially beneficial interaction can be impeded by lack of information, both about research capacities and available knowledge and about the needs and opportunities of users of research. It is also widely felt that a 'cultural gap' between public sector researchers and private firms has

Figure 2. **Business funding of public sector R&D in Australia, 1984-95**

Federal and state government organisations and universities



Source: Australian Bureau of Statistics.

compounded the difficulties confronting interaction. It seems that Australia's researchers are less mobile domestically than is observed overseas. That may also help account for 'cultural' impediments between the public and private sectors.''

III. THE ROLE OF THE CRC PROGRAMME

The CRC Programme addresses several challenges to effective research and innovation in Australia:

- The lack of critical mass that arises from the inevitable constraints of a small country, the structural and spatial fragmentation of research capacity among institutions and the seven Australian states, and the increasing requirement for interdisciplinary research.
- The impediments to interaction between industry (and users of research generally) and the public sector research organisations – these arise, *inter alia*, from institutional cultures, the lack of mobility of research personnel, and the different technological objectives of researchers and potential users.
- The particular problems in creating an effective role for research organisations in the development of industries, including new ventures, in the more research-intensive sectors such as information and communication technologies, new materials, pharmaceuticals and other specialised manufacturing sectors, where there are few large locally owned firms and limited research activity.
- The challenges of maintaining appropriate research support and management for the primary industry sectors, which are vital for Australia, and where knowledge intensity is rising and is increasingly critical for competitiveness and sustainability, but where knowledge appropriation is complex, spillovers are high and simple customer-contractor approaches are not relevant.
- The development of links to leading international centres of research, which is increasingly important due to the internationalisation of research, on terms that are beneficial to Australia.

A central motivation in the development of the CRC Programme was the strengthening both of university research and of co-operation between universities and government research organisations. The Programme is now widely seen as the most successful mechanism in Australia for linking users with research organisations. It is both a ''bridging'' mechanism and a new arrangement for research. It is not another contract research mechanism providing subsidised research to industry. The Programme involves:

- focusing substantial high-level research resources (perhaps ‘‘critical mass’’) on issues perceived to be of national importance;
- research management that entails accountability with considerable flexibility;
- direction setting and evaluation that involves a range of users and research providers;
- developing ‘‘user-aware’’ postgraduates, researchers and research managers;
- changing the ‘‘culture’’ and capabilities of users and research providers in Australia;
- developing focus points from which substantial international links can develop;
- fostering collaboration and networking among research agencies;
- enhancing the quality and relevance of education.

IV. OVERVIEW OF THE CRC PROGRAMME[1]

The CRC Programme aims to strengthen long-term collaboration between research organisations, and between these organisations and the users of research, in order to obtain better value from Australia’s investment in R&D. A 1989 report by an S&T advisory body had recommended the creation of new interdisciplinary science and technology centres, similar to those in several other countries (in particular the Fraunhofer Institutes in Germany), to improve links between higher education, government and the private sector in order to enable the formation of large and integrated research teams. It recommended that these centres be jointly funded by the government and participants and be focused on projects of national importance (Australian Science, Technology and Engineering Council, 1989).

The CRC Programme commenced with the first selection round in 1990 and subsequent selection rounds were held in 1991, 1992, 1994 and 1996. Interest in participation in the Programme has been strong, with 270 applications in the first three rounds. There are now 67 centres. Participation in the Programme is diverse: over 250 companies; 35 universities; 61 state government departments and agencies; 24 Commonwealth Scientific Industrial Research Organisation (CSIRO) Divisions; eight other Commonwealth research agencies; eight rural research corporations; and numerous other organisations.

The Programme's formal objectives are listed in Table 1, with the main strategies for achieving those objectives set out in Table 2. While the objectives have remained largely unchanged, the Programme has nevertheless evolved in several respects. There has been an increasing emphasis both on ''balancing'' the strategic and long-term research orientation with shorter-term and more applied research, and on the commercialisation of research.

The characteristics of CRCs are summarised in Table 3. Each CRC is established through a Centre Agreement, which is a contract among core participants, and a Commonwealth Agreement, which is a contract between the participants and the Commonwealth government. These agreements detail the financial and in-kind commitments of the participants, the details of the research and education programmes, the management structure, performance milestones and indicators. Both agreements cover issues such as ownership of intellectual property, commercialisation and staffing arrangements. The Programme has sought to balance flexibility with accountability through financial monitoring and periodic reviews.

CRCs are, in general, structured like small companies. All are governed by Boards and these have independent chairmen. The Director of the CRC reports directly to, and is usually a member of, the Board. However, most CRCs are unincorporated joint ventures – only 14 have incorporated although several others have created companies responsible for the management of intellectual property created by the CRC.

Table 1. **Objectives of the CRC Programme**

1.	Contribute to national objectives including the establishment of internationally competitive industry sectors, through supporting long-term, high-quality scientific and technological research.
2.	Stimulate a broader education and training experience, particularly in graduate programmes, through initiatives such as the active involvement of researchers from outside the higher education system.
3.	Capture the benefits of research, and strengthen the links between research and its commercial and other applications, by the active involvement of the users of research in the work and management of the centres.
4.	Promote co-operation in research, and through it a more efficient use of resources by increasing the concentration of centres of research and strengthening research networks.

Source: Author.

Table 2. **Main strategies to achieve Programme objectives**

Goal	Strategies
Contribute to economic and social development	– Support long-term, high-quality strategic research – Select centres through expert panels on the basis of open applications
Strengthen education and training	– Integrate postgraduate students into CRC research programmes – Involve researchers from government and users in supervision – Support industry training activities to disseminate new knowledge
Raise the effectiveness of R&D	– Require users to contribute to the support of CRC research – Involve users in the management and activities of CRCs – Strengthen R&D management through the role of CRC Boards – Improve the mobility of graduates and research personnel
Raise the efficiency of R&D	– Stimulate co-operation among public sector research providers to achieve synergy and "critical mass" – Strengthen accountability through performance reviews – Enable sharing of major facilities and equipment

Source: Author.

The Programme overall is under the guidance of the CRC Committee which advises the Minister on the operation of the programme, including the selection of new CRCs. Membership of the CRC Committee is typically from the public sector research granting councils and boards, public sector research agencies, the universities and, with an emphasis on individuals with a research background, business.

To implement the Programme, the responsible government agency has developed selection criteria, evaluation processes, organisational requirements, guidelines for CRC Directors and Boards, performance indicators and monitoring procedures. Recognising that each CRC must find an approach to management that is effective for its unique set of participants, objectives and circumstances, the Programme provides considerable flexibility for the Director and the Board of a CRC.

Table 3. **The key characteristics of a CRC**

Sectors	Manufacturing, information and communication technology, mining, energy, health and pharmaceuticals, environment, agribusiness.
Selection	Selection is on the advice of the CRC Committee, informed by Expert Panels, through a competitive process based on specified criteria.
Activities	– Research: usually a portfolio from short-term applied to strategic; – Education: postgraduate research; – Training: to raise awareness of users and transfer knowledge.
Core participation:	A CRC's core participants are those organisations which have entered into seven-year contracts to support and collaborate in the CRC.
– Research and education organisations	All CRCs involve universities (often more than one and usually more than one department in a university); they also involve Commonwealth government research organisations and in some cases other research organisations such as state government departments and independent research organisations.
– Users	Users who are core participants contribute to the resources of a CRC and participate in all aspects of management. Users may be government departments, utilities (*e.g.* water, conservation, pollution control), GBEs, industry associations or private companies.
Governance	Each CRC has a Director and a Board with an independent chair.
Funding	The CRC Programme grant provides from 16 to 49 per cent of the resources of a CRC. All core participants provide cash and in-kind contributions. The average budget of a CRC is A$ 6.3 million a year. CRC Programme funds can be used flexibly for salaries, research costs and capital items.
Performance evaluation and review	CRCs must enter into a contractual agreement with the Commonwealth government, which identifies performance milestones and indicators. Performance is monitored by the CRC Secretariat. Performance is reviewed by the CRC Committee, through Expert Panels, after the second and fifth years.
Duration	CRCs are established under contracts that generally run for seven years. Established CRCs may compete with new applicants for further funding.
Infrastructure	Most of the physical infrastructure of a CRC (offices, research facilities) is provided by the participants. In some cases additional facilities and equipment are purchased.
Location	Most CRCs have one or more nodes, in addition to a central location (usually in a university), depending on the number and location of participants.
International links	Participation by overseas companies and research organisations is possible, if it clearly provides benefits to Australia, is within the mandate of the core participants, and is approved by the CRC Committee.

Source: Author.

V. RELATIONSHIPS WITH USERS AND THE APPLICATION OF RESEARCH OUTCOMES

While every centre has unique characteristics, it is useful to characterise four groups of CRC:

1) *Specific users:* These are CRCs focused on developing or improving commercial technologies and have a small number of users as core participants. While these CRCs usually disseminate knowledge to a wide range of potential users, they focus links on the core participants. Examples include Advanced Composite Structures, and Maritime Engineering.

2) *Dispersed users:* These CRC are also focused on commercial technologies in specific sectors but their users are generally more dispersed and intermediaries may have a significant role. Examples include Mineral Exploration Technologies, and Viticulture.

3) *Industry development:* These CRCs have a strong commercial focus but many also have substantial public interest objectives. As these centres are in new sectors, industry development and new firm formation are major objectives. Examples include Photonics, and Molecular Engineering and Technology.

2) *Public interest:* These CRCs are primarily focused on public interest outcomes such as health or sustainable resource use.

VI. STRUCTURE AND OPERATION OF THE CRC PROGRAMME

Expert panels, one in the life sciences and one in the physical sciences and engineering, are used to assess applications for new centres. In addition, at least six external referees are requested to comment on the proposals. The chairs and co-chairs of the two selection panels report to the CRC Committee.

A fundamental feature of the CRC Programme is the schedule of performance reviews. Performance indicators are specified individually for each CRC in their Commonwealth Agreement. When negotiating their agreement from a successful application, each Centre is asked to design a set of indicators that are most relevant to their circumstances. Centres are required to report against these indicators in their Annual Report. The second and fifth year reviews are conducted in two stages, by two independent panels.

- Stage 1 is a review of the scientific programme, largely against criteria related to the quality of the science as such. It is a peer review of the scientific research programme and is managed by the CRC, with membership of the independent panel approved by the CRC Committee.
- Stage 2 draws on the Stage 1 Report and is carried out over two days by a three- to five-person independent review panel appointed by the CRC Committee. Performance evaluation and comparison between CRCs is conducted on the basis of evaluation criteria based on the selection criteria.

No CRCs have been terminated due to inadequate performance. However, not all CRCs have been successful in achieving further core funding after their initial seven-year contract. Round 1 CRCs were eligible to apply for ''renewal'' funding in the 1996 Fifth Selection Round: two did not apply; three sought funding but were not successful; and ten were selected for further funding, in competition with new applicants (of which six were successful). For most of those CRCs that gained ''renewal'' funding, the level of CRC Programme core funding declined over time, encouraging a transition to self-funding.

VII. REVIEWS AND EVALUATIONS OF THE CRC PROGRAMME

A comprehensive evaluation of the CRC Programme was carried out in 1995 and was overseen by an independent chairman. The Myers Report, like the later Industry Commission report, emphasized that it was too early to evaluate the performance of a Programme focusing on long-term research and strategic relationships. Nevertheless, the report concluded that the Programme was a ''... major valuable and complementary addition to the range of Australian science and technology funding ... [and that the] four current objectives of the CRC Programme are still highly relevant to Australia's needs'', and endorsed its continuation (Myers Committee, 1995, p. 2). The Report found that the Programme:

> ''... is well conceived and that the prospects of the government's broad objectives for the scheme being achieved are excellent. Indeed there is already clear evidence of a significant and beneficial change in research

> culture – especially insofar as it concerns universities and their co-operation with government agencies and industry. The change in culture extends to industry and other research users who are showing a general enthusiasm for the programme and a willingness to become actively involved with longer-term and more basic research.''
>
> (Myers Committee, 1995, p. 1)

The Myers Report recommended that more attention be given to management of the centres and the overall Programme, through the training of project and centre managers, appointment of independent chairs to CRC Boards, more attention to strategic planning, performance indicators and ongoing evaluation and reporting by the CRC Committee.

The Industry Commission in its review of R&D in Australia observed that:

> ''The CRC Programme has a number of commendable features in terms of programme design. Grants are awarded after a competitive selection process. Extensive monitoring and evaluation processes are in place .... There is a real prospect that continued funding for an existing CRC would be able to be contested by other applicants after seven years.''
>
> (Industry Commission, 1995, p. 850)

This review, however, raised several questions regarding the effectiveness of collaboration among researchers, the extent to which individual firms may benefit from participation, and the interaction between the CRCs and the overall innovation system.

Following a change of government in 1996, a review of the Programme was established in 1997, focusing on the scope for measures to increase commercialisation and self-funding. The review conducted a survey of the 67 CRCs, seeking information on outputs and current and future income, selected 10 Centres as case studies of management issues, invited submissions from over 50 ''stakeholder'' organisations, and held four ''focus group'' meetings, each with 15-20 senior executives of major companies in an industrial sector. The review encountered strong support for the Programme from research providers, major firms and business associations.

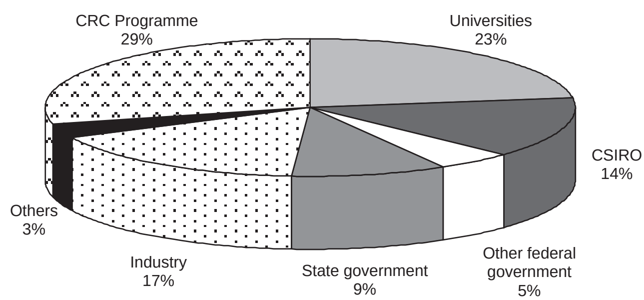
The review concluded that the Programme ''... plays an important role in the Australian innovation system ... has strong and widespread support ... [is] developing valuable new approaches to research management and commercialisation...'' and ''represents an effective investment of public money in R&D'' (Department of Industry, Science and Tourism, 1998). It also concluded that while there were many cases of effective interaction and technology transfer, the risks of ''excessive'' benefits being captured by private firms were exaggerated. In relation to self-funding, the review commented that there was little prospect of centres becoming self-funding after seven years, and only a remote possibility that returns from commercialisation could provide a revenue stream able to displace the need for ongoing government funding of the Programme.

In April 1998 the government announced that it would continue the CRC Programme at the projected funding level and that it would introduce changes to the management of centres and the Programme along the lines of the main recommendations of the Mercer Review.

VIII. SOURCES OF FUNDING FOR CRCS

CRC Programme funds were A$ 147 million in 1997/98 – less than 4 per cent of total Commonwealth expenditure on R&D. However, the majority of the resources for a Centre are provided by the participants and the overall level of support for the 67 Centres is equivalent to about A$ 450 million a year. As shown in Figure 3, which is based on the aggregated whole-of-life core funding commitments for all 67 CRCs, CRC Programme funding provides 29 per cent of the overall support. Other sources of support are: universities (23 per cent); CSIRO (14 per cent); private industry (17 per cent); state government agencies (9 per cent); Commonwealth agencies and departments (5 per cent).

Figure 3. **Funding of CRCs: whole of life commitments of core participants' proportion**

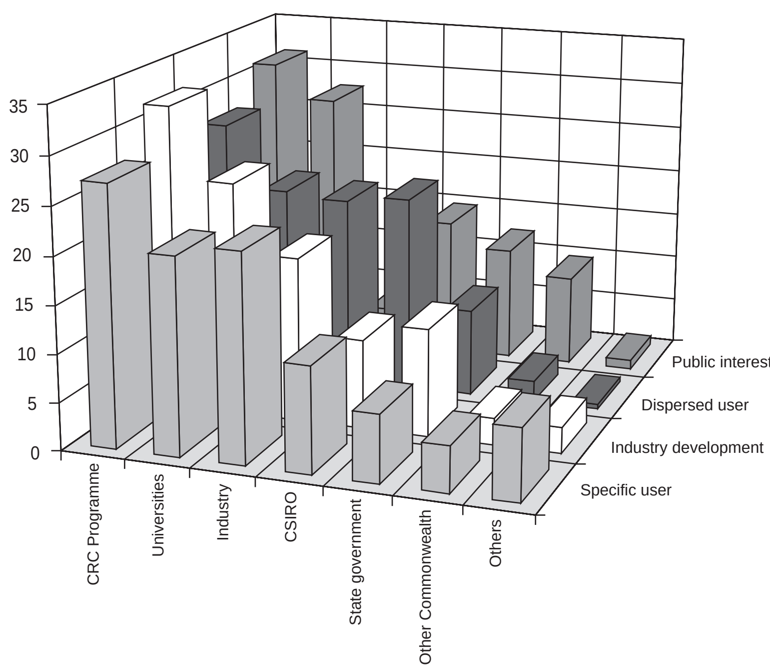


Source: S&T Budget Statement 1997-98, Department of Industry, Science and Tourism.

The proportion of a centre's resources provided by CRC Programme funds ranges from 16.5 per cent in the case of the CRC for Renewable Energy to 49.5 per cent in the case of the CRC for Industrial Plant Biopolymers. In 70 per cent of CRCs, the CRC Programme funding provides less than one-third of the whole-of-life core funding. The support from the different types of participant varies, depending on the type of CRC. For example, state government agencies and departments are particularly significant in the agriculture-related CRCs (Figure 4).

