# MODELS OF TECHNOLOGY DEVELOPMENT IN INTERMEDIATE RESEARCH ORGANISATIONS

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by

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## Abstract

The development and exploitation of new scientific and technological know-how is a prime engine of economic growth. Different innovation systems have developed different approaches to this problem and have built upon varying combinations of public and private support for R&D over time. In this context, research and technology intermediaries play an important brokering and entrepreneurial role. This paper contains a comparative institutional analysis of the policy and business models of the Fraunhofer Society (Germany), IMEC (Belgium), the Holst Centre (the Netherlands), ITRI (Taiwan) and ETRI (South Korea). It includes an investigation and discussion of their main features, modus operandi, opportunities/risks and trade-offs. The study responds to the need to gain better understanding of possible ways to strengthen the capacity of the UK economy to generate value from its science and technology base. The case studies presented in this paper offer a number of useful lessons for the development of new innovation policy instruments of great potential benefit to the UK plc.



**Keywords**: technology transfer, knowledge exchange, research and technology intermediaries, innovation policy

**JEL Codes**: **O25, O30, L50**

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## 1. Introduction

There is great ferment in the academic and policy debate around the opportunities and risks of extracting value from the knowledge generated in public research environments through increased direct exploitation of capital (for example lab facilities) and intellectual assets (human capital and IP). No consensus exists on the best ways to achieve these goals, which are typically multidimensional and reach deep into the fundamental ethos and operating practice of public research organisations. Moreover, different economic systems have developed very different approaches to this problem and these also depend on long-standing historical traditions of funding the creation and use of new knowledge.

In recent years the perception has been growing that technical change is becoming more distributed, modular and globalised. This raises a number of questions – by and large unresolved in the literature – related to vertical disintegration pressures, the benefits of and limits to the growth of network-type organisational forms, intensive use of flexible contractual arrangements and effective IP strategies for fast-changing industrial settings.

Stronger international competition, higher costs of R&D and increasingly complex goods and services – it is argued – have intensified the fundamental uncertainty associated with investments in innovation. These factors are claimed to have contributed to the perceived diffusion of more 'open' models of innovation (Chesbrough, 2003) and have also brought about dramatic changes in the role of higher education institutions (Etzkowitz, 2002; Audretsch and Phillips, 2007; Antonelli, 2008). These changes go hand in hand with the concomitant development of new ways of organizing the provision of capital (as reflected by the growth of the VC sector), the emergence of advanced intermediate markets for knowledge (patents and licenses)[1] and the creation or substantial update of institutional/organizational channels for the transfer of technological knowledge.[2]

Knowledge exchange is an important component of S&T policies. Conceptually, it is a fundamental mechanism by which new knowledge is diffused throughout the system and different organisations participate in the innovation process along the timeline that goes from the development of a new idea with market potential to its translation into new or upgraded industrial processes and new or improved market products. Throughout the process, the division of labour between public research organisations and firms is rarely as clear-cut as the assumed theoretical distinction between basic science, applied research and product development would have it. Also, what is 'transferred' from one organisation to another changes very much according to the knowledge base of the industry, the objectives of the collaboration, incentives and contractual agreements. A classic distinction is drawn, for example, between tacit and codified forms of knowledge. Tacit knowledge is transferred via social interaction; codified knowledge is transferred through transaction of excludable and divisible information goods, such as publications and patents. Knowledge exchange processes involve varying bundles of tacit and codified knowledge and these are partly foreseen and specified ex-ante through contracts and partly unanticipated and co-evolving with contextual factors.

Broadly speaking, there are different channels through which the transfer of technological know-how can take place.[3] These work with different mixes of tacit vs. codified and proprietary vs. non-proprietary knowledge. The literature has highlighted spin-offs, licensing, learning from published patent and papers, informal networks, contract research and consulting, labour mobility and intermediary organisations.

Intermediaries include organisations that are either internal or external to university environments. In the first group (internal intermediaries) are, for example, technology transfer offices. These have proliferated in the UK, and by imitation elsewhere, after the Bayh-Dole Act (1980) granted US universities the right to appropriate and commercially exploit knowledge generated by or jointly with academic departments. In the second group (external intermediaries) are intermediate research organisations that operate as bridges between universities and firms but are autonomous and independent and are funded through combinations of public and private resources. Needless to say, alternative forms of knowledge exchange through intermediary organisations do not exclude other channels, but are in fact ways to incentivise, streamline and manage licensing, spin-off, dissemination, networking and labour-exchange activities.

In this contribution we focus on the role of intermediate research organisations and reflect on their policy and business models and their capacity to connect the needs of industry with the supply of external research and development infrastructures and skills. Our explicit focus is on understanding how a range of such organisations work in different national contexts and in drawing potential policy implications for the UK.

The paper is structured as follows: In the next section we provide a brief overview of the context of knowledge exchange and the role of intermediaries in the UK. Section 3 then sets out the conceptual framework and empirical methodology that we employ. Sections 4-9 set out in turn an analytical description of major intermediary institutions in Germany, Belgium, Holland, Korea and Taiwan[4]. Section 10 provides a brief summary of factors affecting success in intermediary organisations and Section 11 concludes.

## 2. Knowledge exchange and technology development in the UK context

The perceived failure of the UK to exploit effectively its science and technology base has been the subject of hand-wringing by politicians and policy specialists for nearly a century and government efforts to remedy this have been redoubled over the last fifteen years. A key feature of recent policies has been the creation of a third mission for universities alongside research and teaching, and increasing pressure on them and the research councils that fund them, to direct more research towards societal and industrial needs and to collaborate more closely with business.

In contributing to this discussion it is important to establish some important structural features of the process by which firms in the UK access knowledge for innovation. Within that it is also important to locate the role that the higher education institutions in the UK play in that process. The first and most important point to make is that the evidence overwhelmingly shows that as direct contributors to the development of commercial innovation processes higher education institutions are way down the list of sources of knowledge for information that UK businesses cite. This is not only true for the UK, but also for the United States and other OECD economies. (Hughes, 2008; Cosh and Hughes, 2009; Cosh, Hughes and Lester, 2006).

In most systems of innovation, however, multiple sources are combined in a distributed system of knowledge and technology development. In this process it is clear that a major role is played by intermediary organisations which sit between, or on the boundaries of, businesses and the university sector. These organisations are frequently used in combination with other firms in the business sector in accessing knowledge for innovation. Thus, although the vast majority of businesses in the UK, the US and elsewhere cite themselves, customers and suppliers as their main sources of knowledge, hardly any use these alone as a sole source. The next most frequent set of sources combined with business sector sources are intermediary organisations and structures. (Hughes, 2008; Cosh and Hughes, 2009). These perform many functions including foresight and diagnostic analysis in particular sectors, scanning and information processing, gatekeeping and brokering of relationships, testing, validation, various kinds of accreditation, validation and regulation, and finally, activities connected more directly with the commercialisation process including intellectual property protection and appropriation methods, and finally the evaluation of outcomes (Howells, 2006).