Industry funding of individual CRCs ranges from zero, in the case of some public interest CRCs, to 51 per cent in the case of the CRC for Intelligent Decision

Figure 4. **Funding of CRCs: source of resources and category of CRC**
As a percentage of whole of life core commitment



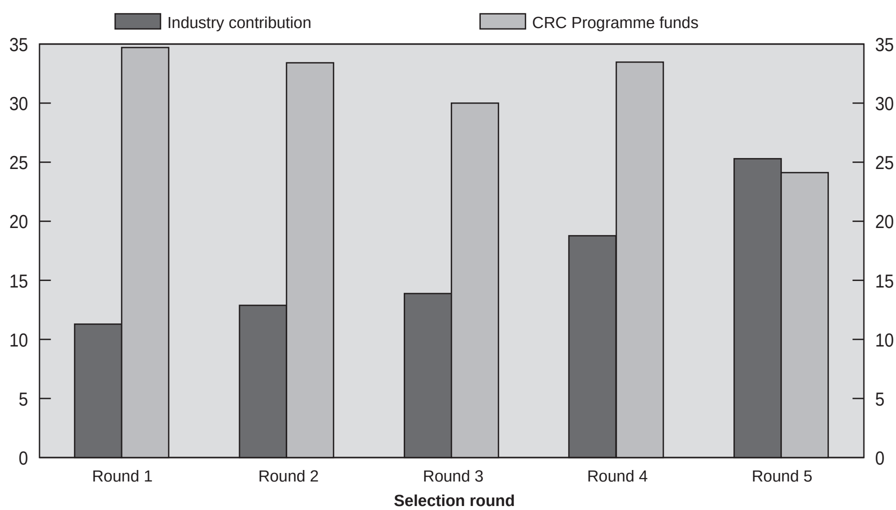
Source: Mercer Review, Department of Science, Industry and Tourism, 1998.

Systems. As shown in Figure 5, private industry funding of CRCs has increased steadily from 11.3 per cent in the first selection round to 25.3 per cent in the fifth round, while CRC Programme funds have accounted for a declining share of the funding of new centres. For the fifth-round CRCs, industry committed more funding for the selected CRCs than did the CRC Programme. This shift is due in large part to government policy which has required a higher level of user funding for industry-oriented CRCs, but also to a steady increase in industry support for the Programme.

In addition to their core funding, some CRCs gain external earnings from such activities as contract research and licensing intellectual property. In 1996/97 such additional external earnings were at least A$ 46 million (equivalent to about 10 per cent of overall annual core funding). As shown in Figure 6, 79 per cent of external earnings were from payments for contract research. A small proportion of CRCs, principally the agriculture and mining CRCs with dispersed users, account for a major share of contract research income. In these cases, the majority of contract research income is in large part a substitute for committed core funding.

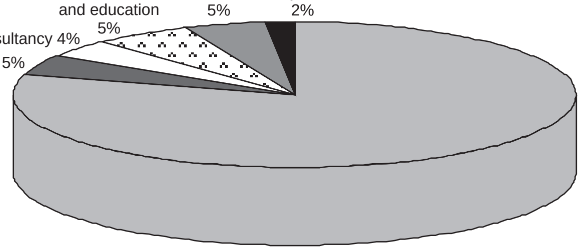
Figure 5. **Industry and CRC Programme funding by selection round**

As a percentage of whole of life funding commitment



Source: Mercer Review, Department of Industry, Science and Tourism, 1998.

Figure 6. **External earnings, 1996/97**
By source



Source: Mercer Review, Department of Industry, Science and Tourism, 1998.

This arrangement has been accepted by the Programme in those cases where funding bodies (such as the Rural R&D Corporations) are unable to make seven-year funding commitments.

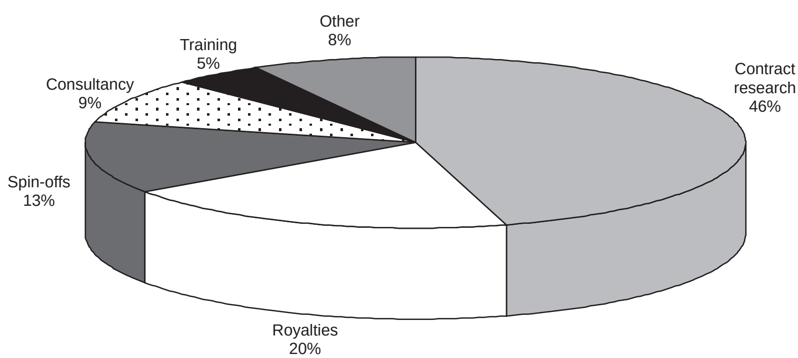
The CRC Programme does not offer the prospect of indefinite core funding to Centres. Whether after seven years or fourteen years, for those gaining ‘‘renewal’’, all CRCs must look to a future independent of CRC Programme funds. For those CRCs that aim to continue, there are four significant potential funding sources: continued core commitments by the existing and new participants; commercial services such as contract research; income from licensing intellectual property; and income from the commercial activities of spinoff companies or capital gains from the sale of equity in such companies.

In a proportion of CRCs, the participating organisations will not seek to continue the co-operative arrangement after the withdrawal of CRC Programme funds. This is likely to be the case either because the participants will revert to competitive or bilateral relationships (in the absence of the ‘‘glue’’ of programme funds) or because the central shared research objectives have been achieved.

While several CRCs have well-developed plans for achieving self-funding, with income from a range of sources, all of these will require longer than the initial seven years of support to achieve that objective. For example, two Round 1 CRCs, renewed in 1997, that plan to achieve self-funding after 10-12 years of CRC Programme support are:

– The CRC for Tissue Growth and Repair plans to be independent of CRC Programme funds in 2004 after 11 years of Programme support. The CRC currently earns A$ 1.2 million from contract research and expects this income to remain at about the same level by 2000. Royalties generated an income of A$ 230 000 in 1996/97 and are expected to grow to about A$ 700 000 a year by 2000 and A$ 2.2 million by 2004. The spinoff company expects to earn A$ 5 million in 2000/01 from royalties and direct production. The spinoff is a core participant in the renewed CRC, providing funding of A$ 900 000 a year.
– The CRC for Eye Research and Technology currently has an income of A$ 2.7 million from contract research. By 2000/01 the CRC expects income from contract research to rise to A$ 4.7 million and income from royalties to reach about A$ 5.4 million a year. The CRC is developing three parallel activities to support ongoing development, by establishing:
  • the National Eye Institute, as a world class multi-disciplinary basic and applied research centre funded by royalty streams and basic science grants;
  • a spinoff company, VPL, to market eye-care services and products in Asia and beyond, and based on a core contact lens business;
  • a second spinoff company, to develop ‘‘designer’’ biomaterials, established in Australia with local and overseas investment, and including significant equity held by the CRC.

Figure 7. **Expected external income, 2000/01**
42 CRCs, total estimated income: A$ 77.6 million

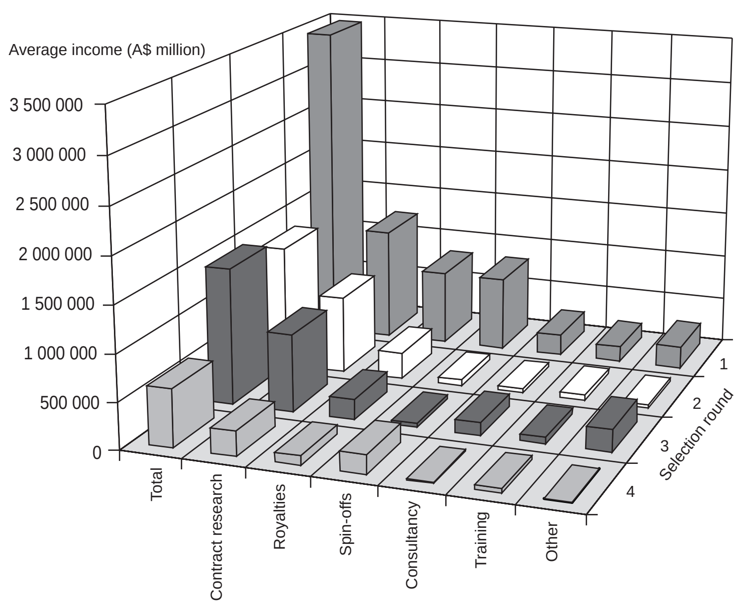


Source: Mercer Review, Department of Industry, Science and Tourism, 1998.

However, of Round 1 and Round 2 CRCs (*i.e.* those over seven years old by 2000), only a small proportion expect to achieve full self-funding. Two in five expect to have an external income of less than A$ 1 million a year, *i.e.* considerably less than the level of core funding from the CRC Programme.

As shown in Figure 7, contract research is the major source of expected external income. This is projected to account for 45 per cent of the A$ 77.6 million in estimated external earnings in 2000.[2] Other services, such as training and consulting, are anticipated to provide an additional 14 per cent of expected aggregate income. Income from the commercialisation of intellectual property (IP) (royalties and the activities of spinoffs) is anticipated to account for 33 per cent of aggregate income.[3] While income from this source is the least predictable, it may be closer to 50 per cent of external earnings by 2000, and account for an increasing proportion of income for several years. See also Figures 8 and 9.

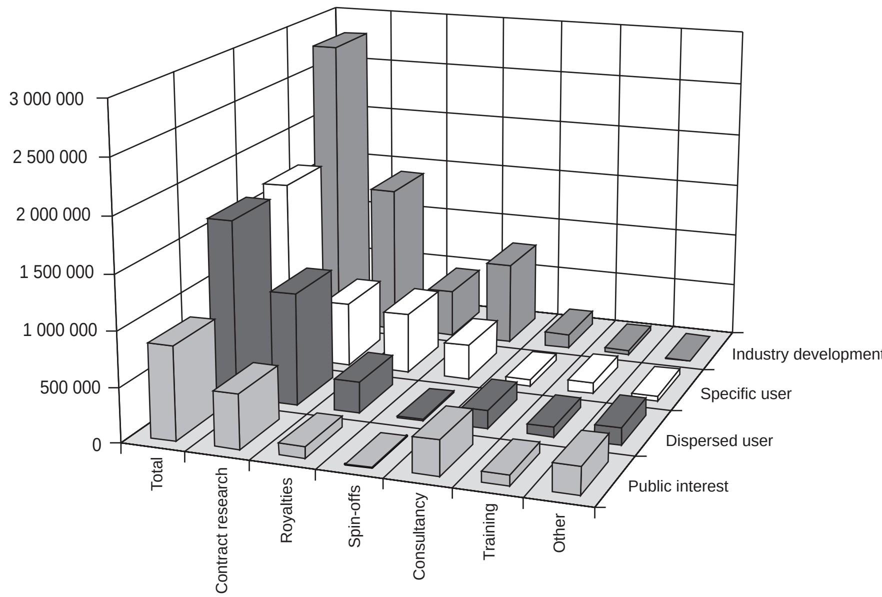
Figure 8. **Estimated average external income, 2000/01**
By source and selection round



Source: Mercer Review, Department of Industry, Science and Tourism, 1998.

Figure 9. **Estimated external income, 2000-01**

By source and category of CRC (A$)



Source: Mercer Review, Department of Science, Industry and Tourism, 1998.

The ''Industry Development'' group of CRCs are the most likely to generate substantial revenue from IP, but may require extended support before royalty income is substantial. For example, the CRC for Alloy and Solidification Technology is focused on a long-term programme to develop the Australian light metals industry. It does not expect to be commercially viable inside 10-15 years.

Even among CRCs oriented to developing a group of technologies and related capabilities, patenting is not always important and other avenues of self-funding would have to be developed. For example, in the case of the Aquaculture CRC, the individual companies are too small and the industry is too new and fragile to support major research. Only a small proportion of the new technology can be appropriated by individual firms. The CRC has developed a close working relationship with the Fisheries Research and Development Corporation and in 1996/97 received almost A$ 800 000 in project funding from the corporation. However, they are not a core participant in the CRC and the corporation's major stakeholders are the wild capture fisheries.

IX. MANAGEMENT OF RESEARCH AND COMMERCIALISATION IN CRCs

Like any research organisation, CRCs must balance the requirements for planned outcomes and structured processes with the importance of creativity and uncertainty. CRCs must manage three fundamental tensions that are summarised in general terms in Box 1.

Box 1. **Fundamental tensions in CRCs**

Loose co-operative arrangement: resources of each participant managed by the participant.	**OR**	**Collaborative venture:** unified management of the CRCs' resources.
''Research push'': focus on long-term research to develop technological opportunity.	**OR**	**''User pull'':** focus on the specific needs and priorities of potential users.
Wide generic application: knowledge for a sector or large number of potential users.	**OR**	**Specific direct application:** knowledge principally for application by core participants or a pre-determined commercial vehicle.

As the characteristics of the balance will be different in each CRC, there can be no *a priori* resolution of these tensions by detailed regulations from Programme managers. To manage these inherent tensions, the CRC Programme relies on:

- the unifying influence of the shared objectives and funding that brought the participants together;
- the good will and professionalism of the participants;

– sound agreements between participants and good commercial practice in each CRC;
– the Boards and Directors of CRCs;
– accountability for performance through review procedures of the Programme.

It is a task of the Board of each CRC to ensure that the CRC's research programme is more than a re-labelled portfolio of independent interests and that the public sector research organisations do not ''appropriate'' the CRC Programme core funding for basic research, restricting shorter-term user-oriented research to that funding provided by users. Outside the context of the CRC Programme, research organisations compete for funding from government and from industry. The strong pressure on research organisations for external earnings and the characteristics of the internal culture of some research organisations, militates against collaboration as a preferred approach to research. There are clearly significant transaction costs in establishing co-operative programmes and one of the roles of the CRC Programme funding is to defray some of those costs. Nevertheless, it can take a great deal of effort in the early years of a CRC, by the Board, Director and Programme Managers, to develop co-operation among the participating research organisations. Some public sector research organisations resist the additional accountability requirements associated with involvement in the Programme.

It is evident that many CRCs have developed effective co-operation among public sector research organisations and with user participants. Many major companies consider that CRCs have developed levels of co-operation that are often substantially better than those that existed prior to the Programme. Even in sectors where a long history of links with public sector research, according to comments from industry, the CRC Programme has significantly improved co-operation. However, a significant proportion of companies consider that many CRCs are not sufficiently user-oriented and that the public sector research organisations dominate the setting of research directions. It was not unusual for a CRC to begin with the public sector researchers having long-term projects in mind and the users focusing on short-term objectives. However, the CRC Committee advises centres to focus on longer-term research: ''Centres will maintain a strategic focus on long-term, high-quality research using contract research and short-term problem-solving as subsidiary means of fostering effective co-operative research. Centres undertaking contract research, where they do not retain control of resulting intellectual property, should apply the principle of full cost recovery or commercial pricing'' (Department of Industry, Science and Tourism, 1995, p. 9).

Issues concerning the ownership and management of IP are a major cause of friction between industry and the public sector research organisations, both within and outside the CRC Programme. CRCs differ both in the importance they attach to IP and in their approach to its management. The ‘‘Specific User’’ group of CRCs tends to have an overall policy for IP management, aims to maximise income from licensing and provides core participants with first right of refusal on IP licensing. The ‘‘Industry Development’’ group of CRCs, often with less links to users, also attaches high importance to IP management but one in two of these centres intends to commercialise their IP through spinoff companies.

X. OUTPUTS AND BENEFITS OF THE CRC PROGRAMME

It is useful to discuss the benefits of the CRC Programme in terms of five types of outcome:

Innovation infrastructure and enabling capacities. Important outcomes are the training of postgraduates in the environment of a CRC, the formation of networks among researchers in different organisations, the changes in attitude and culture that result from collaboration, and the international links that develop with the *foci* that CRCs provide. These are systemic benefits that strengthen the capacities for innovation and knowledge development and transfer in Australia. These outcomes are difficult to measure in a systematic way, but the Myers Report and the Mercer Review found that these types of output are highly valued by users and researchers. Table 4 lists the diverse types of benefits that arise for different types of participant.

Scientific and technical knowledge. CRCs aim to produce new scientific and technical knowledge relevant to significant problems and opportunities in Australia, and to promote its application. Such applications are of diverse types and involve a diverse range of organisations. They could be new approaches to managing environmental impacts (for example in relation to soil, water, reefs, sugar, cotton, pests), changed research and business strategies in industry or the public sector owing to better awareness of technological opportunities, incremental changes in methods, processes or products (for example, in minerals exploration and processing, food processing, engineering), or new products or services. Substantial new product technologies could be applied through newly created ventures, participating private companies, or organisations unrelated to the CRC. These outputs are embodied in publications, patents, postgraduate students, researchers and the staff of users who participate in CRC-related activities.

New organisational developments. The Programme is stimulating the emergence of new commercial organisations and may lead to the establishment of new research organisations. Several CRCs have created spinoff

Table 4. **Benefits of CRCs: strengthening the national innovation system**

1. More effective research:

- critical mass, a diversity of skills and learning to work in multidisciplinary teams;
- focusing on areas of high priority;
- reduction in duplication;
- co-operation and exchange of staff raises trust and communication;
- better identification of user needs leading to improved and faster transfer and adoption;
- stronger research networks and improved access to researchers and facilities;
- developing skills in identifying, protecting and marketing intellectual property;
- a capacity to take research further towards commercialisation and hence be in a stronger bargaining position with potential licensees;
- critical mass of researchers attracts overseas interest, creating new opportunities for interaction.

2. Universities and government research organisations:

- greater acceptance of applied research within a university;
- new knowledge and understanding more quickly introduced into courses;
- greater credibility in the eyes of local and overseas industry;
- strengthens the focus on areas of national importance rather than on international research fashions;
- attracts high-quality postgraduates and enhances opportunities for postgraduate students;
- access to national research programmes;
- enables a long-term and coherent relationship with industry, not chasing small contracts.

3. Postgraduates:

- with a better awareness of user needs;
- experienced in user-oriented research;
- enhanced career prospects;
- focused postgraduate training in areas of priority for users.

4. Industry:

- more ''user friendly'' access to university and government facilities and background IP;
- assists the awareness and evaluation of alternative ideas and techniques and potential technologies;
- leverages the company R&D effort and improves its quality, which is important for companies competing in global markets;
- risk sharing based on the leveraging of overall CRC funds provides co-investment in pre-competitive research;
- stimulates increased corporate funding of long-term R&D;
- can develop collaboration and relationships along and across the value chain;
- industry priorities are more important to the CRC than to a large research provider.

Source: Author.

companies to commercialise technologies. In some cases the activities of CRCs are stimulating investment and organisational decisions by established companies. For example, research in CRCs in the areas of plant biotechnology, optical lenses, photonics, new materials and molecular engineering appears likely to influence major international companies to either locate research and production facilities in Australia or to continue to invest in the technological activities of an established Australian subsidiary.

Applications of knowledge. Knowledge developed through the CRC Programme has led to changes in policies, programmes, methods, products and processes. For example, the CRC for the Ecologically Sustainable Development of the Great Barrier Reef has stimulated changes in policy and practice by public sector organisations and by private sector fishing, tourism and agricultural enterprises. Several CRCs have developed new diagnostics for plant, animal and human diseases.

Economic, social and environmental impacts. The ultimate objective of a CRC, and the reason for support under the Programme, is to contribute significantly to priority economic, social or environmental objectives.

The impact of the Programme goes beyond changing culture. The shared understanding, interests, knowledge and trust that can develop through collaboration establishes networks that bridge organisations and sectors, enabling knowledge to flow and opportunities to be identified. The small size and flexibility of the bureaucracy in CRCs and their focused activities assist CRCs to realise some of the potential synergy between government research organisations, universities and private industry. Companies generally value the involvement in the CRC of customers or suppliers, or firms from other sectors, which share a common technology or range of challenges. For example, the CRC for Advanced Composite Structures has recently expanded to include the marine and transport sector in addition to the initial focus on aerospace. The CRC for the Cattle and Beef Industry faced the challenge of overcoming fragmentation and hostility in the industry and the distrust among research providers. A vital step was the appointment of a Chairman and Board that could command respect throughout the industry. From that base the CRC worked to gradually draw users into the planning and implementation of the CRC's work.

Several state government departments have increased their involvement in the CRC Programme and their role in facilitating the formation of CRCs with nodes in their state. For example, the New south Wales Department of Agriculture will in future channel more of its research support through the CRC Programme. The Queensland Department of Tourism, Small Business and Industry facilitates the development of CRCs with activities in Queensland. In several cases it has assisted the preparation of proposals and provided funding for some of the costs of application and establishment. By mid-1996, the department had provided

A$ 4.35 million in seed funding to assist CRCs (Coopers and Lybrand, 1996). International links can strengthen the effectiveness of research and its commercialisation. The growing, and to some extent unforeseen, role of the CRC Programme in strengthening links between Australian research groups and companies and overseas research and commercial organisations was identified in both the Myers Report and the Mercer Review.

Postgraduate training is a vital activity of almost all CRCs. For example, the CRC for Waste Management and Pollution Control allocates about 40 per cent of the funding from the CRC Programme funds to education and training. By the end of the first seven years of the CRC it will have graduated 50 PhDs, above the normal output of the education organisations associated with the CRC. It also runs additional short training programmes for postgraduate students. These programmes attracted 400 students in 1996 and 350 in 1997.

In 1995/96 there were almost 1 500 students in CRCs, of which over 75 per cent were PhD students. In the period 1991-95, over 3 000 postgraduate students have undertaken their research in a CRC. Students participating in CRCs are exposed at an early stage of their careers to a professional work environment involving industrial and commercial practices, including technology and research management, intellectual property, quality assurance and commercialisation.

It is useful to identify four categories of knowledge generated and disseminated by CRCs:

- ***Scientific knowledge of wide potential application.*** All CRCs attach a high level of importance to publications in the open scientific literature. The publication record is a performance indicator for all CRCs. Publication of research results is least important for the ''Industry Development'' group of CRCs. The reason for this is the need for secrecy prior to patenting. For example, the research underlying the CRC for Molecular Engineering and Technology began in the mid-1980s and the first patent was granted in 1987. But the first publication of the research was in 1997.
- ***Knowledge relevant to environmental, health or other non-commercial community objectives.*** About 70 per cent of individual CRCs consider the generation of knowledge to further non-commercial social and environmental objectives to be ''very important'' or ''of the highest importance''. This is a particularly important objective for CRCs in the ''Public Interest'' and ''Dispersed User'' groups.
- ***Knowledge that contributes to commercial benefits in business enterprises but is not appropriated as IP.*** Some CRCs expend considerable effort on the wide diffusion of knowledge. For example the CRC for Sustainable Cotton Production allocates 25 per cent of its budget to its extension-education programme. The CRC for Polymers has held 25 workshops and seminars to disseminate information on technology developments to

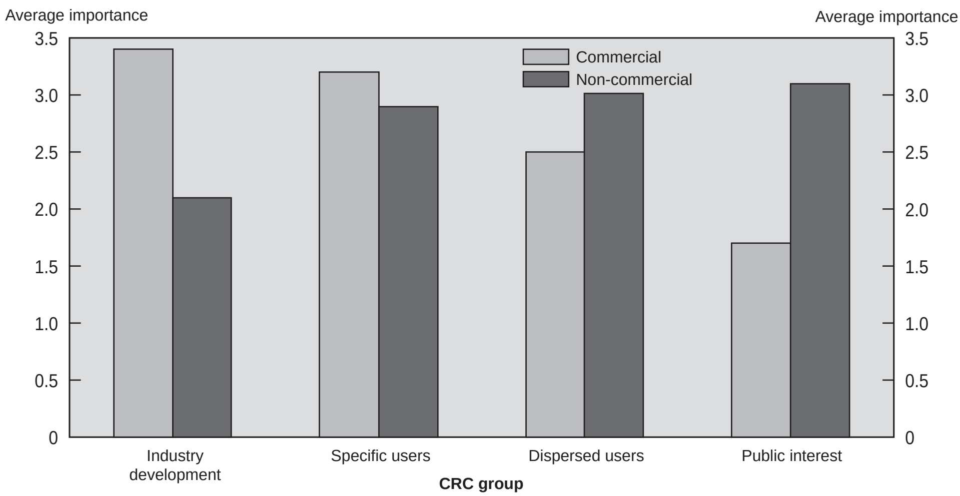
the industry. The CRC for Advanced Composite Structures has held three to five workshops for industry each year – each attracting on average over 150 participants. Similarly, to transfer knowledge to a wider range of potential users, the CRC for Sensor Signal and Information Processing has provided courses and workshops which together have attracted over 2 000 participants.

– ***Commercial IP**.* Only in the ''Public Interest'' group of CRCs does the majority of centres not attach a high importance to patented or otherwise appropriable knowledge.

Figure 10 provides a perspective on the transfer of commercially useful knowledge by different groups of CRC. The relative importance of transfer channels clearly reflects the CRCs' relationship with its users. Non-commercial channels, essentially those not involving licensing, are important.

In some CRCs a good deal of the research is pre-competitive and the participants, or other potential users, may not wish to undertake co-operative R&D which is closely related to their competitive position. One industry association suggested that where an R&D project was successful and led to the identification

Figure 10. **Importance of commercial and non-commercial channels for transferring outputs that provide commercial benefits**[1]



1. Data is the average of R scores.

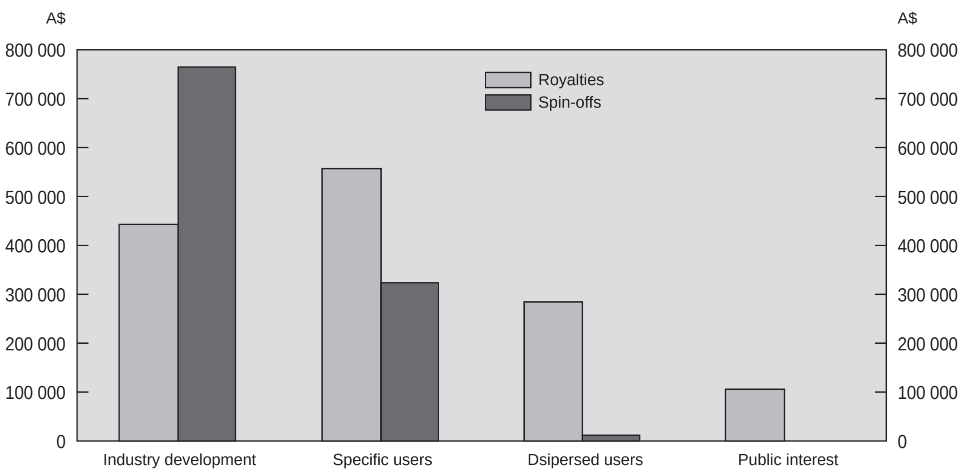
Source: Mercer Review, Department of Science, Industry and Tourism.

of possible commercial applications, the companies would be most likely to carry out this applied research outside the context of a CRC: ''... to ensure protection of intellectual property and exclusivity of market advantage ... The need for confidentiality is paramount because companies need not only to protect the products of R&D efforts through patents and secrecy, but also, and often more importantly, the direction of the R&D must be kept confidential as it provides insights into companies' future business strategies. The success of a CRC therefore should not be measured in terms of its involvement in commercialisation of R&D projects, but rather it should be judged on how well its research is providing opportunities and 'trajectories' for new technologies into the commercial sector'' (submission to the Mercer Review, Department of Industry, Science and Tourism, 1998).

By late 1997, 239 patent applications had been made for inventions arising from CRC research. According to the CRC Programme Secretariat, CRCs derived A$ 1.5 million in 1994/95 and A$ 2.0 million in 1995/96 from ''technical agreements''. The 45 CRCs that provided information on 1996/97 earnings indicated that they derived A$ 900 000 from royalties and A$ 2.24 million from the commercial activities of spinoff companies. The 41 CRCs that provided information on

Figure 11. **Expected income from royalties and spin-offs in 2000/01, by category of CRC**

Average for 42 CRCs



Source: Mercer Review, Department of Science, Industry and Tourism, 1998.

likely income in 2000/01 indicated an expected income from royalties of A$ 15.5 million and from spinoff companies of A$ 10.5 million. See also Figure 11.

XI. NEW VENTURES AND INDUSTRY DEVELOPMENT

Several CRCs have the potential to contribute significantly to the development of new firms and industry segments in Australia. These are high-risk, but potentially very high-reward, initiatives. In some cases the potential for contributing to the development of industry arises from developing technology which will be widely available to new or existing enterprises. The CRC for Aquaculture provides an example. In this sector, techniques have been developed for the commercial-scale culturing of several high-value table fish, thereby underpinning the expansion of a rapidly growing industry. In the case of the CRC for Alloy and Solidification Technology, the Centre is seeking to develop the casting systems and product quality that can underpin a new Australian light metals industry. The research complements work in CSIRO and elsewhere on the use of light metals in automotive and other applications.

At least nine CRCs have formed spinoff companies, and the Programme as a whole has led to at least 12 such companies. In some cases these are commercial agents for unincorporated CRCs, for example the CRC for Viticulture has created CRCV Technologies Pty Ltd as the centre's commercial agent and as a vehicle to commercialise IP.

XII. THE LEVEL AND DISTRIBUTION OF ECONOMIC BENEFITS

CRCs have the potential to generate very substantial economic benefits; they involve users in planning research objectives, and they address major technological issues that are:

– in Australia's major industries (coal, gold, beef, sugar, forestry, cotton, wool, wine) that are central to their future competitiveness;
– in areas of major infrastructure investment (telecommunications, water supply, power generation, waste disposal) that impact substantially on cost and effectiveness;

– in generic technologies that are widely used in Australian industry (new materials, welding, plastics, data analysis, software, minerals exploration, disease diagnosis);
– in several emerging industries (photonics, nanotechnology, light metals, aquaculture, biotechnology) that have the potential to open major new investment opportunities in Australia.

There have been suggestions that private sector firms can derive excessive benefits by appropriating the outcomes of CRC R&D. However, there are several reasons why both the level of economic benefit and the level of spillovers from CRC research would be expected to be higher than either industry-funded contract research, or government-funded research carried out in the public sector. There are five basic reasons for this.

– The involvement of users and public sector research providers, and the competitive selection process and performance reviews, ensure that CRCs focus neither on fundamental research of uncertain economic or social benefit nor on research that will be appropriated by only one or a few firms.
– CRCs allocate substantial resources to the activities that generate external benefits: postgraduate students; improved undergraduate courses; industry seminars; publications in the open literature; contract research that extends the application of generic developments.
– Many CRCs focus their research on technological developments of wide significance in one or more sectors. The vehicle for the commercialisation of that research may be a single enterprise which licences the new technology, but the application of that technology generates benefits among dispersed users. For example, new diagnostics and vaccines for diseases of Australian crops and animals, new techniques and instruments for minerals exploration in the highly weathered Australian conditions, new polymers applied by small plastic product manufacturers, new software used by farms, mines, service companies, new welding systems used throughout manufacturing and construction, new genotypes of crops, trees, cattle, etc., that are more disease-resistant and higher yielding.
– Customer-supplier links along a value chain have an important role in industrial innovation and in the transfer of technology. But there is evidence to suggest that inter-sectoral links in Australia are weakening (Australian Business Foundation, 1997). By bringing together a broad range of research competencies and commercial interests, often including both the potential users and suppliers of a new technology, the CRC Programme has the potential to contribute substantially to dynamic inter-sectoral links. In particular, by focusing research on technological responses to problems in major sectors, the Programme is already contributing to the growth of specialist suppliers of new equipment and services in, for example, mining and agriculture.

– An objective of the CRC Programme has been to build relationships between researchers and users and to demonstrate the value of investment in research. In any sector the priority that firms attach to R&D and external collaboration varies. Some firms have competitive strategies that emphasize technological innovation and these are typically firms that have extensive links with external research and technology suppliers. Such firms are both exemplars of technological ''best practice'' and also, through diverse mechanisms, conduits of new technology to the wider sector. These technological leaders will inevitably be at least the initial participants in CRCs.

The conclusion of the Myers Report on this issue remains valid: ''obsessive concern about potential subsidies to individual companies could be a barrier to achievement of the government's objectives of encouraging innovation and the development of industry in Australia'' (Myers Committee, 1995, p. 31).

XIII. CONCLUSIONS

The CRC Programme addresses important weaknesses in the Australian innovation system. The Centres complement the work of the universities, CSIRO and other research organisations and encourage greater industry involvement in guiding R&D in the public sector. The focus and critical mass of CRCs, in addition to their leading-edge research, attract both international research interest and involvement and the interest of venture capital providers.

CRCs are ''vehicles'' for long-term major research and training but are not necessarily particularly effective institutions for short-term tactical research:

– the structures and mechanisms set up to develop interaction, provide training and ensure accountability lead to higher overheads;
– a CRC seeking contract research could be in competition with some of its participants;
– the management of confidentiality would be more difficult in a multi-party institution.

Many CRCs have interactions with users that are more direct and effective than in many other research organisations. Indeed, they provide examples of effective relationships and governance arrangements that could usefully be extended to other areas of the research system.

NOTES

1. See Department of Industry, Science and Tourism, 1995; Myers Committee, 1995; Industry Commission, 1995, p. 850; Department of Industry, Science and Tourism, 1996*b*; Slatyer, 1993.
2. This estimate is derived from the survey of CRCs carried out by the review and is based on estimates provided by 42 CRCs. While most CRCs for which estimates are not available are either new Round 5 centres, predominantly ‘‘Public Interest’’ CRCs, or do not expect to continue to 2000, information is not available for some CRCs that may have significant, but unpredictable, royalty income.
3. Due to the coverage of the available information, the contribution of IP-related income is likely to be underestimated.

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THE INTELLIGENT MANUFACTURING SYSTEMS INITIATIVE: AN INTERNATIONAL PARTNERSHIP BETWEEN INDUSTRY AND GOVERNMENT

TABLE OF CONTENTS

This article was prepared by Mr Michael Parker, Head of the Inter Regional Secretariat for the international Intelligent Manufacturing Systems initiative (IMS) in Canberra, Australia. It draws on information gathered by the regional secretariats for IMS located in Brussels, Washington, Tokyo, Canberra, Ottawa and Bern and provided by projects operating under the IMS initiative.

I. INTRODUCTION

Intelligent Manufacturing Systems (IMS) is an industry-driven and government-endorsed initiative which assists and encourages the formation of international research consortia to address technical and other emerging manufacturing challenges in the 21st century. IMS provides local assistance and a framework for companies and research groups to identify and define issues requiring resolution, to seek appropriate project partners world-wide, to establish mutually beneficial agreements on workload and disposition of intellectual property rights (IPR) and in many instances, to link into sources of government funds. It offers broad-based technology trials, involving a world-wide user community and ensuring general applicability of the technology developed.

The IMS initiative places special emphasis on the establishment of R&D projects which demonstrate equitable co-operation, including the protection of intellectual property, and which assist in the advancement of manufacturing professionalism world-wide. International co-operation through IMS-endorsed projects provides improved contacts, new opportunities for collaboration and a better understanding of global markets through improved market intelligence.

IMS started in 1995 following a two-year international feasibility study. The regions involved are Australia, Canada, the European Union (EU) – Norway, Japan, Switzerland and the United States. Korea is in the process of admission to IMS.