In an international comparison of the relative importance of these intermediary organisations, a recent survey comparing several thousand UK and US firms indicated that in the US a higher proportion of businesses relied on combinations of knowledge flows from customers, suppliers and the business itself combined with such intermediaries than was the case in the UK. (Cosh and Hughes, 2009; Hughes, 2008; Cosh Hughes and Lester, 2006).

The UK appeared to have a much more diffused system of interactions with firms more likely to report a connection with universities, but much less likely to report combinations of knowledge sources including intermediaries. Moreover, this comparison also showed that US firms, whilst less likely to report a direct interaction with universities were more likely to report investing substantially in such interactions. Finally, this research also showed that whereas UK businesses were more likely to receive state support for innovation activities, the level of support received per firm receiving support was an order of magnitude greater in the United States than in the UK. This suggests that the relative role of intermediaries in international systems, in particular in comparisons of their role in relative international innovation performance, is worthy of further study. This paper makes an explicit attempt to consider the role that specific kinds of intermediary organisations play. It focuses on functions concerned more directly with commercialisation and technology development rather than the other functions played by intermediaries in the typology suggested in Howells (2006).

The UK science and technology infrastructure already benefits from the activities of a number of research and technology organizations (RTOs) operating independently from Universities, Research Councils and public sector research establishments. Two related studies have recently addressed the role and impact in the context of the UK innovation system. The first one is the

2004 CBR/PACEC/IFS report on “The Contribution of Research and Technology Organisations to Innovation and Knowledge Transfer” commissioned by the Economic and Social Research Council (ESRC) on behalf of HM Treasury, the Department of Trade and Industry (DTI) and the Inland Revenue. The second one is the 2008 “Study of the impact of the Intermediate Research and Technology Sector on the UK economy” conducted by Oxford Economic for the Association of Independent Research and Technology Organisations (AIRTO).

The first of the two reports focused on the contribution of UK RTOs to innovation and knowledge transfer and on the way in which fiscal policies and taxation mechanisms affect their activities. RTOs were defined as providers of “support for company innovation” by means of “in-sourcing expertise, business models and technology to increase productivity”.[5] The analysis included all of the organisations which were members of the Association of Independent Research and Technology Organisation (AIRTO). For the year 2002 the report estimated the RTO community generated a turnover of £501 million, total employment of around 6,000 and research employment of around 3,400, excluding the contribution of Qinetiq. Qinetiq was by far the largest RTO at that time and its inclusion heavily skewed the data in the population and sample. When Qinetiq was included RTOs are shown to have generated £1.1 billion turnover and had 16,000 employees (of which over 10,000 scientists). The relative contribution of RTOs to total UK R&D employment was also significant: the report estimated it to be in the order of 5% of private business sector science and engineering employment without Qinetiq (15% including Qinetiq).[6]

The majority of RTOs analysed had a sectoral focus, with several examples in food and drink, construction, ceramics, clothing and textiles, footwear, motor vehicles and aerospace. Their role was to develop and apply technological knowhow, for example, in the areas of joining, chemicals, security systems/software, measurement, testing, and modelling. Linkages with the research base (universities, research councils and public research institutes) were generally funded through public sector schemes. Dissemination of results from R&D was either direct via dedicated events or mediated by partnering universities. Linkages with firms included the provision of contract research and joint R&D with support from public funds (UK and EC). These were seen by clients to contribute to the development of their skills and capabilities.

In 2008 Oxford Economics carried out a second study of the intermediate research and technology sector which was more widely drawn. This report estimated that in 2006 RTOs were responsible for employing about 22,000 workers, 60% of which were highly skilled holders of at least a degree-level qualification. The value of R&D expenditure by RTOs was estimated at around £400 million (one third of total UK extramural R&D expenditure, i.e. carried out outside the funding organisation)and RTO turnover was estimated at around £3 billion (all figures including Qinetiq). The report confirmed the importance of the brokering role of RTOs, their contribution to problem solving for client firms, and their facilitation of risk-sharing and open innovation. 80% of the sample of client firms involved in this study reported that "they could have not achieved the same results by just working in-house or with a university" (p. 3).

Although the contribution to UK plc of existing RTOs seems to be considerable, the question remains whether their activities (with the exception of Qinetiq's) operate on a sufficiently large and sustainable scale for the successful development and growth of emergent industries and whether the opportunity exists for the UK innovation system to foster initiatives based on the intermediate research lab model. The sectoral coverage of existing RTOs is very uneven and areas where the UK clearly has significant competitive advantages in fundamental and applied research are missing. As a consequence exploratory development phases of a number of major emergent technologies are overall underfunded relative to other countries that are instead committing to them substantial direct investments. Moreover, their structure is typically of a collaborative or trade association structure rather than a single focused development institution.

Finally, in considering how best to exploit the UK science base, a number of important structural and macro-economic factors need to be taken into account:

(i) The erosion of the UK's manufacturing base over the last 30 years means that it is now highly skewed, with some strong R&D intensive sectors such as pharmaceuticals and defence and aerospace and some, including electronic devices, ITC and materials, with weak absorptive capacity;

(ii) The UK's relatively high wage costs mean that the manufacturing function will tend to gravitate towards lower cost economies, especially where volumes are large, permitting economies of scale, and where learning curve effects enable further cost differentials through continued incremental process improvement (LCD manufacture is a classic example)

If we take the example of the Cambridge cluster – one of the most dynamic in the whole European area – we observe that this has created some successful devices companies, but among them the largest so far in employment terms (notably ARM, Domino Printing Sciences and Cambridge Silicon Radio) are all spin-outs from research-intensive commercial companies (Acorn Computers and Cambridge Consultants respectively), all recipients of funding for the development and/or team and competence building coming from customer funded development contracts). A key – but often overlooked – strength of the Cambridge cluster has been its broadly based technology 'consultancies' (Connell and Probert, 2010), effectively contract R&D labs that operate profitable private sector business models. It is, however, important to emphasise that even the most successful Cambridge device companies are modest in terms of size compared with US successes.