II. COMMON GOALS IN DEVELOPING MANUFACTURING TECHNOLOGY

IMS builds on common ground between government and industry and recognises the research sector (academia and research agencies) as a uniting factor and third partner essential to overcoming challenges driven by the changing nature of manufacturing. This change has been described as ‘‘a new paradigm where human labour is being steadily divided and substituted for in the discrete areas of creation, design, conceptualisation, judgement and decision making’’ (Furukawa, 1990). Other aspects of this new manufacturing paradigm could include a move away from traditional mass production, a decentralisation of production facilities, and an emphasis on communication on a global scale. IMS may also be viewed as a mechanism for the collaborative management of an accelerated rate of economic change driven in turn by rapid technological change (Williams, 1998).

Governments and industry have a number of strategies in common for the globalisation of industry and the development of strategic alliances. Each places substantial emphasis on technology transfer and the development of the best technology model for commercial survival or for national economic benefit. Both parties are working to achieve world best practice in manufacturing and share the challenges of working across cultural boundaries and a growing shortage of skilled people. The incentive for co-operation between government and industry within IMS grows from a recognition of common agendas and of the leverage potential of a common approach. IMS provides the umbrella for this co-operation and adds benefits which include quality assurance for international R&D collaborative projects, a partner search facility and a framework for intellectual property protection.

Industry and government also have particular interests and priorities. Industry places special emphasis on factors such as cost-effectiveness, the secrecy of commercial knowledge, tools for survival in a global marketplace and the need for effective co-operative R&D to be driven by industry itself. The special interests of government related to international co-operative R&D include compliance with international law, appropriate protection of intellectual property rights, an acceptable international framework or agreement to allow co-operation and consistency with domestic policies such as the attraction of external investment, the growth of small and medium-sized enterprises, technology diffusion and growth in the skills base. In the main, these special interests are not in conflict, nor do they detract from the benefits of co-operation.

III. ACCOMMODATING JOINT AND PARTICULAR INTERESTS

‘‘Never perhaps has such a diverse and numerous group of private firms made common cause. And rarely if ever have governments taken such determinative and persistent stances towards international industrial collaboration’’ (OECD, 1995).

IMS grew out of an initiative from Japan proposed by Professor Yoshikawa, recently the President of the University of Tokyo (Hayashi, 1993). The vision of IMS was for a global system of industrial co-operation and technology sharing to the general benefit of mankind and the particular benefit of partners involved in co-operative projects. Governments initially reacted cautiously to the IMS proposal. There was a concern that an industrial co-operative venture such as this needed careful review with an overlay of government to ensure, in particular, that technology sharing was always a two-way process.

The IMS proposal originally embraced the larger manufacturing regions of Europe, the United States and Japan. At an early stage, it was agreed that the inclusion of a small group of European Free Trade Association (EFTA) countries as well as Australia and Canada would provide a broader perspective, particularly with relation to the involvement of small and medium-sized enterprises, while maintaining a ''regulatory dimension'' by restricting membership to industrial regions (Warnecke, 1993). All six regions participated in a two-year feasibility study to test the benefits of the proposal, the modalities of co-operation, and the means for ensuring equity and balance in co-operative projects. The feasibility study established and reviewed five international test-case projects in different aspects of manufacturing technologies and systems and one study on clean manufacturing.

The feasibility study was, and the IMS initiative overall continues to be, driven by industry. However, the influence of governments brought a dimension of checks and balances largely unfamiliar to industry. In particular, governments had a responsibility to ensure that any programme developed should not contravene international trade, intellectual property agreements or treaties to which they were party. The political processes in some regions to allow them to nominate members to an International Steering Committee for IMS, or to allow them to accede formally to the full-scale programme, differed substantially from usual industry practice. For example, the processes of obtaining successive approvals through the European Council and European Parliament to join IMS extended over two years.

For its part, industry showed considerable caution about the development and sharing of intellectual property across national boundaries and endorsed the desire of governments to put time and effort into developing a properly agreed set of intellectual property and management rules for any co-operative programme which might eventuate. The feasibility study demonstrated, to the satisfaction of government and industry, that there was value in establishing a full-scale IMS programme. At the end of the feasibility study, the participants prepared a comprehensive report and established a set of Terms of Reference mutually agreeable to governments and industry which set out a management structure, technical themes, and a set of intellectual property provisions (ISC, 1994*a*).

The governments of participant regions in IMS have committed their regions to the IMS initiative through a formal exchange of letters agreeing to the Terms of Reference, including the goals of the programme and its regional implementation. On the industry side, corporations have undertaken to provide and support leadership of the IMS programme at a regional and an international level. All entities, including corporations, involved in IMS projects are subject to Consortium Co-operation Agreements (CCA) which reflect the provisions of the Terms of Reference.

A broader goal of IMS, outlined in the early stages by Japan (Furukawa, 1989) and continued in the present Terms of Reference, is global benefit through the transfer and sharing of technology beyond the regions formally involved, with emphasis on developing economies. Projects developed under IMS have a requirement to transfer and diffuse their developed non-commercial technology. Leading on from this, the International Steering Committee has started to consider issues related to new growth theory, resource sharing, resource balance in economies with different rates of GDP per capita and the overall ability of countries to achieve optimal growth. A recent treatment of this issue by a member of the International Steering Committee (Danielmeyer, 1997) illustrates the challenges of a technologically developing economy with particular reference to China.

IV. RESEARCH PROJECT DEVELOPMENT ACROSS NATIONAL BOUNDARIES

Projects under IMS usually begin with the definition of an issue or area of manufacturing technology, for example, the application of biological principles to the manufacturing process, which would benefit from a concerted approach by experts from a number of countries. Following a stage of development and partner search, a project is usually proposed in abstract form for review and constructive comment by each participant region. Once endorsed by each region, the proposal is further developed to include such items as work packages, milestones and regional contributions. At this stage, the project partners must also develop and agree on a Consortium Co-operation Agreement (CCA) based on the IPR provisions set out in the IMS Terms of Reference. The full project and the signed CCA are further circulated for review, and if acceptable to all regions and to the International Steering Committee for IMS, are endorsed as an IMS project. In parallel with this process, partners in a project are free to negotiate with or apply to their regional funding agencies for financial support.

While the process of project definition, review and endorsement is largely driven by industry, often with input from researchers, governments also have the opportunity to contribute. Where government funding is involved, governments have particular influence on the regional component of a project. Once projects are endorsed under IMS, they are autonomous but have a requirement to report to the International Steering Committee on an annual basis in addition to any domestic reporting requirements for individual firms or research groups.

Research projects developed under IMS require the participation of entities (firms, research agencies, universities, etc.) from at least three participant regions and work within a set of five technical themes outlined in the Terms of Reference. These themes are:

– *Total product life cycle issues including:* future general models of manufacturing systems; intelligent communication network systems for information processes in manufacturing; environment protection, minimum use of energy and materials, recyclability and refurbishment; economic justification methods.
– *Process issues including*: clean manufacturing processes; energy efficient processes; technology innovation in manufacturing processes; improvement in the flexibility and autonomy of processing modules; improvement in interaction or harmony among various components and functions of manufacturing.
– *Strategy/planning/design tools including:* methods and tools to support process re-engineering; modelling tools to support the analysis and development of manufacturing strategies; design tools to support planning in an extended enterprise or virtual enterprise environment.
– *Human/organisation/social issues including*: promotion and development projects for improved image of manufacturing; improved capability of manufacturing workforce/education, training; autonomous offshore plants; corporate technical memory-keeping, developing, accessing; appropriate performance measures for new paradigms.
– *Virtual/extended enterprise issues including*: methodologies to determine and support information processes and logistics across the value chain in the extended enterprise; architecture (business, functional and technical) to support engineering co-operation across the value chain, *e.g.* concurrent engineering across the extended enterprise; methods and approaches to assign cost/liability/risk and reward to the elements of the extended enterprise; team working across individual units within the extended enterprise.

An outline of each of the current projects under IMS and representing an international commitment level of around US$ 240 million is found in Annex 1. In addition, there are over 30 new proposals in various stages of development and review. Early analysis has shown that the majority of these themes are addressed in the existing projects or current project proposals to a greater or lesser degree. At this stage of development, the market appears to be placing most emphasis on process issues and least on human organisational, social and environmental issues.

The value to firms of working across international boundaries in a co-operative venture include shared R&D cost and risks, technological and market complementarity, customer-supplier links, a means to address market access barriers, access by small firms to complementary skills, structured competition and economies of scale (TASC, 1990). In addition to these more objective statements of value, there are synergies and serendipity effects which are difficult, if not impossible, to quantify. All of these work towards the goal of globalisation common to both governments and industry.

While these benefits may be self-evident particularly to governments and large firms, they, and the impact which IMS can have on a firm's international success, are not always obvious, particularly to small and medium-sized enterprises. For this reason, the International Steering Committee for IMS has established an international marketing programme to complement regional marketing initiatives designed to ensure optimum participation by firms in each region. In many instances, government agencies endorse or actively support these marketing measures.

In accordance with international agreements, projects under government sponsorship should not involve competitive R&D. This issue is most usually addressed at a regional level. Also at a regional level, particularly where funding agencies are involved, there is a continuing review of IMS projects and the nexus between them and regional R&D priorities for manufacturing. For example, most governments involved in the IMS programme have a special interest in supporting and strengthening a base of SMEs. This is also an objective of the IMS programme and a goal of its strategic plan.

The treatment of intellectual property rights in IMS projects was one of the most contentious issues dealt with at the feasibility study stage and one of the most successful outcomes of that study. The Terms of Reference for IMS incorporate an agreed set of intellectual property provisions which allow companies, research groups and government agencies to work together and forge consortium agreements (Annex 2). The development of provisions acceptable both to the governments and to the industry representatives in the IMS feasibility study is a landmark in international co-operation and a unique benefit of the IMS (ISC, 1994*b*).

V. REGIONAL VARIATIONS IN R&D GRANT SUPPORT FOR IMS PROJECTS

Under the Terms of Reference for IMS, each of the participants has responsibility for funding its own R&D activities. There is no common format for granting support for research conducted under the IMS umbrella. Some regions have granting programmes targeted exclusively to pre-competitive R&D under IMS, others have IMS elements of broader R&D support programmes and others simply allow or encourage IMS-related proposals to participate in one form or another in their regional competitive granting and/or tax concession measures. Australia initially established, and Canada proposed, granting programmes specific to IMS, which were subsequently wound down in favour of broader-based technology support initiatives. The United States has consistently taken the view that because IMS is an industry-run programme, industry itself should support participation in IMS projects.

While all the governments involved in the IMS initiative are supportive, or at least benign, in their attitude to projects developed under IMS, the variety of funding programmes and the timelines associated with them, pose substantial problems to international partners attempting to set up R&D consortia. In recognition of this difficulty, the International Steering Committee for IMS has recently agreed that Consortium Co-operation Agreements may be signed conditional upon research funding being obtained through the granting process of a region.

While this does not solve all problems associated with establishing an R&D consortium under IMS, it does allow the project to be formally endorsed under IMS and potentially strengthens the regional case for funding support. The various funding support mechanisms in each of the IMS regions are set out below.

Australia

Australia has a mix of IMS-specific support funds through IMS Australia and general R&D support measures which may be applicable to IMS, available through the Department of Industry, Science & Tourism.

Limited seed funds in the form of grants for consortium formation activities associated with an existing or proposed IMS project are available through IMS Australia. The types of organisations eligible for funding include small and medium-sized enterprises, industry and research organisations. Applications may be submitted at any time for assessment.

Firms and research groups planning participation in an IMS project may also apply for up to 50 per cent support of eligible project costs under the R&D START programme, which has a particular emphasis on SMEs. In addition, companies conducting R&D in Australia are eligible for a 125 per cent tax concession under certain conditions.

Canada

In Canada several national funding sources are available to support R&D under IMS. In particular:

– *IRAP*, the Industrial Research Assistance Program, includes R&D projects involving applied research and development and the adaptation of technologies of proven technical merit. This programme is intended primarily for small and medium-sized enterprises. IRAP provides support of C$ 15 000 to C$ 350 000 covering up to 36 months. IRAP's share of the costs of the project must be no more that 50 per cent.
– The *NRC* (National Research Council) has several research institutes that fund IMS-related research. These institutes have participated in previous IMS consortia, and can fund joint research with corporations.
– *NSERC* (National Sciences and Engineering Research Council) offers grants to university professors through a competitive peer-review process.

There are two types of NSERC grants that can be used in the IMS context:

– *Strategic:* awarded to universities and professors for research of interest to the professor.
– *Industry/university partnership programme:* funding provided for research of interest to a particular firm or group of firms on the condition that the research be conducted at the university.

In addition, there are several provincial-level funding sources in Canada, some of which are prepared to entertain IMS projects for companies and/or universities in their province. These include, but are not limited to, the Ontario Centres of Excellence, British Columbia Science Council, and the Alberta Research Council.

Non-government sources for R&D support under IMS include:

– *PRECARN* Associates Inc.: a member-owned industrial consortium which supports industrially relevant, market-oriented research and development, and which has a mission to promote the understanding, use and exploitation of intelligent systems and advanced robotics by Canadian industry. PRECARN supports up to 50 per cent of the developmental research costs under Industry Canada funding. Projects are selected through a series of Requests for Proposals (RFPs). PRECARN is prepared to consider IMS project funding applications.
– *CANARIE* (Canadian Network for the Advancement of Research, Industry and Education): which facilitates the development by Canadian companies of next-generation products and applications for the information highway.

European Union

Proposals are evaluated in a process organised by the IMS Secretariat at four-month set intervals (in line with the agreed international timetable). Each proposal is evaluated by at least three independent experts from industry, research institutes and academia. One additional expert is charged with assessing the compliance of the Consortium Co-operation Agreement with the IPR provisions. The criteria against which the proposals are assessed are those of the IMS Terms of Reference.

General principles

A European Group can submit an IMS proposal for support from the EU Framework Programme for Research and Technological Development (RTD), in particular the specific programmes concerning the Information Technologies (IT) and the Industrial and Materials Technologies (IMT) of the current (Fourth) RTD Framework Programme. The European Module of an IMS proposal must be capable of being implemented as a European self -standing project in one of the two aforementioned programmes.

Funding mechanisms

Proposals to IMS are dealt with jointly by IT and IMT Programmes. A maximum of ECU 55 million could be made available for European participation in IMS up to the end of 1998 (end of the Fourth Framework Programme). A joint IT/IMT call for proposals was published in April 1997 and there are evaluations at set intervals, the last of which took place in April/May 1998.

Japan

Japanese partners in IMS projects have access to a fund which will cover half of its total cost, if partners participating in the projects are members of the IMS Promotion Centre in Japan. The total amount of available funds is about US$12 million in FY 1998. Partners which are not members of the IMS Promotion Centre must provide their own R&D funding. Usually, such partners are encouraged to be members of the IMS Promotion Centre.

Switzerland

Projects are evaluated against the criteria set in the IMS Terms of Reference by two experts and the Swiss IMS Executive Steering Committee. Swiss partners in IMS projects can be financed like European partners, through the Commission of the European Communities. However, Swiss partners will not receive money directly from the Commission, but from a special fund dedicated to Swiss partners in European RTD programmes. Swiss partners can participate in European RTD projects like other partners from EU countries with two exceptions: Swiss partners cannot propose or lead projects. Swiss partners automatically receive their funding from the special Swiss fund if the project is accepted and financed by the Commission.

Swiss partners can also be financed by the Commission for Technology and Innovation (CTI), the key instrument of the Swiss government for technology policy. CTI is chaired by the director of the Swiss Federal Office for Professional Education and Technology (FOPT) and the Swiss IMS Secretariat is part of FOPT.

CTI has delegated its competence to the Swiss IMS steering committee for attributing grants. The Swiss IMS steering committee is chaired by a member of the CTI who is also the head of the Swiss Delegation to the International Steering Committee (ISC).

As a rule, Swiss partners have to finance their participation in IMS projects through participation in a European consortium. The financing through CTI is reserved for feasibility studies and special cases.

The Swiss IMS Secretariat is the contact point and gives information on funding. An application form for funding must be submitted to the Swiss IMS executive steering committee. The executive committee will appoint two experts and ask them to evaluate the application against specific Swiss criteria for funding IMS projects. For feasibility studies, the executive committee will submit its recommendation to the chairman of CTI, who will make the decision. For projects, the full committee (not only the executive committee) will submit its recommendation. Funding applications can be submitted at any time. CTI has an earmarked fund for IMS projects of FS 10 000 000 for 1996-99.

United States

In the United States, the Coalition for Intelligent Manufacturing Systems (CIMS) reviews project proposals. For each round of project reviews, CIMS assembles a team of four or five experts. Reviewers do an individual review and come together via teleconference to develop the final US position on each proposal. A separate group of three reviews the Consortium Co-operation Agreement for each proposal.

While there is no government fund labelled ‘‘IMS’’ in the United States, those seeking funding for IMS projects can apply to many agencies such as the National Institute of Standards and Technology’s (NIST) Advanced Technology Program, Defense Advanced Research Projects Agency, Department of Defense, Department of Energy, National Aeronautics and Space Administration, National Institutes of Health, Navy Manufacturing Technology Program, and the National Science Foundation. NIST’s Manufacturing Engineering Laboratory funds travel costs for its members who participate in IMS projects.

Information on how to apply to these agencies can be found on the IMS Web site <www.ims.org> under ''Other Sites of Interest''; ''Academic Coalition for Intelligent Manufacturing Systems''; ''Links to IMS and HMS Web Sites''; ''Funding Source Sites''.

Project partners must meet the criteria of the organisation to which they apply to be eligible for funding. Partners are encouraged to review the material listed under ''Funding Source Sites'' and apply to the source whose requirements they can most easily satisfy.

VI. ADMISSION OF NEW MEMBER REGIONS TO IMS

Under the agreed Terms of Reference, the IMS initiative is open to new regions and entities from those regions. The International Steering Committee for IMS, in consultation with the governments of existing participant regions, has developed a set of guidelines for new participant regions (ISC, 1996). The process of admission, currently under way for Korea, has a number of steps, beginning with an approach at government level from the applicant region and ending with consideration by the governments of the existing participants, assisted by evaluations prepared by the International Steering Committee and by projects which have included entities from the applicant region.

This process provides a balance between the desire of industry to work with firms which can enhance their manufacturing capability without damaging their intellectual property ownership or market position, and the interests of government in ensuring that member countries within IMS will make a positive contribution and will observe appropriate international protocols and agreements.

VII. STRATEGIC PLANNING, MANAGEMENT AND ORGANISATION

The management of the IMS programme is set out in the agreed Terms of Reference. Each participant has the responsibility to establish and run a regional secretariat, to nominate delegates to an International Steering Committee managed by industry, and to contribute to the cost of running an Inter Regional Secretariat. The extent of liaison with government is a matter for each region, although most delegations to the International Steering Committee for IMS include a government representative. At this time, most regional secretariats for

IMS are associated with government departments or agencies. Participant regions, usually through their IMS secretariats, are responsible for encouraging participation at a regional level in IMS projects and for reviewing project proposals from other regions.

Leadership of IMS including responsibility to chair the International Steering Committee and to organise the Inter Regional Secretariat and rotates around member regions. At present this responsiblity is held by Australia and it will pass to Japan in late 1999.

The International Steering Committee for IMS has developed and agreed a Mission Statement to:

> *''mobilise at an international level, industry, government and research resources to drive the co-operative development and spread of manufacturing technologies and systems in a global environment of change''.*

Within this mission, the International Steering Committee has agreed on a set of five key results:

- build an international IMS project portfolio;
- encourage the effective and broad diffusion and exploitation of manufacturing technology;
- enhance the standing of manufacturing as a profession;
- support globalisation of manufacturing; and
- make IMS an internationally recognised initiative.

The implementation of the strategic plan takes place at the regional and the international levels. The goals of the plan are relevant both to industry and to government and each sector is expected to contribute towards their achievement.

VIII. A VISION FOR THE FUTURE

IMS is a unique international initiative which addresses changes not only in manufacturing technology but also in society, including consumer demand, economic theory and the nature of work. Other initiatives such as the Consortium for Advanced Manufacturing International (CAM-I) are industry-driven and industry-funded but, at this time, do not have the formal endorsement and active involvement of governments enjoyed by IMS. Standards-setting bodies and international systems such as CALS enjoy a degree of government endorsement but have a quite restricted field of responsibility. IMS remains the sole example of an industry-driven and government-endorsed programme of international co-operation in the field of manufacturing technologies and systems.

The IMS initiative has now been in operation for three years although some regions, in particular the EU, have had full participation for a shorter period. It is only now that IMS is starting to realise the original vision of an international portfolio of world-class research and development in manufacturing and can begin to review and implement its broader role envisaged under the Terms of Reference, to encourage the development and diffusion of manufacturing technology world-wide and to enhance the status of manufacturing as a profession. The International Steering Committee for IMS plans to review these more global goals, including the future of manufacturing, at a broad-based forum planned for Europe in 1999. A five-year evaluation of the IMS initiative and its outcomes to that time, will take place in the year 2000.

Annex 1

OUTLINE OF EXISTING IMS PROJECTS

95001 Enterprise Integration for Global Manufacturing for the 21st Century (Globeman 21)

Globeman 21 is an industrial project aimed at creating the new processes and technologies for manufacturing in the 21st century. Three areas of research are paramount: *i)* the development of a virtual manufacturing environment to reduce lead times from production line planning to design and production; *ii)* distributed autonomous manufacturing technology for flexible manufacturing; *iii)* global manufacturing taking full advantage of world-wide information technology infrastructure.

95002 Next Generation Manufacturing Systems (NGMS)

The objective of this IMS programme is to develop and integrate intelligent information and processing technologies to support complete product life cycles for the next generation of manufacturing systems (NGMS). NGMS will have to support all facets of globally distributed ‘‘virtual enterprises’’. Two such systems, ADAMS and BMS, are under exploration, as is compatibility with the Agile Manufacturing System (United States) and the Fractal Production System (EU).

95003 Holonic Manufacturing Systems (HMS)

The objective of this project is to develop discrete, continuous and batch manufacturing systems through integrating highly flexible, agile, reusable and modular manufacturing units. Such systems will be constructed of autonomous, co-operative intelligent modules capable of reconfiguration automatically in response to new system demands and/or components. The long-term goal of HMS is the development of flexible, adaptive systems for manufacturing, equivalent to the ‘‘plug and play’’ information technologies.

95004 Knowledge Systematisation: Configuration Systems for Design and Manufacturing (GNOSIS)

GNOSIS aims to establish the framework for a new manufacturing paradigm through the utilisation of knowledge-intensive strategies covering all stages of the product life cycle, in order to realise new forms of highly competitive manufactured products and processes which are environment-conscious, society-conscious and human-oriented. Study topics include soft artefacts, virtual manufacturing, knowledge management, and various enabling and integration technologies.

96002 Metamorphic Material Handling System (MMHS)

''Metamorphic'' material handling systems are capable of changing their shape in a highly flexible, automated and autonomous manner so as to meet the frequently varying demands from a flexible manufacturing system within which they are to work. Research topics include material flow analysis, development of key enabling technologies, and simulation modelling.

96003 Organisational Aspects of Human-Machine Coexisting System (HUMACS)

This project aims to pursue practical methodology to establish an optimum relationship between humans and manufacturing facilities based on ergonomical, informational and socio-technical studies on next generation manufacturing systems. The project encompasses three study areas: optimum design of manufacturing systems for efficiency and ease of operation at the human-machine system interface; interactive factory-periphery growth simulation modelling of factory organisation; application of new media and imaging technologies to ease the operation of manufacturing processes.

96004 Digital Die Design System (3DS)

Three different research subjects will be studied to establish basic technology for constructing a powerful ''digital die design system'', applicable particularly to sheet metal forming: *i)* advanced mechanical modelling of deformation behaviour of materials and development of standard tests to obtain material parameters; *ii)* development of methods to evaluate forming defects based on the results above; and *iii)* development of measurement and software technologies to reconstruct the measured three-dimensional formed parts geometry on computer, in order to make a precise comparison of actual and simulated parts geometries.

96005 Rapid Product Development (RPD)

RPD aims to explore, adapt and integrate tools and strategies for accelerating the development and deployment of new products with improved quality. It involves timely, cost-effective development, application and deployment of innovative product and process technologies in the product development process, coupled with appropriate business practices which support the adoption of ''time to market'' strategies. Interface development for information and data exchange, databases, rapid prototyping, technical studies infrastructure, best business practices and benchmarking are key elements.

96008 Intelligent Composite Products (INCOMPRO)

The goal of this project is to develop an integrated design system for composite materials which is based on the concept of parallel development of the product and process. The system is composed of the two sub-systems ‘‘Virtual Manufacturing Environment System (VMES)’’ and ‘‘Real Manufacturing Environment System (RMES)’’. The integration approach in the design system covers all the software tools (SW) and machines used to develop the VMES and RMES framework.

96007 Innovative and Intelligent Field Factory (IF7)

This is a joint international project to develop new methods and systems to handle materials and assemble them into large-scale structures. Research will also be undertaken to create a computer-aided system capable of supporting industry in decision making at any stage of a given work by duly handling all the information related to planning, material acquisition and transportation, actual construction, conditions at the site, and customer.

97002 Human Sensory Factor for Total Product Life Cycle (HUTOP)

This project will develop a comprehensive enabling technology called ‘‘Advanced Human Technology’’. Computer graphics (CG) and virtual reality (VR) technologies will be developed to evaluate customer response to virtual products designed for their particular requirements, thereby reducing development costs. Real time simulation of the production process will create ideal manufacturing environments for workers, thus optimising delivery, recycling and maintenance systems. The project will also develop high accuracy manufacturing process, assembly and inspection systems by emulating human sensory systems.

97001 Modelling and Simulation Environments for Design, Planning and Operation of Globally Distributed Enterprises (MISSION)

The primary objective of MISSION is to bridge from today’s tools and regionally oriented factory design processes into those needed for extended enterprises and/or virtual enterprise networks. An integrated modelling and simulation platform will be built to support engineering, on the one hand, and systems integration, on the other. Modelling techniques will develop a consistent interface with distributed engineering works. Object-oriented and agent-based simulation, and the integration of commercial tools, CAD/CAM, design tools and related business practices will be undertaken.

96001 Sensor Fused Intelligent Monitoring (SIMON)

The Sensor Fused Intelligent Monitoring System for Machining (IMS-Simon) project is an international industry-driven project addressing research and pre-competitive development in the area of machining. The project will model turning, milling and grinding processes to maximise efficiency, reducing cycle time and scrap rates. Further productivity improvements will be obtained by installing integrated sensors and intelligent machining strategies for in-process detection of tool wear, breakage, and in-process compensation for tool and part deformations. Each algorithm will be lab tested and then tested in consortium members’ machining operations without disturbing production schedules.

97004 Highly Productive and Re-configurable Manufacturing System (HIPARMS)

The project aims to construct a highly flexible and productive manufacturing system, responsive to technological and market changes, and based upon a recently developed high-speed, general-purpose machine tool. Reduced non-processing time (transfer, loading and unloading of work pieces) and cost savings in automated handling systems are expected. High production flexibility (configurable tools and systems) should enable HIPARMS to accommodate future technological change.

Annex 2

INTELLECTUAL PROPERTY RIGHTS PROVISIONS FOR IMS PROJECTS

Objectives

These provisions lay down mandatory requirements as well as recommended principles for PARTNERS which wish to participate in a PROJECT conducted within the Intelligent Manufacturing Systems Program (IMS PROGRAM). The objectives of these provisions are to provide adequate protection for intellectual property rights used in and generated during joint research and development PROJECTS under the IMS PROGRAM while ensuring:

a) that contributions and benefits by PARTICIPANTS, from co-operation in such PROJECTS, are equitable and balanced;

b) that the proper balance is struck between the need for flexibility in PARTNERS' negotiations and the need for uniformity of procedure among PROJECTS and among PARTNERS; and

c) that the results of the research will be shared by the PARTNERS through a process that protects and equitably allocates any intellectual property rights created or furnished during the co-operation.

Article 1: Definitions

1.1 ACCOUNTING. The sharing of any consideration such as royalties or other license fees by one PARTNER with another PARTNER when the first PARTNER which solely or jointly owns FOREGROUND discloses, licenses or assigns it to a third party.

1.2 AFFILIATE. Any legal entity directly or indirectly owned or controlled by, or owning or controlling, or under the same ownership or control as, any PARTNER. Common ownership or control through government does not in itself create AFFILIATE status.

Ownership or control shall exist through the direct or indirect:

a) ownership of more than 50 per cent of the nominal value of the issued equity share capital; or

b) ownership of more than 50 per cent of the shares entitling the holders to vote for the election of directors or persons performing similar functions, or right by any other means to elect or appoint directors, or persons performing similar functions, who have a majority vote; or,

c) ownership of 50 per cent of the shares, and the right to control management or operation of the company through contractual provisions.

1.3 BACKGROUND: All information and INTELLECTUAL PROPERTY RIGHTS except BACKGROUND RIGHTS owned or controlled by a PARTNER or its AFFILIATE and which are not FOREGROUND.

1.4 BACKGROUND RIGHTS: Patents for inventions and design and utility models, and applications therefor as soon as made public, owned or controlled by a PARTNER or its AFFILIATES, a license for which is necessary for the work in a PROJECT or for the commercial exploitation of FOREGROUND, and which are not FOREGROUND.

1.5 CONFIDENTIAL INFORMATION: All information which is not made generally available and which is only made available in confidence by law or under written confidentiality agreements.

1.6 CONSORTIUM: Three or more GROUPS which have agreed to carry out jointly a PROJECT.

1.7 CO-OPERATION AGREEMENT: The one or more signed agreements among all PARTNERS in a CONSORTIUM concerning the conduct of the PROJECT.

1.8 FOREGROUND: All information and INTELLECTUAL PROPERTY RIGHTS first created, conceived, invented or developed in the course of work in a PROJECT.

1.9 GROUP: All PARTNERS in a given PROJECT from the geographic area of a PARTICIPANT.

1.10 IMS PROGRAM: The Intelligent Manufacturing Systems Program.

1.11 INTELLECTUAL PROPERTY RIGHTS: All rights defined by Article 2*(viii)* of the Convention Establishing the World Intellectual Property Organisation signed at Stockholm on 14 July 1967 (see Appendix III.3), excluding trademarks, service marks and commercial names and designations.

1.12 NON-PROFIT INSTITUTIONS: Any legal entity, either public or private, established or organised for purposes other than profit-making, which does not itself commercially exploit FOREGROUND.

1.13 PARTICIPANT: Australia, Canada, the EU, the participating EFTA countries (Norway and Switzerland), Japan and the United States and any other country or geographic region whose participation in the IMS PROGRAM may be approved in the manner determined by the PARTICIPANTS.

1.14 PARTNER: Any legal or natural person participating as a contracting party to the CO-OPERATION AGREEMENT for a given PROJECT.

1.15 PROJECT: Any research and development project carried out by a CONSORTIUM within the IMS PROGRAM.

1.16 SUMMARY INFORMATION: A description of the objectives, status and results of a PROJECT which does not disclose CONFIDENTIAL INFORMATION.

Article 2: Mandatory provisions

Each CO-OPERATION AGREEMENT must contain substantive terms and conditions that are fully consistent with each of the provisions 2.1 through 2.13 in this Article and the definitions used in each CO-OPERATION AGREEMENT shall be those specified in Article 1 of this document.

Where a PROJECT or a potential PARTNER or its AFFILIATES is subject to government requirements, whether by law or agreement, and such requirements will affect rights or obligations pursuant to the CO-OPERATION AGREEMENT, the potential PARTNER shall disclose to the other PARTNERS all such requirements of which it is aware prior to signing the CO-OPERATION AGREEMENT. PARTNERS must ensure that ownership, use, disclosure and licensing of FOREGROUND will comply with these mandatory provisions if the PROJECT is subject to government requirements.

PARTNERS will, at the outset of a PROJECT, promptly notify one another of their AFFILIATES which will be involved in the performance of the PROJECT, and will notify one another of any changes in the AFFILIATES so involved during the life of the PROJECT. At the time of entering into a CO-OPERATION AGREEMENT, and immediately after new legal entities have come to meet the AFFILIATE definition, PARTNERS may exclude AFFILIATES from the rights and obligations set forth in these provisions in accordance with the terms of the CO-OPERATION AGREEMENT.

Written agreement

2.1 PARTNERS shall enter into a written CO-OPERATION AGREEMENT that governs their participation in a PROJECT consistent with this document.

Ownership

2.2 FOREGROUND shall be owned solely by the PARTNER or jointly by the PARTNERS creating it.

2.3 A PARTNER which is the sole owner of FOREGROUND may disclose and non-exclusively license that FOREGROUND to third parties without ACCOUNTING to any other PARTNER.

2.4 A PARTNER which is a joint owner of FOREGROUND may disclose and non-exclusively license that FOREGROUND to third parties without the consent of and without ACCOUNTING to any other PARTNER, unless otherwise agreed in the CO-OPERATION AGREEMENT.

2.5 A PARTNER may assign its sole and/or joint ownership interests in its BACKGROUND, BACKGROUND RIGHTS and FOREGROUND to third parties without the consent of and without ACCOUNTING to any other PARTNER.

PARTNERS who assign any of their rights to BACKGROUND RIGHTS or FOREGROUND must make each assignment subject to the CO-OPERATION AGREEMENT and must require each assignee to agree in writing to be bound to the assignor’s obligations under the CO-OPERATION AGREEMENT in respect of the assigned rights.

Dissemination of information

2.6 SUMMARY INFORMATION shall be available to all PARTNERS in other PROJECTS and to the committees formed under the IMS PROGRAM.

2.7 The CONSORTIUM will make available at the end of the PROJECT a public report setting out SUMMARY INFORMATION about the PROJECT.

License rights

Foreground

2.8 Each PARTNER and its AFFILIATES may use FOREGROUND, royalty-free, for research and development and for commercial exploitation. Commercial exploitation includes the rights to use, make, have made, sell and import.

However, in exceptional circumstances

a) PARTNERS may agree in their CO-OPERATION AGREEMENT to pay a royalty to PARTNERS which are NON-PROFIT INSTITUTIONS for commercial exploitation of FOREGROUND which is solely owned by such NON-PROFIT INSTITUTIONS; and

b) PARTNERS may agree in their CO-OPERATION AGREEMENT to pay a royalty to PARTNERS which are NON-PROFIT INSTITUTIONS for commercial exploitation of FOREGROUND which is jointly owned with such NON-PROFIT INSTITUTIONS, provided such royalties are both small and consistent with the principle that contributions and benefits in the IMS PROGRAM must be balanced and equitable.

A non-owning PARTNER and its AFFILIATES may not disclose or sub-license FOREGROUND to third parties except that each PARTNER or its AFFILIATES may, in the normal course of business:

a) disclose FOREGROUND in confidence solely for the purposes of manufacturing, having manufactured, importing or selling products;

b) sub-license any software forming part of FOREGROUND in object code; or

c) engage itself in the rightful provision of products or services that inherently disclose the FOREGROUND.

Background

2.10 A PARTNER in a PROJECT may, but is not obligated to, supply or license its BACKGROUND to other PARTNERS.

2.11 PARTNERS and their AFFILIATES may use another PARTNER'S or its AFFILIATES' BACKGROUND RIGHTS solely for research and development in the PROJECT without additional consideration, including, but not limited to, financial consideration.