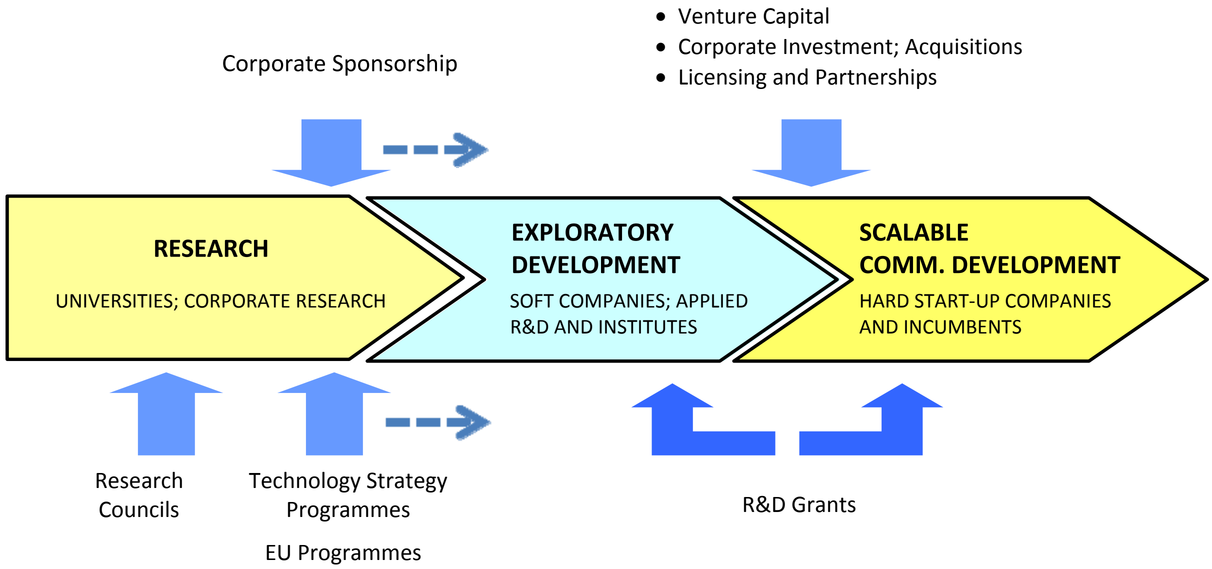
These considerations suggest that because so much of the value chain in these sectors is outside the UK, commercial exploitation through partnering with major multinational companies, often promoted as a reason for encouraging academic-industrial collaboration at the research stage, is quite unlikely to lead to significant added value, and jobs, in the UK. Secondly, exploitation of IP through university spin-outs has probably underperformed with respect to expectations. Some of the reasons can be captured by looking at the novel electronic and photonic devices, arguably an emergent general purpose technology with high potential for disruptive technical change.

This is a sector where the time between invention and commercialisation can be very long. This reflects both the difficulty of managing scale up and achieving consistency of quality and yield *and* also the time to find and test the many possible application markets typical of platform technologies. The policy challenge is that this "exploratory development" stage in the commercialisation process is neither backable by venture capital, nor by all but the very largest industrial companies absent in this sector in the UK. At the same time, it must be undertaken in a mission driven environment that is very difficult to create, for example, in a normal university department. There the pressures to publish and teach, turnover of research staff, weak project management, lack of imbedded commercial IP and contractual discipline, among other factors, can impede the creation of viable exploitation teams and can compromise the ability to create viable and commercially exploitable IP.

## 3. Motivation for the study, data and methodology

Innovation processes are complex and multidimensional. Technical and commercial uncertainty is one of their pervasive features and in particular in the pre-competitive development of new ideas with commercial potential. This is a phase where uncertainty of outcomes is associated with highest financial risks in the funding of new projects or new ventures. As a consequence, funding gaps are often registered at the stage comprised between research and scalable commercial development. These gaps tend to coincide with activities of exploratory development where research outcomes need to be formalised, tested and refined in order to reach the market as viable businesses (Figure 1).

**Figure 1: The Funding Gap**




Research can be carried out in various parts of the ecology of innovation systems, but it is mainly conducted by firms – and above all large firms – government laboratories and universities. Exploratory development activities are typically carried out by very large companies, specialised contract R&D companies ("soft companies" in Figure 1, as in Connell and Probert, 2010) or other intermediate organisations operating at the public-private interface. These activities are often less visible than activities of pure research or product development, but require long lead times and are extremely resource-intensive.

This study is part of broader programme of research on alternative modes of financing early-stage innovation, including specialised service providers, venture and corporate venture capital and intermediate research organisations (Connell and Probert, 2010, Mina and Sharpe, 2010). It builds on research interactions with teams of scientists and engineers at the EPSRC funded Cambridge Integrated Knowledge Centre for Photonics and Electronics (CIKC). This is a joint initiative of the Electrical Engineering Division, the Cavendish (Physics) Laboratory, the Judge Business School, the Institute for Manufacturing and the Centre for Business Research at the University of Cambridge. The CIKC focuses on the development and exploitation of new molecular and macromolecular materials, an area of great potential for radical transformation of products – and manufacturing thereof – as diverse as computers, sensing technologies, displays and communication systems through applications based on polymers, advanced liquid crystals, and nanostructures (including carbon and silicon nanowires) that are relevant in sectors, again, as diverse as telecommunications, health and energy.

The research design for this study involved a set of pilot interviews with the principal investigators of the CIKC programme and all the major technical projects (7) funded at the Centre. This was followed by repeated formal and informal interactions through meetings, seminars and workshops. A question was systematically posed by the research team on alternative modes of financing exploratory development in the area of advanced electronics and photonics to aid the identification and selection of relevant cases. A consistent group of answers clearly pointed in the direction of intermediate research organisations and included the German Fraunhofer Society, the Inter-University Micro Electronics Centre - IMEC (Belgium), the HOLST Centre (Netherlands), the Industrial Technology Research Institute – ITRI (Taiwan) and the Electronics and Telecommunications Research Institute – ETRI (South Korea).[7]

After the selection of cases was corroborated by the literature and desktop analysis of official public sources, a programme of interviews and site visits was devised and implemented in two phases: the first phase in Spring-Summer 2008 and the second in Spring 2009, with one further extension in Autumn 2009. Research materials were generated from meetings with a total of 60 interviewees at the different sites including senior managers, researchers or directors. Further interviews with founders and staff members of other organisations, including some large and small firms, with direct experience of collaboration with ITRI and ETRI were carried out in Taiwan and South Korea respectively. The interview programme was completed by a number of follow-up email exchanges and a policy research workshop with representatives from the Fraunhofer Society and IMEC. Finally, the interview materials were cross-checked and integrated with information sourced from secondary quantitative and qualitative sources, including the latest official publications from and about the different institutions (Annual Reports, policy documents and related literature).

The results of this study are presented here. We cover the models of knowledge exchange and technology development of the Fraunhofer Society, IMEC, the Holst Centre, ITRI and ETRI and then discuss some of the findings in relation to the UK debate on the funding gap, research and technology organisations and the role of research interfaces between public research and industry.

## 4. The Fraunhofer model

Germany has a rich ecology of research organisations. Among them, the Fraunhofer Society plays a distinctive and influential role. It is widely cited as an important component of the German innovation system and an important institutional channel for technology transfer in the country.[8] A 60-year old institution this year (2009), the Fraunhofer Institutes engage in applied research in a national context where the total R&D budget approximates 55.7 billion euros according to the latest available figures released by the German Federal Ministry of Education and Research. The main sources of R&D funding in Germany are the Industry (37.7bn), the State (15.8bn), foreign institutions (2.1bn) and Not-for-profit organisations (0.2bn). Industry accounts for 69 per cent of total expenditure, Universities for 17, Federal and Private Not-for-profit organisations for 14.[9]

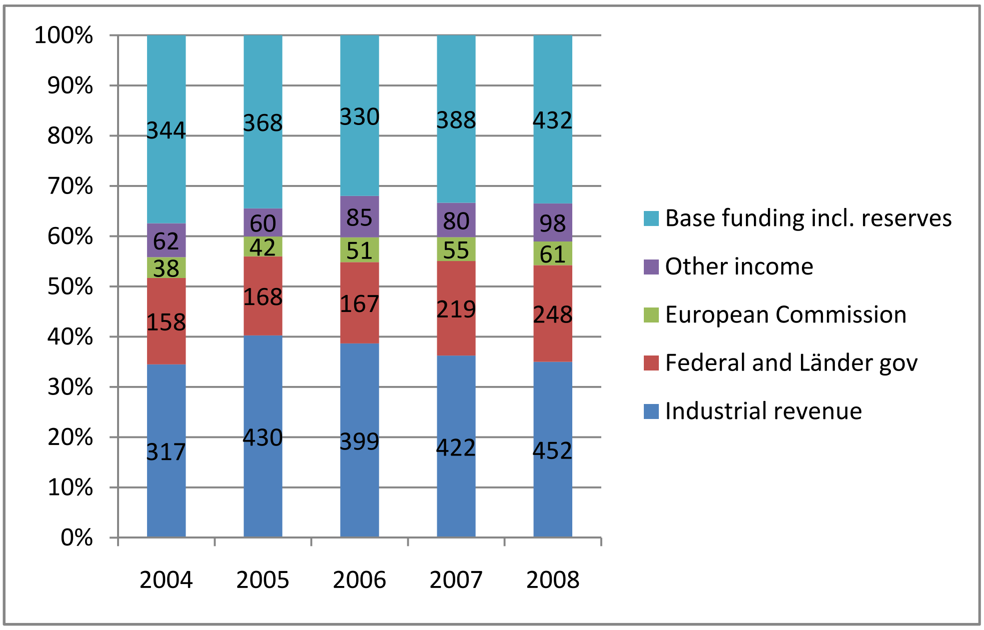
In the broader context of the German innovation system, the activities of the Fraunhofer Society are overall positioned in a mid-range area between basic research and commercial technology development in industry.[10] Research is funded through contracts from industry and publicly funded organisations (approximately two-thirds of the total figure), and through direct contribution from the federal and Länder governments (approximately one-third).

The Fraunhofer Society was founded in Bavaria in 1949. Its initial focus was geological research, but this soon expanded to cover a much broader spectrum of disciplines with the support of public procurement policies. The Society relied heavily, for example, on the Ministry of Defence as its main contractor until 1968, when it was formally incorporated in the Federal Government research budgets (Beise and Stahl, 1999). Over the 1970s the defence budget fell sharply while the Max Plank Society, born also in the Post War period from the pre-existing Kaiser-Wilhelm Society, reinforced its shift away from applied research and strengthened its focus on basic science in cutting-edge areas broadly complementary to research conducted in university departments.

Today the Society comprises 56 institutes and about 14,000 employees across 40 different locations. It is active in the following technical macro areas: ICTs, Life Sciences, Microelectronics, Materials and Components, Production, Surface Technologies and Photonics and Defence and Security. From an organisational viewpoint, an Assembly of Members of the Society elects the Senate. This appoints an Executive Board, which forms the Presidential Council with the elected Group Spokesmen. The Senate has responsibilities of strategy. A separate organ, the Policy Committee, supervises financial matters. A Scientific and Technical Advisory Board assists the Executive Board in decision-making, while external Boards of Trustees advise the Institutes. Each Institute is led by a Director and a Steering Committee. Directors often have joint appointments at local Universities.

In 2008 the total business volumes of the Society's activities was approximately 1.4bn euros.[11] Of this figure, slightly less than 1.3bn euros derived from R&D contracts, 38m euros from defence research and 72m euros from expansion in infrastructure. Figure 2 charts the composition of Fraunhofer's income between 2004 and 2008. For the year 2008 the total revenue from projects for private and public sector customers (excluding base funding) was 859m. Industry contributed 53% of this figure, Federal and Länder Governments 29%, the European Commission 7% and the remaining 11% came from other sources. The base funding contribution (including reserves) is calculated on the basis of contract research turnover generated by each Institute in the previous financial year. In 2008 this base funding amounted to 432m euros.

**Figure 2: Composition of Fraunhofer's income 2004-2008**




*Data Source: Fraunhofer Society's Annual Report 2008.*

Total expenditure went down from the year 2007 after rising significantly between 2006 and 2007 because of capacity expansion through new investments in infrastructure and staff. Significant investments were made in Dresden (Institute for Photonic Microsystems IPMS, 19m euros), Erlangen (Institute for Integrated Circuits, 17m) and in Leipzig (Institute for Cell Therapy and Immunology IZI, 10m).

By volume of inventive output, recent figures show that the Fraunhofer is one of the top performers in the German innovation system. By number of German patent applications in the year 2006 the Society was ranked eleventh and resulted first among non-corporate organisations. With respect to the relative performance of the different research groups in the same year, comparisons between the share of total employment and share of invention reports per group indicate a particularly good performance in Microelectronics (22.6% of tot employees vs. 35.4% of tot output) and Surface Technology and Photonics (7.5% of tot employees vs. 15.2 of tot output).

The Fraunhofer appropriates new knowledge via patenting whenever the process of contract research generates results which not only solve a technical problem on the basis of existing know-how but have been produced with a substantial contribution by Fraunhofer staff and are deemed to have potential commercial value in their own right. Overall, up until 2008, the Fraunhofer has accumulated more than 2,400 (granted) German patents and has a total of 1,700 active exploitation contracts. The 2008 licensing revenues amounted to 83m, more than half of which was generated by the Fraunhofer Institute for Integrated Circuits (IIS - Erlangen) and the Institute for Digital Media in Technology (Ilmenau) from research in audio coding (including MP3 technology).[12]

Despite its established role in the German innovation system the Fraunhofer model has had its problems and its critics. A model of research based on contract tends to be responsive to existing market needs and is more suited to react to technology trends than to anticipate them. This implies a focus on sectors that have traditionally been strong in the German economy to the possible detriment of emerging sectors (see Harding, 2002). Interestingly, the Fraunhofer has not figured prominently in biotechnology research, an opportunity that has arguably been better exploited by the Max Planck, at least until the recent cross-organisational alliances between the two institutions in this area. In terms of new products and new process technologies, the Fraunhofer model has often been said to privilege incremental innovation over radical breakthroughs. Beside the dominant mode of funding (contract) other co-determinants might include some degree of organizational rigidity, the stronger emphasis of top-down over bottom-up approaches and the fundamental not-for-profit status of the Society. Margins do exist to allow for – arguably slow – evolutionary change within the organisation and new institutes can be founded while other decay or merge with others. Moreover, new channels have been introduced to favour bottom-up approaches to the exploitation of research and commercialisation opportunities.