PARTNERS and their AFFILIATES must grant to other PARTNERS and their AFFILIATES a license of BACKGROUND RIGHTS on normal commercial conditions when such license is necessary for the commercial exploitation of FOREGROUND unless:

a) the owning PARTNER or its AFFILIATE is by reason of law or by contractual obligation existing before signature of the CO-OPERATION AGREEMENT unable to grant such licenses and such BACKGROUND RIGHTS are specifically identified in the CO-OPERATION AGREEMENT; or

b) the PARTNERS agree, in exceptional cases, on the exclusion of BACKGROUND RIGHTS specifically identified in the CO-OPERATION AGREEMENT.

Survival of rights

2.13 The CO-OPERATION AGREEMENT shall specify that the rights and obligations of PARTNERS and AFFILIATES concerning FOREGROUND, BACKGROUND and BACKGROUND RIGHTS shall survive the natural expiration of the term of the CO-OPERATION AGREEMENT.

Article 3: Provisions that need to be addressed in the Co-operation Agreement

PARTNERS shall address each of the following items in their CO-OPERATION AGREEMENT:

Publication of results

3.1 PARTNERS shall address the issue of the consent required, if any, from the other PARTNERS for publication of the results from the PROJECT other than SUMMARY INFORMATION.

3.2 PARTNERS shall address the issue of whether PARTNERS which are NON-PROFIT INSTITUTIONS may, for academic purposes, publish FOREGROUND which they solely own, provided that adequate procedures for protecting FOREGROUND are taken in accordance with Articles 3.3 and 3.4.

Protection of foreground

3.3 PARTNERS shall identify the steps they will take to seek legal protection of FOREGROUND by means of INTELLECTUAL PROPERTY RIGHTS and upon making an invention shall notify other PARTNERS in the same PROJECT in a timely manner of the protection sought and provide a summary description of the invention.

3.4 PARTNERS shall address the issue of prompt notification of all other PARTNERS in the same PROJECT and, upon request and on mutually agreed conditions, disclosure of the invention and reasonably co-operate in such protection being undertaken by another PARTNER in the same PROJECT in the event and to the extent that a PARTNER or PARTNERS which own FOREGROUND do not intend to seek such protection.

Confidential information

3.5 PARTNERS shall identify the measures they will take to ensure that any PARTNER which has received CONFIDENTIAL INFORMATION only uses or discloses this CONFIDENTIAL INFORMATION by itself or its AFFILIATES as far as permitted under the conditions under which it was supplied.

Dispute settlement and applicable laws

3.6 PARTNERS shall agree in their CO-OPERATION AGREEMENT on the manner in which disputes will be settled.

3.7 PARTNERS shall agree in their CO-OPERATION AGREEMENT on the law which will govern the CO-OPERATION AGREEMENT.

Article 4: Optional provisions

PARTNERS may, but are not required to address each of the following provisions in their CO-OPERATION AGREEMENT: affiliate provisions; antitrust/competition law issues; cancellation and termination; employer/employee relationships; export controls and compliance; field of the agreement; intent of the parties; licensing partners in other projects; licensor 's liability arising from licensee's use of licensed technology; loaned or assigned employees and resulting rights; new partners and withdrawal of partners from projects; post co-operation agreement background protection, use and non-disclosure obligations regarding confidential information; residual information; royalty rates for background right licenses; software source code; taxation; term/duration of agreement.

There are likely to be other provisions the PARTNERS will need to put into their CO-OPERATION AGREEMENTS depending on the particular circumstances of their PROJECT. PARTNERS should seek their own expert advice on this and note that no additional terms may conflict with Articles 1 and 2 of these provisions.

Appendix III.3: Convention establishing the World Intellectual Property Organisation (Stockholm, 14 July 1967)

Article 2(viii) defines Intellectual Property to include:

''...the rights to literary, artistic and scientific works; performances of performing artists; phonograms, and broadcasts; inventions in all fields of human endeavour; scientific discoveries; industrial designs; trademarks, servicemarks, and commercial names and designations; protection against unfair competition; and all other rights resulting from intellectual activity in the industrial, scientific, literary or artistic fields.''

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THE FIFTH RESEARCH AND TECHNOLOGY DEVELOPMENT FRAMEWORK PROGRAMME OF THE EUROPEAN UNION

TABLE OF CONTENTS

This article was written by William Cannell, DG XII, European Commission, Brussels, Belgium. The article has benefited from substantial inputs from colleagues in DG XII; however, it should not be taken to represent the official position of the European Commission.

I. INTRODUCTION

International collaboration in research, involving universities, research centres and industry, has long been supported by the European Union. Organised since 1984 within successive, multinational framework programmes, the Union's research activities are designed to complement those of the EU's member states and work towards closer integration of Europe's scientific and industrial communities. The central objective of Community research policy is to reinforce and mobilise the Union's scientific and technological capabilities in support of industry, the economy and quality of life. The context is one of progressive internationalisation of research and technology, within which cross-border collaborations involving industry, the public research base and other relevant actors can reinforce European integration, development and competitiveness.

The Fifth Framework Programme (1998-2002) breaks with tradition in targeting resources on specific socio-economic objectives, by means of focused research actions of a highly integrated and essentially interdisciplinary nature. The approach will be more selective than in the past and will favour partnerships and networks of research actors – public and private – which are oriented towards utilisable results.

II. THE BENEFITS OF EUROPEAN COLLABORATIVE RESEARCH

Encouraging higher investment in research and technology, as well as improvements in research productivity, are clear economic priorities for Europe. Levels of expenditure on research and development tend to lag behind those of competitors overseas: overall, the European Union spends 1.8 per cent of its GDP on civil R&D, as opposed to 2.5 per cent in the United States and 2.8 per cent in Japan.[1] Moreover, the EU's position on patenting technological inventions (patents granted per unit of research expenditure) is lower than those of the United States and Japan, and appears to be deteriorating in relative terms. Furthermore, Europe's strongest industries on the world stage tend to be those in which the science intensity is relatively low, and links between industry and the university sector are relatively weak. (There are, of course, considerable differences between the positions of different member states with regard to these indicators.)

In this context, action at Community level helps to bring about research collaboration on a European scale which can enable a number of benefits to be realised:

– Bringing together the research capabilities of research actors in different member states improves the linkages between the different types of actors (public and private) at European level; provides a deeper pool of expertise to address existing as well as new and emerging problems, and provides a stimulus towards a more dynamic technological and business environment.
– There are an increasing number of areas in which research can only be carried out effectively on a transnational basis. Some phenomena which need to be studied are intrinsically international (*e.g.* climate change, marine and terrestrial ecosystems). In other areas, the research effort needed surpasses the capacity of individual countries (*e.g.* genome sequencing).
– Large-scale research infrastructure is of crucial importance to many areas of science and technology but, in view of its costs, is not evenly distributed around the European Union; cross-national access can optimise its effective utilisation as well as the direction of its further development.

III. ROLE OF THE FRAMEWORK PROGRAMME IN RELATION TO OTHER INSTRUMENTS FOR EUROPEAN COLLABORATIVE RESEARCH

The nature of the Framework Programme

Under the present Treaties,[2] the Framework Programme encompasses all the research activities carried out by the European Union. It aims to strengthen the scientific and technological bases of European industry, thereby encouraging it to be more competitive, and to implement research which provides support for the broad range of Community policies. According to the Treaty, the Framework Programme comprises four different ‘‘activities’’, each of which is implemented by means of one or more ‘‘specific programmes’’.

1. *Research, technology development and demonstration*, mainly through international collaborative research networks involving enterprises, research centres, universities and a variety of other actors. This activity comprises the majority of expenditure, amounting to about 87 per cent of funds under the Fourth Framework Programme. Other than projects carried out by the Community’s Joint Research Centre, funding from the Community budget is normally allocated to a maximum of 50 per cent of total project costs.

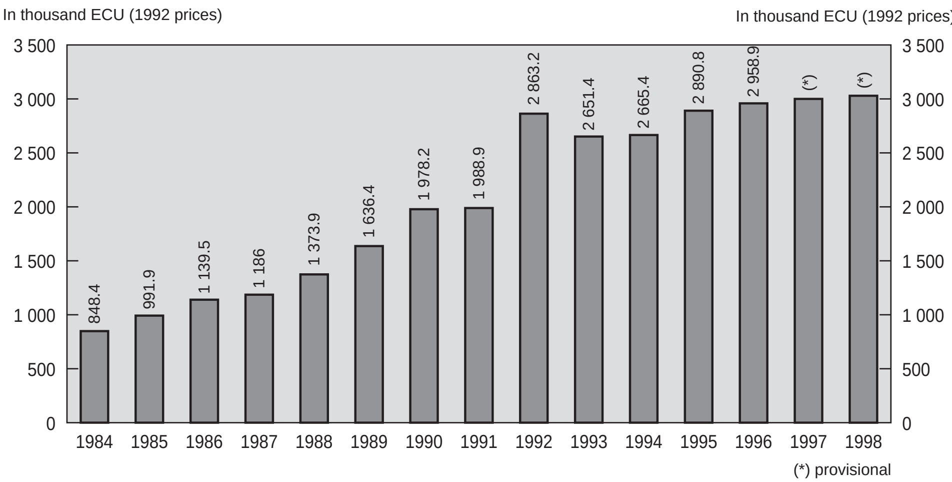
2. *International co-operation in research* involving partners outside the European Union and/or international organisations. Several specific objectives are pursued through such co-operation: supporting the development of less-developed countries, ensuring that Community researchers have access to important technologies being created in advanced countries outside the Union, and building research networks with neighbouring countries, such as in Central and Eastern Europe and the Mediterranean area, especially those which are candidates for accession to the Union. A number of different types of S&T agreements define the opportunities for researchers from outside the Union to participate in the Framework Programme.
3. *Dissemination and exploitation* of research results, which takes a variety of forms, including networks for the transfer of technology and innovation, support for best practice in management of research and technology, and advisory structures.
4. *Stimulation of the training and mobility of researchers*, through fellowship schemes allowing researchers to spend time in laboratories outside their home country, so as to foster the transfer and development of skills, and through research training networks across a wide range of research areas.

Historical evolution of the Framework Programme

The first Framework Programme was established in 1984, as an umbrella for a number of research activities which had been developed earlier under the European Community and Euratom Treaties. These comprised both ‘‘direct actions’’ (carried out in the Communities’ own Joint Research Centre) and ‘‘indirect’’ collaborative research, carried out by external consortia and part-funded by the Communities. A specific legal base was put in place at the time of the Single European Act, which came into force in 1987, and was subsequently modified under the 1993 European Union (Maastricht) Treaty and the 1996 Amsterdam Treaty.

During the period from the first programme to the fourth, yearly expenditure on Community research has grown by a factor of three in real terms; it now amounts to nearly ECU 3.5 billion.[3] The evolution of the budget is shown in Figure 1. Collaborative projects under the Framework Programme account for expenditure amounting to 3.8 per cent of civil government-funded research in the Union. Research now represents nearly 4 per cent of the total Community budget (making it the third largest item of expenditure after the Common Agriculture Policy and the Structural Funds). If other funding arrangements such as EUREKA and COST and those run by the European Science Foundation, European Space

Figure 1. **Evaluation of the Framework Programme budget**



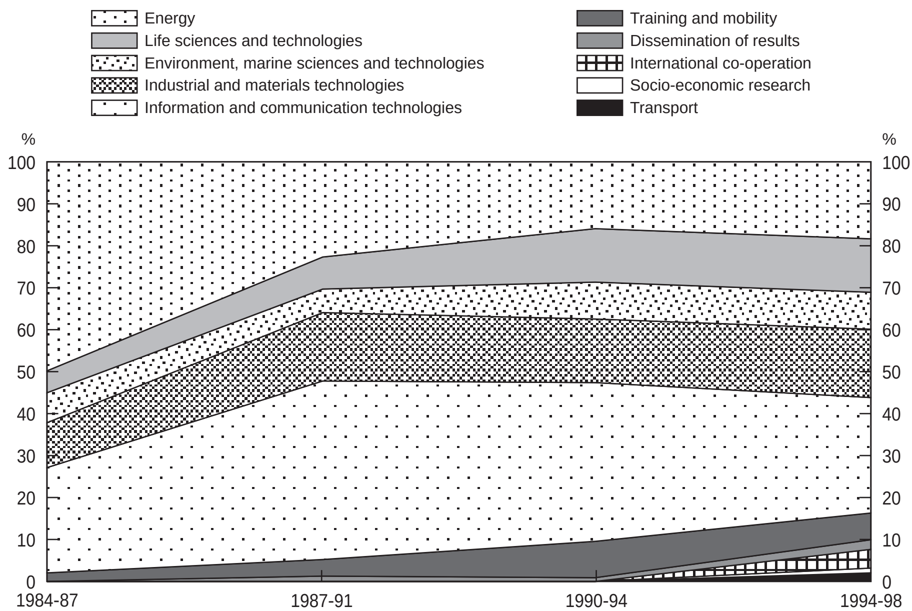
Note: The additional 115 million ECU agreed for the Fourth Framework Programme is not taken into account in this figure.
Source: DG XII-AS4, Data: European Commission Services, *Second European Report on S&T Indicators,* 1997.

Agency, and so on are included, the total European collaborative research effort accounted for 16.2 per cent of government expenditure on civil research in 1996 (as compared with 6.2 per cent in 1985).

Figure 2 shows how the priorities of the Framework Programme have evolved over time, when considered in terms of major research areas. Several points are worth noting:

– The majority of funding under the four framework programmes has been allocated to five broad themes within the first activity indicated above: energy, life sciences, environment, industrial and materials technologies, and information and communication technologies (see Box 1).
– Nevertheless, the relative proportion of expenditure associated with each of these areas has changed quite radically over the period. For example energy research has diminished in relative importance, life sciences have progressively increased and, after increasing quickly in the first part of the period, information and communications technologies have subsequently somewhat declined.
– At the same time, the presence of a number of other research areas, such as transport and socio-economic research, has increased, along with the relative weight of activities 2, 3 and 4 above, *i.e.* international co-operation,

Figure 2. **Evolution of research priorities over time**



dissemination and optimisation, and training and mobility. This represents a progressive broadening of the support mechanisms of the Framework Programme, as described in more detail below.

Impact of the Framework Programme on the European research landscape

Over the 13 years of its existence, despite the rather modest resources which it has at its disposal, the Framework Programme has had an impressive impact on European research. International co-operation has become embedded in the European research system and transnational collaboration has become an every-day occurrence on the part of individual researchers, firms and public research centres. For contracts signed in 1996 alone, the number of international research linkages created by the Framework Programme (counting links between each partner and every other partner in a project, and including those between EU research teams and those in the rest of the world) amounted to 71 680, resulting from 6 395 projects.[4]

Box 1. **Some examples of projects funded under the Framework Programme**

Life sciences

A large European Union-funded project is in the process of unravelling, for the first time, the complete genome sequence of a model plant, *Arabidopsis thaliana*. Besides its scientific impact, the project also provides a model for international co-operation in science. The success of this project, which is the most advanced publicly funded plant genome project in the world, is largely the result of EU-stimulated international co-operation which involves up to 30 laboratories from ten countries, funded under the Biotechnology programme (over ECU 16 million to date). One startling discovery is that the functions of about 50 per cent of the genes are not (yet) known. These results should allow considerable advances in the understanding of the basic mechanisms of life in plants and open the way for biotechnology applications. It is expected that 40 per cent of the sequence will have been completed by the end of 1998.

Information technology

ChipShop was an activity to address a lack of expertise among European SMEs concerning microelectronics technologies. By providing practical support for designing microelectronics into a greater range of products, it helped a considerable number of companies put European high technology to work. ChipShop was started within the ESPRIT III programme and provided SMEs with Competence Centres for design, MPW (multi project wafer) and testing, via a range of industrial quality services in such fields as CAD tools, fabrication, testing and quality assurance, allowing easy application and optimisation of microelectronics. All ChipShop's services were equally accessible to all parties in the market, and 1 077 projects were established in 30 months. The main result of ChipShop has been to establish a European Microelectronics Community, enhanced further under the new First Users Action (FUSE) project, which aims to accelerate the uptake of existing microelectronics technologies in European industry.

Environment and climate

In January 1998, the Third European Stratospheric Experiment on Ozone, THESEO was launched, an ambitious co-ordinated campaign to monitor and study the ozone loss over Europe. The programme will run until the end of 1999 and involves over 400 scientists in the EU, with participation from Canada, Iceland, Japan, Norway, Poland, Russia, South Africa, Switzerland and the United States. It will address two particular and interrelated concerns: the fact that huge chemical ozone depletion (up to 50 per cent at altitudes between 15 and 20 km)

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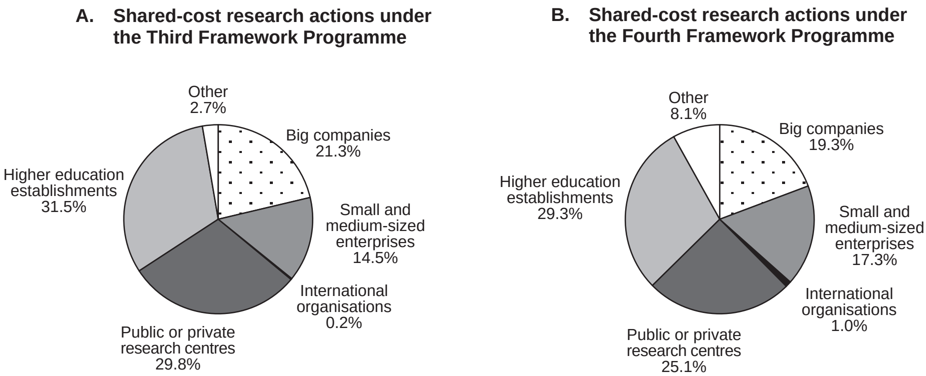
has occurred in the Arctic stratosphere during each of the last three winters, causing much discussion about a possible Arctic ozone ''hole''; and the long-term ozone decline over Europe (total column ozone levels in winter and spring are more than 10 per cent below those in the late 1970s). THESEO consists of a core of 12 major EU-funded projects which are closely co-ordinated with national research programmes, and which form part of a broader programme on stratospheric ozone and UV-B radiation (22 projects in total, with ECU 16 million of Community funding) including laboratory-based research into the fundamental principles of stratospheric chemistry, the development of new devices to measure the atmosphere's composition, research into improving atmospheric chemical models, and UV-B field measurements. European research on stratospheric ozone and UV-B makes a valuable contribution to the international research which underpins the Montreal Protocol.