Although the Fraunhofer model is regarded as an important point of reference as a particular paradigm of R&D funding and governance, it would probably be a mistake to look at it in overly static terms. Business and IP strategies have evolved considerably within the organization and risk management and exploitation practices have been changed to bring them closer to fast moving markets for technology and technology services. The possible avenues of co-operation with the Society have been enriched to encompass not only contract research (whereby clients appropriate R&D results and IPs), but also horizontal collaborations and strategic alliances with more varied contractual arrangements than in the past. Co-operative agreements include non-exclusive rights and royalty-free use of know-how by clients, which become royalty-bearing when key patents underpin commercial developments, for both foreground and background IP.

Renewed emphasis has been given to intellectual property protection and exploitation. Focus is now on a market-oriented patent portfolio approach aimed at concentrating investments in areas with high revenue potential. This is identified on the basis of the perceived attractiveness of a market and the relative strengths of internal patent clusters as sources of licensing revenues. Strategic planning has been substantially reinforced by anticipating foresight of future technology developments. A set of "frontline themes" have been launched in addition to existing areas previously identified as "signposts to tomorrow's markets". On the basis of market and social relevance criteria, these themes are expected to be developed with a time horizon of three to five years. Also, importantly, they are expected to be developed with a higher degree of co-operation within regional innovation clusters and in close association with the Max Plank Society and the newly established Fraunhofer Technology Academy (a training branch of the Society offering part-time masters courses, teaching programmes and specialised seminars). With regards to the Fraunhofer's constraints in the accumulation of liquidity and the direct exploitation of successful R&D, a separate foundation where revenues from past research can be re-invested to generate further IP has been established.

The Fraunhofer Venture Group is another relatively new channel for knowledge exchange. 41 spin-off projects were supported in 2008 and 11 companies were created through the Venture Group. Further support to commercialisation is provided by the "Fraunhofer Promotes Spin-offs" programme, started in 2005 with the objective of supporting the entrepreneurial ambition of Fraunhofer researchers. So far more than 60 researchers have participated in the scheme and in 2008 19 new projects were supported through total funds of about 2.6 million. Overall, according to the latest Annual Report, the Society holds equity investments in 68 companies for a total value of 3.1m.

## 5. The IMEC model

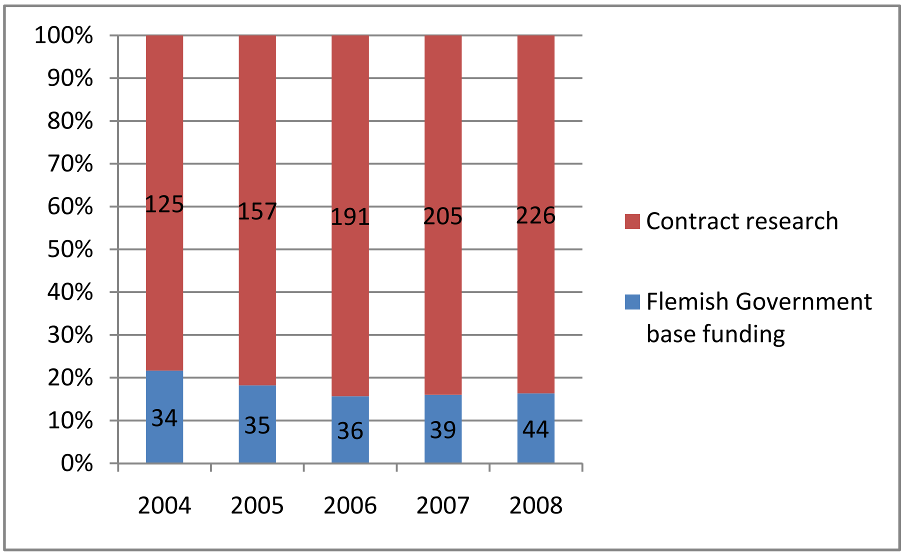
IMEC (Inter-University Micro Electronics Centre) was founded in Belgium by the Flemish government in 1984. Based in Leuven, with an initial investment of 62 million euros and about 70 members of staff, IMEC is now one of the largest independent centres for R&D in micro and nano-electronics in the world. The centre was created to carry out cutting-edge research for application in the ICT domain. Its mission is to operate 3 to 10 years ahead of industrial needs and to foster the development of the local industrial base through spin-off creation, collaboration and training. Like the Fraunhofer Society, IMEC's legal status is that of a not-for-profit organisation.[13]

The local context in which IMEC is set typifies the challenges of innovation systems in small countries. Belgium has a few public research centres of excellence (for example the Catholic University of Leuven) and local links with some major corporate headquarters (among them Alcatel Microelectronics and Philips) but overall counts on a less rich ecology of research organisations than larger European countries.[14] A problem of critical mass became clear soon after the beginning of IMEC initiatives and operating at an international level emerged as the only effective strategy. To achieve this goal IMEC engaged in a variety of activities aimed to increase its international profile and attract talent from abroad.[15] Moreover, the view was taken that IMEC should work as a *programme-driven* institute coherently organised around forward-looking, multidisciplinary, open-ended and highly networked projects.

IMEC is organised in three main units covering Business Development, R&D Operations (with specialised subgroups) and Corporate Support. IMEC's CEO supervises activities with the aid of a Corporate Strategy and Strategic relations office, a HR department, selected Executive Advisors and a training division.

Figure 3 shows the composition of IMEC's income from 2004 to 2008. Over this period total income grew from 159 to 270 million euros. The split between public sector funding and contract research has varied over time, but the former has typically been sustained at around 20% of a rapidly increasing total income. It is important to note, moreover, the reported total contract research income might also include revenues from government contracts independent from the core funding grant.

**Figure 3: Composition of IMEC income 2004-2008**




*Data Source: IMEC Annual Report 2008*

*NOTE: Contract research income includes a minor amount of miscellaneous income (amounting to 7m euros in 2008).*

A break-down of 2007 revenue figures indicates that foreign firms contributed 77% of the total amount of revenues not coming from government, local (Flemish) firms 15%, the European Commission 7% and the European Space Agency 1%. In terms of employment, in 2007 a total of 1,025 members of staff were on payroll at the Centre. In addition, in the same year IMEC hosted 547 guest researchers and residents from academic institutions and industry, including around 170 PhD students involved in the centre's research programme. The recent figures are in line with a pattern of steady growth in capacity and human resources. In parallel, IMEC's patent output has also grown significantly in recent years. From slightly more than 20 in 1997, IMEC filed nearly 120 applications in 2007.

The research and competence base of IMEC reflect the twin principles guiding its research strategy. One focal objective is technology scaling, or, as it is often referred to, *More Moore*. More Moore-type research implies a strong focus on transistor density increase for process technologies. In this case 'miniaturisation' roadmaps take into account the increased complexity of micro and nano-electronic systems but essentially maintain the direction of set technological trajectories and aim to achieve steady incremental change (for example, CMOS scaling). The second and co-exiting objective of IMEC is *More Than Moore*. It is concerned with opportunities for technology convergence with chances of radical innovation associated with potential entry in new micro and nano-electronic markets (for example the shift from CMOS towards 'environment conscious smart devices', including biochips).