The structure of participation in the Framework Programme, and its evolution between the Third and Fourth Framework Programmes, is shown in Figure 3. Higher education establishments and research centres account for a little more than half of the total participations (and roughly half the budget for indirect research actions). Enterprises account for about 38 per cent of participation, and there has been a noticeable increase over the last two framework programmes in the weight of SMEs in this total (see also the section on SME measures below).

What is also significant is the rapid diversification of the actors which appear to be participating in research partnerships, with increased presence of hospitals, museums, libraries and international research centres – participants outside the normal ''constituency'' of research institutes, universities and industrial labs. These accounted for 9.1 per cent of participations in the Fourth Framework Programme (as opposed to 2.9 per cent in the Third). Moreover, the forms of partnerships are also changing, with links between large firms and universities, on the one hand, and large firms and SMEs, on the other, both rising.

The specific programmes which implement the Framework Programme, and the programme overall, are subject to very comprehensive independent evaluation arrangements, comprising two major elements. On an annual basis, a monitoring exercise is conducted, to provide ''real-time'' input to enable improvements to be made from year to year. In addition, a five-year retrospective assessment of the performance of the programmes is required prior to the Commission tabling proposals for new programmes. Both exercises are carried out by experts from outside the Commission.

Figure 3. **Structures of participation in the Fourth Framework Programme**



Note: Geographical coverage: EU15.
Source: DG XII-AS4, Data: European Commission Services, *Second European Report on S&T Indicators,* 1997.

The Fifth Framework Programme: towards a new strategic approach

The development of the Fifth Framework Programme (1998-2002) has been the occasion for rethinking some fundamental aspects of its structure and operation. The Commission has recognised the need to give new momentum to Community research and technological development (RTD) within a broader strategy which recognises the decisive importance of knowledge policies: research, innovation, education and training.[5]

– as the new millennium approaches, the European Union is rapidly integrating, under the impetus of monetary union, while looking forward to future expansion and closer partnerships with its neighbours, within a wider and economically stronger Europe;
– there are major questions concerning unemployment, threats to the environment, the stability of social Communities and the well-being of citizens, to be addressed alongside the issue of competitiveness in a world economy which is increasingly interlinked;
– science and technology is becoming increasingly important to the fortunes of industries, nations and regions which are subject to major structural transition; the speed of technological change is increasing, and research is becoming increasingly expensive and specialised.

It has also been recognised, and confirmed by the recent five-year assessment of the Framework Programme,[6] that a more strategic approach encompassing adaptations of structure, content and management is needed if the programme is to make the best of its potential in the future. Although the programme has proved its value, its impact could be still greater, especially with regard to the uptake and utilisation of research for innovation.

Two weaknesses, in particular, of past programmes have been recognised. The first is the dispersion of effort on too many areas of research, which may have limited the impact of expenditure. The *leitmotif* of the traditional approach has been ''generic research'', wherein Community research has been structured around scientific and technological disciplines (such as information technology and biotechnology) or sectoral interests (such as energy and environment) which have the potential for a wide range of possible applications. This is an agenda defined by science and technology ''push'', which is called into question by present understanding of the nature of innovation and the ways in which research contributes to industrial competitiveness. The second weakness derives from rigidities in programme implementation and management, which have made it difficult to keep up with the pace of scientific and technological change.

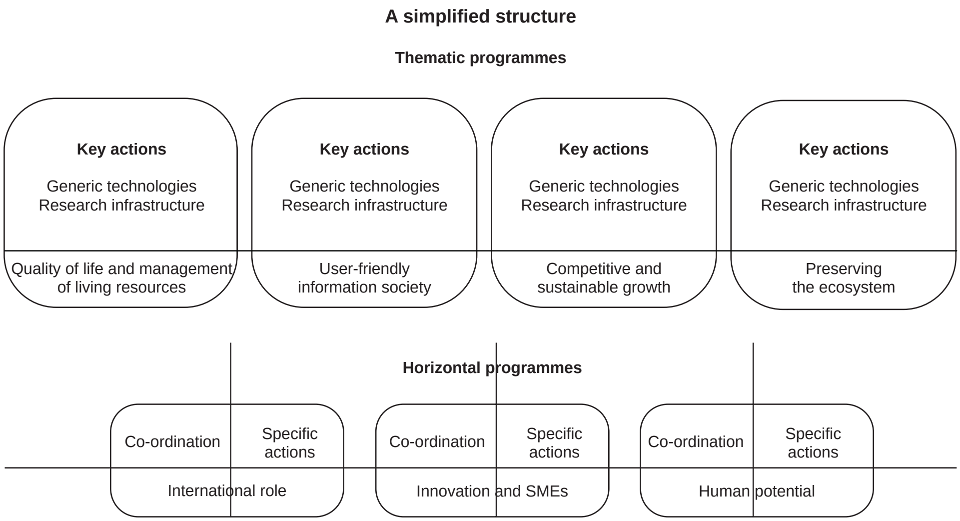
Structure of the Fifth Framework Programme

The watchwords for the Fifth Framework Programme are concentration and flexibility. It is focused on more precise objectives than in the past, which are essentially socio-economic, rather than technological, in nature, and are to be achieved, in large part, through integrated actions. Moreover, it is structured in a way which should allow more flexible allocation of resources to follow changing priorities as time progresses. The intention is to ensure that the research efforts undertaken will be more effectively translated into practical and visible results.

In contrast with the disciplinary structure of the Fourth Framework Programme, involving some 20 separate specific research programmes, the Fifth Framework Programme is organised around just seven individual programmes (see Annex and Figure 4). These come in two categories:

– four *thematic programmes* which correspond to the first activity of the programme as described above (*i.e.* collaborative RTD as such);
– three *horizontal programmes*, which correspond to activities 2 (''Confirming the international role of European research''), 3 (''Innovation and participation of SMEs'') and 4 (''Improving human potential'').

Figure 4. **Structure of the Framework Programme**



The ***thematic programmes*** combine a focus on a limited number of objectives, with actions to maintain and strengthen the science and technology base. They comprise:

– a series of *key actions* which are directed towards well-defined problems and objectives and are intended to mobilise, through an integrated ‘‘system approach’’, various disciplines and technologies needed to meet these goals;
– *generic research* and development of technologies which follow a more ‘‘traditional’’ approach and are directed towards maintaining the technological capabilities of the Community and ensuring the flow of knowledge and expertise in Europe;
– support for *research infrastructure* which is designed to optimise the utilisation and further development of infrastructure and facilities across Europe.

The ***horizontal programmes*** complement the thematic programmes by focusing on issues (*i.e.* international co-operation, SMEs, dissemination and exploitation, training and mobility) which are common to all thematic programmes but also require specific activities in their own right. These programmes combine two sorts of activities:

– co-ordination, support and accompanying measures for activities related to their respective objectives which are carried out in the thematic programmes;
– specific activities linked to the objectives of EU policies in their respective fields which cannot for one reason or another be carried out by the thematic programmes themselves.

The philosophy is one in which the horizontal programmes act as ''champions'' of certain of the policy objectives of the Framework Programme which are nevertheless delivered in large part through the thematic programmes.

This very simple structure has the potential to bring major benefits in terms of strategic focus and flexible implementation, because it orients research activities at all levels towards clearly defined objectives and minimises the number of interfaces between different elements of the programme, thus improving the prospects for co -ordination and limiting arbitrary compartmentalisation of different activities. Nuclear research under the Euratom Framework Programme, under this structure, will be combined with non-nuclear energy research within one of the thematic programmes (see Annex). It will however, remain legally separate as required by the Treaties.

The selection of topics under the thematic programmes

The rationale for the ''generic'' and somewhat disparate research activities under previous framework programmes was that they should provide added value at European level, above and beyond national activities, for example as a consequence of the scale of the activities undertaken, or the fact that they dealt with problems with an international dimension. This is in fact a *sine qua non* condition for EU research.[7]

The targeted, and therefore selective, approach of the Fifth Framework Programme demands more specific criteria, which, as well as European added value, include also the relevance of research to the challenges facing the EU described above.

The criteria which have been defined for the selection of research themes therefore comprise three elements:

– *Criteria related to social objectives:* improving the employment situation; promoting the quality of life and health; preserving the environment.
– *Criteria related to economic development and scientific and technological prospects:* areas which are expanding and create good growth prospects;

areas in which Community businesses can and must become more competitive; areas in which prospects for significant technological progress are opening up.

– *Community "value added" and the subsidiarity principle:* a "critical mass" in human and financial terms, and the combination of complementary expertise; significant contribution to Community policies; problems arising at Community level, standardization; development of the European area.

For the selection of research proposals put forward under the programme, these criteria will be supplemented with more specific criteria relating to, for example, the quality of the scientific and technological research being proposed (excellence being a fundamental principle), the innovativeness of the project, and the prospects for exploiting research results.

During the development of the Commission's proposals a protracted and wide-ranging consultation exercise has been carried out to ensure that the research areas selected do indeed conform to these requirements. The final content of the programme will be decided by the European Parliament and Council of Ministers on the basis of a proposal which has been put forward by the Commission, following the so-called "co-decision" procedure for European Union legislation. The Annex shows the position of the Commission (based on the Common Position of Council) at the time of writing.

IV. OTHER ASPECTS OF COMMUNITY RESEARCH POLICY AND THEIR IMPLEMENTATION UNDER THE FIFTH FRAMEWORK PROGRAMME

International co-operation

A number of the objectives of the Fifth Framework Programme can only be tackled fully by complementing the research effort within the Union with selective co-operation beyond its frontiers. Globalisation of science, technology and industry means that firms in the EU may need to incorporate expertise developed by universities and firms outside the Union and co-operate to promote standardization or to develop access to foreign markets for high-tech products. There are, in addition, international problems like environmental change and pollution, or infectious diseases, which have a global or regional dimension and which the EU cannot solve alone, and areas which need international effort because of the volume of work and/or facilities required, such as nuclear fusion.

Besides these scientific and technological objectives, external research co-operation contributes to the EU's external policy. Science and technology are closely linked to industrial development and thus to economic and political stability, so the EU pursues external co-operation in support of development policy and in particular to provide assistance to partners from neighbouring countries. These include countries from the Mediterranean region and Central and Eastern Europe, and countries which are candidates for accession to the Union.

Participation by partners from outside the Union in the Framework Programme is possible for projects under all of the specific programmes, if this is in the Community interest and conforms to the objectives of the programme. Such participation is based on open access to the programme by neighbouring regions, or for other countries on specific co-operation agreements signed with the EU for science and technology, or on evaluation of the situation on a case-by-case basis as to whether it is appropriate to include a non-Union partner to meet the programme's objectives.

In addition to participation under the thematic programmes, specific actions will be initiated under the horizontal programme on ''Confirming the international role of Community research'', to address problems relevant to particular groups of third countries which are of strategic interest to the Union. These will target separately the accession candidate countries, other central and eastern European countries and New Independent States (NIS) of the former Soviet Union, Mediterranean countries and developing countries.

SMEs

A number of special measures have been developed to facilitate the participation of SMEs in Community research, by addressing the constraints which are faced by companies with limited research capabilities:

– Principal amongst these is the *Co-operative research* (CRAFT*)* scheme whereby groups of SMEs (at least four from two different member states) facing common problems or opportunities but not possessing the necessary in-house research capacity, can entrust the required research to a third party (generally a research centre). CRAFT projects have a maximum duration of two years and total value of up to ECU 1 million (of which the Commission finances 50 per cent).
– A second measure consists of *exploratory awards*, grants of up to ECU 45 000 (75 per cent of total costs) allowing two SMEs from two different member states to prepare a project proposal for a Community RTD programme. This may concern a project for collaborative research, in which SMEs with high RTD intensity participate, or one for co-operative

research (CRAFT), in which SMEs with limited research capability are involved.
– A network of *focal points* (advisory services in the member states) has also been established to inform SMEs about CRAFT and exploratory awards, and to provide assistance to SMEs in the preparation of proposals (*e.g.* search for partners).

The CRAFT scheme and exploratory awards are implemented via an open call for proposals, meaning that proposals may be submitted at any time during the programme. They are not, of course, compulsory; SMEs are encouraged also to participate in standard collaborative research projects.

These measures are being improved under the Fifth Framework Programme, in the light of experience. For example, information and assistance networks will be rationalised and reinforced to ensure high standards of quality and offer services such as ‘‘pre-screening’’ of proposals, thus reducing the levels of over-subscription to Community RTD programmes (and consequent frustration on behalf of the proposers); a special entry point for SMEs will be created, to which small firms can address all their questions and proposals; and the flexibility of SME measures will be increased (for example, it is proposed to reduce to three the required number of SMEs for a CRAFT project).

Exploiting research results

The benefits of the Framework Programme to the European economy and society will only be fully realised if there is a high level of uptake and utilisation of the research which it promotes. Europe does not have a particularly good record in this respect: although it is remarkably creative in terms of knowledge and know-how, there is an acknowledged discrepancy between the EU’s overall scientific potential and its ability to transform that potential into commercially viable products.

This is at heart a matter of innovation capacity, which is a complex function – still poorly understood – of many factors other than research, including for example the regulatory and fiscal environment, the presence of infrastructure, trained personnel, organisation and financial resources. Recognising this, efforts to improve the exploitation of Community research have evolved from purely ‘‘end-of-pipe’’ measures coming into play after research projects, towards a more systemic approach which is embedded within the operation of the research programmes themselves. (Such a systemic approach, of course, has to be linked to policies outside the context of the Framework Programme, see Box 2.)

Box 2. **The Framework Programme in a broader policy context**

The benefits of research arise from the integration of its outputs into society and the economy. Just as the Framework Programme serves a number of different policy objectives, so the impact of the programme depends on the broader policy context. For this reason, a good deal of attention has been given to ensuring complementary impacts from other major Community policies and the Framework Programme on the institutional, research and innovation environment, while preserving the specific, and distinct, vocations of these policies.

Of major interest in this respect are the *structural funds*. Increasing attention has been given to RTD actions within the EU's structural expenditures, in recognition of the importance of research to economic development. ECU 8.5 billion will be spent on RTD activities under the structural funds in the period 1994-99 (5.7 per cent of the total), mainly on regions which are designated ''Objective 1'' (lagging behind in economic development) and ''Objective 2'' (affected by industrial decline). Because of this concentration of funds on regions which have relatively low RTD intensities, the levels of expenditure on RTD in these regions via the structural funds are often higher than those of the Framework Programme. The targets of this expenditure include research infrastructure, training, RTD projects and technical service development – activities which broadly modernise the structure of local innovation systems. A number of innovative pilot projects have been launched, such as an activity on ''Regional Innovation Strategies'' to encourage the development of local partnerships involving industry, universities, local authorities and other actors around locally relevant innovation initiatives.

A second area of interest is the Community's first *Innovation Action Plan*. Although innovation does not appear explicitly as a Community objective under the Treaties, an innovative and dynamic economy is recognised as an essential requirement for growth, competitiveness and employment – the Union's central political concerns. Research and technology are clearly important contributors to innovation, but they are not the only factors involved. For innovative knowledge-based economies, such as those of Europe and its competitors, to thrive requires constant investment in a range of material and intangible assets (education and know-how, organisational adaptation, as well as research). Not only does this imply that the necessary financial means are available, it also depends on a strong appetite for risk taking, creativity on the part of firms, and a society willing to countenance substantial change in the interests of social and economic development. For these reasons, the Community has developed a strategy towards innovation by means of the co-ordination of actions in a number of policy areas (including research) under the title of the ''First Action Plan for Innovation''.

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The priorities include adapting legal and regulatory conditions (*e.g.* for intellectual property and venture finance) to improve the climate for innovation, and gearing research more closely towards innovation needs. A recent communication of the Commission reports on the implementation of these measures.[8]

The Fifth Framework Programme continues this process of evolution, building on what has been achieved in earlier programmes. The structure and philosophy of the programme is more innovation-friendly than in the past, being objective-led, focusing on relatively tangible outcomes and integrating research from different areas needed to develop real products and services. Design and management of projects will ensure that exploitation prospects are built in from the beginning. And ''innovation units'' will be established within each of the thematic programmes to provide support and advice to innovation-related aspects of programme management, including access to innovation financing and the protection and exploitation of intellectual property. Overall co-ordination of these activities will be the responsibility of the horizontal programme on ''Innovation and participation of SMEs''.

Improving Europe's human potential in research

Europe's research and innovation capacity depends in large part on the quality of its human capital. A base of well-trained researchers who are familiar with the latest techniques and who are in regular close contact with their peers is essential to the free flow of ideas. Europe's size and cultural diversity make action on this front especially important, to encourage mobility among the population of researchers and break down barriers which would otherwise exist between the research milieux of different European countries. Compared with its main competitors, the Community has a relative shortage of researchers, a fragmented research base and rather low researcher mobility, both geographically (for example, researchers in the peripheral regions remain fairly isolated) and between academia and industry.