With respect to its overall strategic positioning in technologies' lifecycles, IMEC's core research activities are concentrated in early phases where potential commercial value starts to emerge out of basic science. The earlier the stage in the developmental process, hence the longer the period of expected returns, the higher the probability that IMEC co-operate with universities. Also, the earlier the start of the collaboration with industrial partners the more 'general', in the sense of shared within the working group, the know-how that is generated in the process of joint research. Early stage research is carried out on a co-operative basis and results are shared by the agreements set in the so-called Industrial Affiliation Programmes (IIAP). In cases where the potential for growth of innovative ideas is identified after a phase of shared fundamental research, IMEC enters bilateral agreements with partners and the intangible assets generated throughout the applied research process become proprietary.

IMEC's Industrial Affiliation Programmes (IIAP) are broad R&D schemes by which industrial partners embed in IMEC as resident researchers members of their staff together with relevant equipment where necessary. These are often prototypes that are studied, further developed and tested at IMEC.[16] The principle behind these schemes is the sharing of risk and resources, as well as the sharing of new knowledge generated through information-exchanges, joint work and cross-fertilisation of projects.[17]

According to the extent of their interest and capacity in partnering IMEC, firms can contribute to, and acquire in exchange, non proprietary knowledge shared among different partners, shared licensed IP, co-owned IP or proprietary and exclusive rights. To join the research 'pool', firms pay a fee that entitles them to non-exclusive and non-transferable rights to exploit the existing know-how of the programme and participate in joint research activities. When valuable results are generated in the course of R&D processes, possibly leading to patents, each firm that has contributed to it can choose to co-own the IP. This can be made freely available on a non-exclusive and non-transferable basis also to a partner that has not contributed to it but might have an interest in using this know-how, for example as an end-user/manufacturer. Moreover, if a partner has an interest in pursuing specific research activities that cannot be shared with other firms collaborating to the IMEC programme, the firm can negotiate with IMEC terms and conditions for conducting proprietary research.

Beside the industrial partnerships programmes, great emphasis – and great expectations from local institutional investors – appears to have been put on the IMEC's business model for technology transfer through spin-off. The precondition for a spin-off is that key IPs are generated the IMEC's research processes. This might happen inside or outside one of centre's R&D programmes. In the first case, a large amount of know-how will be spread across many partners and many patents and the potential market for the spin-off is likely to be large. With respect to IP exploitation, although the baseline is the non-exclusive transfer of property rights to the new company, IMEC will have the option to grant exclusive rights. If instead the IP has been generated outside an IMEC programme but with the involvement of IMEC scientists, IMEC will also consider the full transfer of ownership. In this case, however, the potential market for the spin-off is likely to be fairly small. There might be difficulties is attracting VC investments in both scenarios. In the first one, a complex IP distribution will not incentivise investment; in the second a niche market might not be attractive enough. As a consequence a phase of incubation can be supported by IMEC until the team is mature, a prototype exists, the business model is sufficiently clear and market opportunities have been fully researched.

The incubation phase can last up to 1.5 year while the plan for a spin-off typically covers a five-year period. Innovative ideas are screened to select those that can enter the incubation facilities and 'sales fora' are organised to identify commercialisation routes. When an idea is approved for incubation, an activity roadmap is drafted to move the technology from an idea to a product, then a new legal entity can be set up together with a team willing to take forward the business. A CEO and business development capacity are typically sourced from outside IMEC. They will contribute to the development of a business plan for a spin-off. In order to pursue financial gains, IMEC, not unlike the Fraunhofer, had to create a for-profit arm to the organization (FIDIMEC). This separate legal entity is owned by IMEC. It supports and manages the incubation programme by investing in the start-up and reinvesting revenues from start-up businesses in new spin-offs and in IMEC's stock option plan. FIDIMEC also interacts with potential corporate and VC investors once the new company has been set up. According to latest available figures (2009), IMEC has so far been involved in the creation of about 23 spin-offs.

## 6. The Holst Centre

Very much related to IMEC is a recent joint initiative by the Dutch and Flemish governments: the Holst Centre. The Holst Centre was founded in 2005 as an independent open innovation centre with a focus on general-purpose technologies in the area of advanced microelectronics. Its two main streams of research are in intelligent microsystems (e.g. wireless sensors) and systems-in-foil (e.g. roll-to-roll printed electronics).

Named after the first director of Philips Research and located in Eindhoven's High Tech Campus, the Centre was set up as by IMEC and TNO.[18] The two main research programme lines have one scientific director each. One of them is appointed by IMEC and one by TNO. Both IMEC and TNO can provide access to their own (complementary) facilities for Holst-related research. The initiator of the Centre was Philips Research wanting to set up an open innovation strategy to attract and create synergies between technologies originated from inside and outside the company. The Holst's mission is to facilitate cross-fertilisation of university and industry research towards the development of technologies at a pre-competitive stage. The Centre conducts applied research up to *demonstrator level*. Industry partners are eventually responsible for independent prototyping and product development.

The Centre is part of TNO and legally a Dutch organisation. IMEC is involved through a separate legal entity (Stichting IMEC Nederland, IMEC-NL) after difficulties encountered in setting up a cross-national research institute. Most of the funding is provided by the Dutch government, but the model for the Centre appears to be closer to IMEC. The target for the medium term appear to be a 50-50 split of funding between public and private sources. Now government funding is still dominant, which is not surprising given its short history. Income from research contracts (undisclosed) is, however, increasing. In 2008 68 per cent of this revenue stream came from Dutch companies, 11 per cent from Flemish companies, 9 per cent from foreign companies (incl. Germany, USA and Japan) with an additional 12 per cent generated through public subsidy programmes. To date the Holst employs over 145 staff, hosts 26 PhD students and works with about 20 industrial partners. Local facilities are managed by MiPlaza, a ‘service arm’ of Philips Research, and include labs formerly used by Philips. Overall, in-house equipment comprises over 200 office spaces, a number of smaller labs and large scale clean-room facilities for printed electronics (the ultimate goal of the latter is demonstration of a complete systems-in-foil manufacturing process). Additional pieces of equipment are being installed in co-operation with industry partners.

The rationale for the Centre’s operation is the need perceived by companies to share the costs of R&D, reduce risks, shorten time to market, and exploit synergies of know-how across the value chain. Furthermore, companies might decide to join to access relevant know how through the Centre’s research network and to use the neutral platform of the Centre to make new contacts, exploit complementarities and start new business relations (source: Technopolis intermediate evaluation of the Holst Centre, cited in the Holst 2008 Executive Report). Non-exclusive IP agreements are the norm, although exceptions can be made for a few partners to conduct some exclusive R&D.

Companies can join one or more technology Integration Programmes for a fee. While access to foreground IP is guaranteed upon joining, access to background IP developed at the Centre or previously and independently by other partner-companies needs to be negotiated. The programmes currently available are 1) Healthcare and Wellness and 2) Organic Lighting and Signage. New programmes might be started in the future in response to demand from industry and/or expected societal benefit. New candidate programmes include: Intelligent packaging, Predictive maintenance and Flexible solar cells.

The development of demonstrators is central to the Holst Centre’s mission. Demonstrators allow researchers to show – and work on – real-world applications of new technologies. When these technologies are especially complex, the development of demonstrators can greatly benefit from open innovation arrangements. In the field of micro and nano-electronics a combination of know-how in materials, processes, components/devices, and system design is essential. A potential solution to the challenge of complex research is a programme which includes elements of the whole value/production-chain and brings together otherwise disperse know-how in chemistry, physics and different branches of engineering. This, jointly with the larger scale of operations made possible by resource sharing, also allows experimentation with multiple solutions.

In the systems-in-foil division, for example, companies with know-how and IP in substrates and materials (Dupont Tejin Films, Agfa and Merck) can work along equipment suppliers and organic electronic manufacturers (Orbotech, ASML, Singuls Mastering and Plastic Electronic) and integrated device manufacturers (Philips), who understand the specs and system design required by the market. The whole value chain is represented. A similar case of complementarities is exemplified in the Wireless Solutions division in relation to health. Here the Centre provides a mix of expertise in IC design, silicon processing and sensor-system manufacturing, data extraction and algorithms, real-time data interpretation and database management applied in the real context of partnering local health service providers.[19]

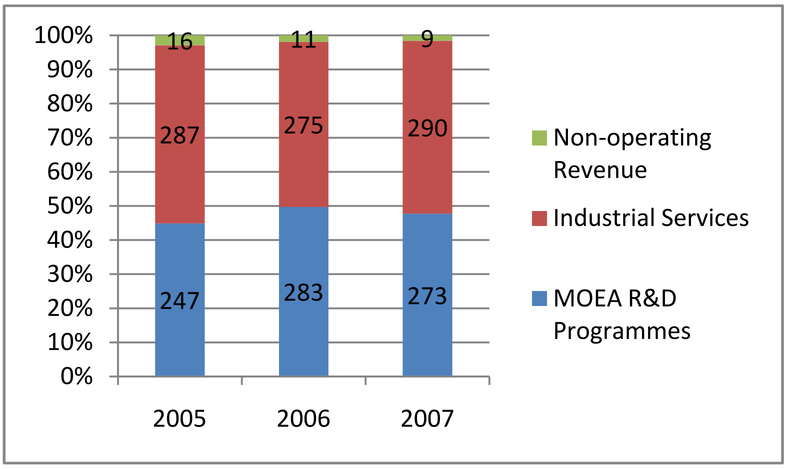
Organisationally, the mix of know-how rests on flexible staffing arrangements by which full-time employees of the Holst can work alongside researchers from industry and PhD and MSc students of (usually local) universities conducting their research at the Centre. Of the current international staff of the Holst (as of Sept 2009), 39 per cent came from industry, 48 per cent from academia, 9 per cent from either IMEC of TNO and 4 per cent from a research institutes other than IMEC or TNO. As an open innovation platform, and also because of its short history, the Holst Centre does not appear to have a record of licensing or spin-off activities by staff.

## 7. The ITRI model

The Industrial Technology Research Institute has been one of the most important instruments of industrial policy in the Far East. It has been credited with a fundamental role in the history of economic development in Taiwan and is still a model of intervention for developing countries.[20] ITRI was founded in 1973. It resulted from the merger of three research-oriented organisations previously operating under the Ministry of Economic Affairs: the Union Industrial Research Laboratories, the Mining Research & Service Organisation and the Metal Industrial Research Institute.

From the early years, ITRI has grown into a very large organisation currently employing about 6000 people, 70% of which hold either an MSc or a PhD. Its activities span over information and communication technology, optoelectronics, advanced manufacturing, materials and chemical engineering, biomedical technology, energy and environment and nanotechnology. Out of the total workforce (Feb 2009 data), 84 per cent are R&D staff, 15 per cent have administrative and management roles and 1 per cent are technicians. 48 per cent of staff have more than 10 years professional experience, 20 per cent between 5 and 10 years, 13 per cent between 3 and 5 and 19 less than 3. Figure 4 shows the composition of ITRI's revenues in 2005, 2006 and 2007.

**Figure 4: Revenues 2005-2007 (Million US dollars)**




*Data Source: ITRI, February 2009*

The Institute's revenues appear to come in even proportion from the provision of industrial services for client organisations and from dedicated government programmes managed by the Ministry of Economic Affairs (MOEA). Note, however, that the figure for industrial services still includes revenues from government procurement contracts (accounting for about half of this subtotal according to internal sources). The total revenue for the latest available year (2007) is 572m US dollars.

In its first years of operation the Institute's revenues came entirely from government while contracts from industry grew slowly over time in number and volume. The growth of ITRI was inextricably linked with the development of the Taiwanese semiconductors industry in the mid 1970s. At the time the problem for the policy maker was to foster the emergence of a whole new sector in the absence of significant infrastructures and competences. Universities might have provided a starting point but they were not considered as a suitable environment for commercialisation processes. The decision was taken to transfer technology in from abroad and to invest heavily in training through ITRI.

ITRI was the bedrock for the creation of two spin-offs that grew into market leaders of the global semiconductor business. The first one, UMC, was founded in 1980 from a group of about 40 ITRI people, including technicians and equipment operators, and additional staff specifically recruited from outside. The company's new lab was funded by the government but capital was also sourced from a consortium of private firms operating in traditional sectors (including petrochemicals and consumer products). UMC was the first foundry for wafer manufacturing in the country. The second fundamental breakthrough was the creation of TSMC in 1987.[21] The original ITRI lab where operations had started, and which later developed into a complete facility, span out if ITRI as part of the new company. Much of the technology was again bought on the market through a special government R&D fund and transferred in.[22] ITRI sustained the broader ecology of small and medium size firms by centrally managing the acquisition, integration, development and organisation of IP to be licensed to local companies (from which the Institute also generated good licensing revenues).

After – and on the basis of – its success in semiconductors, in 1990s ITRI played an important role in the development of the Taiwanese TFT-LCD industry, the second high tech area where Taiwanese firms have achieved market-leading positions. Again, the government took the initiative with resolve. It converted to LCD one of the two major programmes previously dedicated to IT in ITRI and managed to transfer in Japanese technology right after the 1997 Asian crisis. Although ITRI did not itself generate the technologies taken up by the market, it greatly contributed to the governance of the process and the training of engineers and technicians. It is, however, important to observe that at the time when the TFT-LCD industry was emerging, Taiwan already had strong large companies who played at least as important a role as ITRI.[23] Moreover, after the outstanding results in semiconductors and LCDs, successful spin-outs have been fewer, private companies now have or can independently acquire top-of-range facilities.