The ''horizontal'' programme in the Fifth Framework Programme on ''Improving Human Potential and the socio-economic research base'' includes the latest manifestation of a range of activities designed to combat these problems, which are directed mainly towards younger researchers (under 35 years of age), and which have been given increasing weight in the Framework Programme in recent years. The specific actions under this programme to reinforce the Community's human research capacity comprise two elements:

- *Research training networks*, whose primary objective is to promote training through research, in the framework of high-quality, transnational collaborative research projects which are not restricted as to their content. Community support could be given for the appointment of young researchers to such networks, coming from a country other than that of the team itself (and participating in an appropriate training programme) and for contributing to the costs of co-ordinating the research network.
- A system of ''*Marie Curie'' fellowships*, which will provide opportunities for researchers to carry out their work in laboratories of countries other than their own, or to return from abroad to their own country. A number of different types of fellowships will be involved, relevant to researchers at different levels (from postgraduate to experienced scientists) and to different mobility requirements. For example, in addition to the general fellowships for young experienced researchers (*individual fellowships*), there will be fellowships applicable to industrial and commercial environments (*industry host fellowships*) and fellowships directed towards the development of new competencies in institutions in less-favoured regions (*development host fellowships*).

Alongside these training and mobility actions, the ''Improving Human Potential'' programme will include a number of other types of activities to enhance access to major research infrastructures, promote scientific and technological excellence and the public image of research, improve the socio-economic knowledge base, and support the development of science and technology policies (see Annex).

Socio-economic research

In keeping with the Treaty requirement to support the scientific and technological bases of European industry, the Framework Programme is mainly concerned with ''hard'' science and technology. However, increasing importance has been given to the social and economic sciences in successive framework programmes. This is an acknowledgement that the substantial impact of social, behavioural and economic factors on the development and use of science and technology (and their role in competitiveness) is not matched by our understanding of these aspects. It is also a recognition that benefits can be achieved from improving the international linkage of Europe's research community in these areas, through increasing the size and diversity of data sets, bringing different perspectives to bear on major problems, and creating a ''critical mass'' of effort on truly European problems, which would otherwise be addressed in a rather fragmentary manner.

The reality is that socio-economic factors are at work to some degree in attempts to resolve any scientific and technological problem. Moreover, as the Framework Programme becomes more targeted and focused on questions which are themselves presented in socio-economic terms (control of illness, ageing, management of water, sustainable mobility, etc.), the interaction between socio-economic and technical research becomes increasingly relevant. Hence, building on developments in earlier programmes, the Fifth Framework Programme has been designed to accommodate socio-economic research in several contexts:

– First, there will be important elements of socio-economic research in each of the thematic programmes. To meet the various objectives of the key actions, following the integrated, interdisciplinary philosophy, research will include issues such as learning, natural language, and the human constraints on the design of technologies and systems; consumer perceptions and preferences which affect market development, uptake and use of technology-based products andprocesses; and the policy and regulatory regimes which are needed alongside technology developments in order to optimise their economic, industrial, environmental and social benefits. Moreover, the generic research label will cover research in areas such as health systems, biomedical ethics and bioethics, socio-economic aspects of life sciences and environmental change.
– Second, part of the horizontal programme on ''Improving human potential and the socio-economic research base'' is dedicated to socio-economic research as such, its focus being on the structural changes which are facing European society, and the ways in which such changes can be managed, so that citizens can be more in control of shaping their future. The idea in this part of the Framework Programme is to see European society as a subject for study in its own right, and to understand the very important relationships between European integration, the evolution of European society and the fundamental policy objectives of the Framework Programme such as competitiveness and employment. This element of the programme will thus focus on structural, demographic and social trends, the relationships between technological change, employment and society, the changing roles of European institutions, systems of governance and citizenship, and the validation of new development models.
– Third, also part of the horizontal programme on ''Improving human potential and the socio-economic research base'' and continuing from earlier framework programmes, research will be promoted on science and technology policy issues, and related indicators, to provide a basis for the development of future policies

The Joint Research Centre

A proportion of funding under the Framework Programme (about 7.3 per cent in the Fourth Framework Programme) is allocated to the European Community's own research laboratory, the Joint Research Centre (JRC), through so-called ''direct actions''. The JRC's main role is to provide neutral and impartial scientific and technical support to the development of Community policies and regulations (see Box 3).

The activities of the JRC are focused on areas where its skills and equipment – in many cases unique in Europe – can provide added value, through client/supplier relationships with the Commission's Directorate Generals. However, the JRC is increasingly participating also in ''indirect'' actions under the Framework Programme, as a partner in trans-European consortia, for which it competes with other research proposers in the normal manner.

Box 3. **The Joint Research Centre**

The Joint Research Centre is organised into seven institutes at five different locations:

- *Institute for Reference Materials and Measurements (Geel, Belgium),* which works on European standards and the harmonization of reference materials and methodologies.
- *Institute for Transuranium Elements (Karlsruhe, Germany),* which carries out research on management of nuclear waste and provides scientific and technological support for nuclear safeguards.
- *Institute for Advanced Materials (Petten, Netherlands),* which works on materials and operates the High Flux Reactor for the Dutch, German and French authorities.
- *Institute for Systems Informatics and Safety (Ispra, Italy),* which contributes to a number of Community policy areas concerned with safety. *Environment Institute (Ispra, Italy),* which focuses on aspects of environmental policy.
- *Institute for Space Applications (Ispra, Italy),* which provides support for the utilisation of remote sensing in agriculture and other applications.
- *Institute for Prospective Technological Studies (Seville, Spain),* which has a technology-watch function and carries out a variety of studies on developments in science and technology for different clients.

Conclusions

This article describes the role and broad objectives of the Framework Programme and its importance within the European research scene and gives a detailed picture of the outlook for the programme in the coming years.

The Framework Programme is both a political instrument, designed to deliver tangible outcomes in terms of institutional change and innovation, and a funding mechanism which must be sensitive to the demands of the local situation encountered by potential participants. It is recognised that the programme has benefited European research, but nevertheless needs to be updated and made more strategic. Such a change has considerable implications for the research and industrial communities, who have come to regard the Framework Programme itself as a central institution in European research.

The challenge to these groups will be to adapt to the new situation and to take advantage of what it can offer by amending their approach to it. Achieving this will require, however, a change in the culture of research partnerships which have hitherto regarded European Community research expenditure as the last refuge of ‘‘manoeuvrable’’ funds in an environment where member states are increasingly targeting research resources on rather precise strategic objectives. By focusing effort at Community level on those objectives which are truly strategic for Europe, it is hoped that a much more profound benefit will be achieved for the Union’s citizens.

NOTES

1. These and other figures in this article are taken from the *Second European Report on Science and Technology Indicators*, EUR 17639, December 1997.
2. There are in fact two research Framework Programmes, provided for under the EC and Euratom Treaties, respectively. Their content is complementary (the EC focusing on non-nuclear and the Euratom programme on nuclear research) and their administration is harmonized; hence they will be considered here under the generic title ''Framework Programme''.
3. Figures from the ''1997 Annual Report on Research and Technological Development Activities of the European Community'', COM(97)373, July 1997.
4. ''1997 Annual Report'', *op. cit.*, note 3.
5. ''Agenda 2000'', Volume 1: ''For a Stronger and Wider Union'', European Commission, Brussels, COM(97)2000, 15 July 1997.
6. See, for example, the report of the Davignon Panel: ''Five-year Assessment of the Framework Programme''.
7. EU RTD policy is subject to the the ''subsidiarity'' requirement which specifies that action can only be taken by the EU if it ismore effective to do so at this level rather than at that of the Member States.
8. ''Implementation of the First Action Plan on Innovation in Europe: Innovation for Growth and Employment'', COM(97)736 final, 14 January 1998.

Annex

THEMATIC PROGRAMMES

1. Quality of life and management of living resources

a) Key actions

i) *Health, food and environmental factors:* improving health through safe, balanced and varied food supply for consumers covering the whole food chain, and through reduction of environmental hazards.

ii) *Control of infectious diseases:* the fight against infectious diseases, based on new and improved vaccines, a better understanding of the immune system, and public health aspects.

iii) *The "cell factory":* exploiting advances in understanding the cellular and subcellular properties of micro-organisms, plants and animals, for health, environment, agriculture, chemicals, etc.

iv) *Sustainable agriculture, fisheries and forestry, including integrated development of rural areas:* developing the knowledge and technologies needed for the production and exploitation of living resources, covering the whole production chain.

v) *The ageing population:* promoting the health and autonomy of older people by prevention and treatment of age-related illnesses and their social consequences.

b) Generic research and technological development

- Chronic and degenerative diseases (in particular cancer and diabetes), cardiovascular diseases and rare diseases.
- Research into genomes and diseases of genetic origin.
- Neurosciences.
- Public health and health services research.
- Study of problems relating to biomedical ethics and bioethics in the context of respect for fundamental research values.
- Socio-economic aspects of life sciences and technologies within the perspective of sustainable development.

c) Support for research infrastructures: databases and collections of biological material, centres for clinical research and trials, facilities for fishery and aquaculture research.

2. Creating a user-friendly information society

a) Key actions

i) Systems and services for the citizen: fostering the creation of next-generation general interest digital services (health, disabled, public administrations, environment, transport) for flexible access to all citizens.

ii) New methods of work and electronic commerce: developing technologies to help companies operate and trade more efficiently, and facilitating improvements in working conditions.

iii) Multimedia content and tools: future information products and services, enabling linguistic and cultural diversity, for electronic publishing and education and training, including innovative forms of multimedia content, and tools for structuring and processing them.

iv) Essential technologies and infrastructures: promoting technologies for the Information Society (communications, networks, software, microelectronics, etc.), speeding up their introduction and broadening their field of application.

b) Generic research and technological development

- Future and emerging technologies (open domain and proactive initiatives)

c) Support for research infrastructures: support for broadband interconnection of national research and education networks, and advanced European testbeds to assist in development of standards, results and applications, to facilitate implementation and inter-operability of advanced computer and communication systems for research.

3. Promoting competitive and sustainable growth

a) Key actions

i) Innovative products, processes, and organisation: facilitating the development of high-quality innovative products and services, and new methods of sustainable production and manufacture.

ii) Sustainable mobility and intermodality: developing integrated options for the mobility of people and goods, improving transport efficiency, safety and reliability, reducing congestion and environmental disbenefits.

iii) Land transport and marine technologies: developing innovative materials, technologies, and systems for sustainable and efficient land transport, and for sustainable exploitation of the sea's potential.

iv) New perspectives in aeronautics: helping the development of aircraft, systems and components to improve European competitiveness whilst assuring rational management of air traffic.

b) Generic research and technological development

- New materials and their processes of production and transformation.
- New materials and production technologies in the steel field.
- Measurements and testing.

c) ***Support for research infrastructures:*** support for large infrastructures through networking (‘‘virtual institutes’’), laboratories and facilities for measurements and tests, and specialised databases.

4. Preserving the ecosystem

a) *Key actions*

i) *Sustainable management and quality of water:* producing the knowledge and technologies needed for rational management of water resources for domestic, industrial and agricultural needs.

ii) *Global change, climate and biodiversity:* developing the scientific and technological understanding and tools to underpin Community environmental policies and help deliver the goal of sustainable development.

iii) *Sustainable management of marine ecosystems:* promoting sustainable and integrated management of marine resources.

iv) *The city of tomorrow and cultural heritage:* sustainable economic development of the urban environment, improved urban planning and management; protection of quality of life and cultural identity of urban inhabitants, restoration of social equilibria and protection of cultural heritage.

v) *Cleaner energy systems, including renewables:* minimising the environmental impact of the production and use of energy in Europe, through research on cleaner and renewable energy sources, and fossil fuel use.

vi) *Economic and efficient energy for a competitive Europe:* providing Europe with a reliable, clean, efficient, safe and economic energy supply, through improved efficiency and reduced costs at every stage of the energy cycle.

b) *Generic research and technological development*

- The fight against major natural and technological hazards.
- Development of earth observation satellite technologies.
- Socio-economic aspects of environmental change in the perspective of sustainable development.
- Socio-economic aspects of energy within the perspective of sustainable development (the impact on society, the economy and employment).

c) ***Support for research infrastructures:*** research installations on climate and global change, marine research and natural risks.

5. Euratom activities

a) *Key actions*

i) *Controlled themonuclear fusion:* the aim is to pursue the development of fusion energy as an option for clean and safe energy production; this embraces all research activities undertaken in the member states on fusion.

ii) *Nuclear fission:* the aim is to help ensure the safety of Europe’s nuclear installations, the protection of workers and public, and the safety and security of waste; to improve industrial competitiveness, and explore new concepts.

b) Generic research and technological development

- Radiological protection and health.
- Environmental transfer of radioactive material.
- Industrial and medical uses and natural sources of radiation.
- Internal and external dosimetry.

c) Support for research infrastructures: large facilities, networks for collaboration, databases and biological tissue banks.

HORIZONTAL PROGRAMMES

Confirming the international role of community research

The aims are to promote S&T co-operation internationally; to reinforce Community capacities in the fields of science and technology; to generally support the achievement of scientific excellence within the wider international framework; and to contribute to the implementation of the Community's external policy also with the accession of new members in mind.

Actions specific to the horizontal programme

a) Co-operation with third countries: activities would be differentiated by category of country:
Candidates for EU membership (*e.g.* promotion of centres of excellence, facilitating of participation in the other programmes of the Framework Programme); *NIS and other Central and Eastern European countries:* (support for their RTD potential, and co-operation in areas of mutual interest); *Mediterranean partner countries:* (improving their RTD capacities and promoting innovation; co-operation in areas of mutual interest); *developing countries:* (sustainable management and use of natural resources, health, nutrition and food security); *emerging economy and industrialised countries:* (exchanges of scientists; organisation of workshops; promotion of partnerships and enhanced mutual access, *e.g.* through S&T co-operation agreements).

b) Training of researchers: fellowships for young researchers from developing countries, Mediterranean and ''emerging economy'' countries to work in Community laboratories and vice versa.

c) Co-ordination: with COST, EUREKA and international organisations, with other external assistance activities (PHARE, TACIS, MEDA, EDF, ...), and with member states.

International co-operation pursued through the other Framework Programme activities

Participation by third countries in the specific programmes may take basically two forms:

- countries which are ‘‘fully associated’’ with the Framework Programme can participate on similar conditions to member states;
- otherwise, countries may participate on a project-by-project basis, *e.g.* if they have a bilateral or a multilateral ‘‘co-operation agreement’’ (generally with no funding).

Promotion of innovation and participation of SMEs

The aim is to improve the social and economic impact of RTD, especially the Framework Programme, through better dissemination and exploitation of research results and technology transfer, by means of policies consistent with the Innovation Action Plan, and with particular attention to the participation of SMEs in the Fifth Framework Programme.

Co-ordination activities on innovation and participation of SMEs

d) Promotion of innovation: assuring synergy and co-ordination of the activities of ‘‘innovation units’’ to be set up in the thematic programmes; definition of methods and mechanisms to improve the exploitation of results.

e) Encouraging SME participation: support for SME participation in RTD and demonstration activities to be carried out in the programmes; including ‘‘co-operative research’’ activities and ‘‘exploratory awards’’.

Actions specific to the horizontal programme

f) Promotion of innovation: activities to improve the level of uptake of technologies and results; new approaches to technology transfer, integrating the technological, economic and social aspects of innovation, co-ordination of studies and analyses on innovation policy.

g) Encouraging SME participation: a special entry point for SMEs, providing help and assistance on research programmes; common instruments to harmonize and simplify SME access; ‘‘economic intelligence’’ to help SMEs identify and meet their current and future technological needs.

h) Joint actions innovation/SMEs: rationalisation, co-ordination and management of networks for promoting research and innovation, electronic and other information services, providing information and assistance on the Community’s research and innovation activities; provision of information and pilot activities on intellectual property rights; access to private finance; and assistance for the creation and development of innovative start-ups.

Improving human potential and the socio-economic research base

The aim is to preserve and help develop the Community's knowledge potential through greater support for the training and mobility of researchers, by enhancing access to research infrastructures and making Europe attractive for research investment; to mobilise research on the social and economic sciences and humanities to understand critical economic and social trends and requirements, and to support the Community's science and technology policies.

Actions specific to the horizontal programme

Supporting training and mobility of researchers: research training networks focusing on young researchers at pre-doctoral and at post-doctoral level; a system of ''Marie Curie'' fellowships, including fellowships for young high-quality researchers; fellowships awarded to young researchers and hosted by enterprises (including SMEs); fellowships in the less favoured regions of the Community; fellowships for experienced researchers to promote mobility between industry and academia; and support for short stays by doctoral students in training sites.

Enhancing access to research infrastructures: enhancing international access to research infrastructures; networks of co-operation between infrastructures; RTD projects orientated towards infrastructure.

Promoting scientific and technological excellence: stimulating through exchange scientific and technological excellence and to making the most of the achievements of research, *e.g.* through high-level scientific conferences, prizes for high quality research; actions to improve understanding of science and technology.

Key action: Improving the socio-economic knowledge base: improving understanding of structural changes in Europe to better manage them and help citizens build their future; social trends and structural changes; technology and society; governance and citizenship; new models of development favouring growth and employment. Defining the knowledge base for employment-generating social, economic and cultural development and for building a European knowledge society.

Support for the development of science and technology policies: strategic analysis of key policy questions; development of a common base of science, technology and innovation indicators; supporting the development of the specific knowledge base needed by policy makers and other users on European science and technology policy issues.

Action pursued through other Framework Programme activities

The horizontal programme would provide co-ordination, support and accompanying actions needed to ensure consistency with action undertaken elsewhere in the Framework Programme on the aspects related to the objectives and activities of this programme.

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