ITRI projects fall into two categories: *technology development* projects contracted with government and *industrial service* projects, contracted with the private sector, but also with government. In charge of Technology Development projects are Programme Offices from the MOEA Department of Industrial Technology, the Department of Energy and the National Science Council. A strategy planning division allocates resources between advanced projects (1/4 research budget), exploratory projects (1/4 budget) and R&D Fundamental Construction Projects (1/2 research budget). Advanced projects are supported for a few years to focus on 'hard' technologies, possibly in co-operation with academia and across disciplinary domains when necessary. The proposal of projects is both top-down (R&D Planning Division and General Director Office) and bottom-up (R&D Labs and Centres). Project selection takes place through an Advanced R&D Advisory Committee, which includes the top level management of the centre, consultants, including professors from local universities, and international experts. A Technology Advisory Committee, including members of Advanced R&D Advisory Committee, is instead charged with the task of advising on technology development, and components and technologies' integration.

ITRI is open to collaborations with local and overseas industrial partners, but aims to enforce the option of retaining fundamental IP to favour the creation of start-ups. Arrangements for collaboration are flexible; they include single-firm as well as multi-firm agreements and there is always the possibility that the government chooses to match industry funding on selected projects. A figure comprised between 80 and 90 per cent of companies in Taiwan have or have had contracts with ITRI.

In terms of IP protection, patenting is extremely important and has higher priority than scientific publications. Over the last four years, ITRI has filed an average of about 900 patents per year. Normally, ITRI uses its own state-of-the-art pilot facilities. The Institute can, however, access TSMC's facilities for larger pilots. The average duration of advanced project is around 3 years, as opposed to approximately four years for experimental projects. The duration of a research contract is typically one year. Partners include universities and various national research centres in various areas such as health and computing. In addition, ITRI has joint research centres of small proportions at six national universities in nano-materials and biomedical, micro-to-nano manufacturing engineering, semiconductors, environmental technologies, communications and IC chips, optoelectronics. Agreements entail the sharing of staff (all of whom already have positions at either ITRI or the university), facilities and IP.

ITRI has recently been keen to enhance its innovation culture. It was felt that more risk-taking and creativity were needed to further develop and diversify the Institute's activities in new directions.[24] International co-operation with global leaders in research has also become highly strategic: a scheme of institute-to-institute relationships, for example, has been put in place to develop cutting-edge research in areas of strategic importance. Partners include Carnegie Mellon, MIT, AIST (Japan), UCB, CMU, NRC (Canada) and MSU (Russia). Like the Fraunhofer and IMEC, ITRI was founded by legislative act and is a not-for profit organisation. It has therefore developed a separate VC/incubation branch through which it can attract capital and eventually retain excess returns.[25]

ITRI is trying to move away from a catch-up paradigm and to focus on innovation in an environment where local firms are still rather conservative when it comes to accepting technology risks. ITRI still excels at delivering reliably and fast ("because we have the speed to get there first!" is one of the selling point of ITRI's services). It does, however, recognize the need for more risk taking at the frontier of technological opportunities. The incentives in place for innovation are strong; inventors can capture up to 50 per cent of the revenues generated by a successful idea. Good incentives complement a lively entrepreneurial culture. One of the strengths of ITRI has been the network of CEOs of new companies who were former employees of ITRI. Labour mobility between ITRI and industry has traditionally been high and highlights both the role of ITRI in training engineers/entrepreneurs and its role in supporting start-ups. In recent years the yearly staff turnover probably reached around 15-20 per cent of total R&D staff, which is high although this slowed down to 10 per cent during the current recession. In terms of yearly recruitment, ITRI's new staff are approximately evenly split between university and industry. A funded overseas visiting scheme is in operation and includes the binding close the returnee spend at ITRI the following 2-3 years after coming back (usually from the US).

ITRI's clients are focussed on IC design, optoelectronics, mechanical systems, materials and over the last 3-4 years also biotech, although the latter is not ITRI's top priority. Materials and chemical engineering are the divisions where most business with firms is done. There are two groups of client firms: start-ups (many of which are local firms producing components for overseas markets) and established companies (including multinationals). They come to ITRI to strengthen their products and access lab facilities. They also have the option of pitching to ITRI's VC branch for investment in their business. ITRI's spinoffs are less likely to come back in search for further funding (to date ITRI has spun off 15 companies). One of the advantages of ITRI is that it provides clients with a one-shop stopping opportunity comprehensive of testing services.[26]

Overall, after the success of the largest spin-offs (UMC, TSMC and Taiwan Mask) the perception is that it is becoming more difficult to spin out companies. This is partly attributable to the technological differences between IC design and displays, where technology opportunities for Taiwan have moved. It is also felt that ITRI needs to do more fundamental science to lead technology development from the front of the global competitive process.

## 8. The ETRI model

The South Korean experience with intermediate research organisations differs in many respects from the case of Taiwan. The Korean government also adopted robust technology-push policies. In the electronics and advanced electronics domain, the Electronics and Telecommunications Research Institute (ETRI) played a fundamental role in executing the government's science and technology policy objectives and made important contributions to gradual build-up of the country's strengths in information and communication technologies.[27]

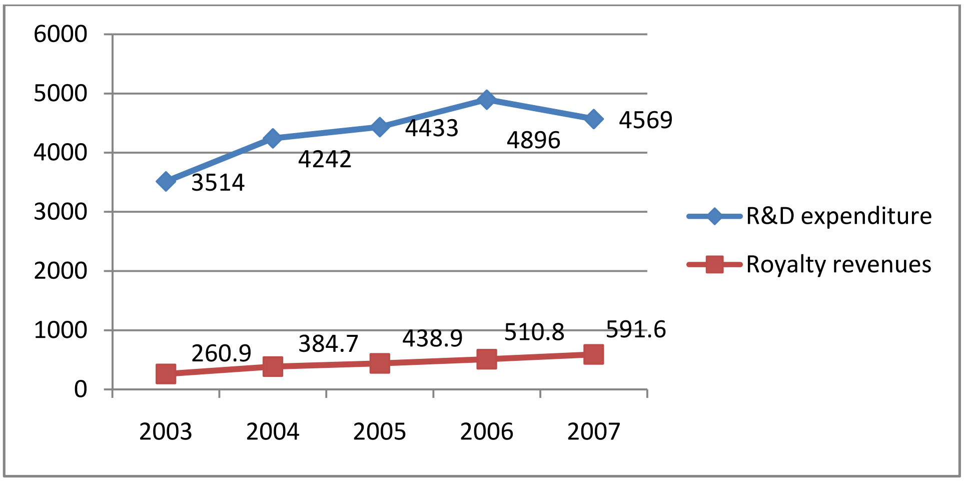
The South Korean total national expenditure on R&D grew constantly year on year from 2003 to 2007. The average yearly growth rate over this period was above 12 per cent. For the year 2007 – the latest available for this study – total expenditure reached 31.3 trillion KWR. The government contributed 26 per cent of this figure while the remaining 74 per cent came from private investment. More than 30 per cent of the current budget is under the Ministry of Knowledge and the Economy, which is in charge of the funding of applied research and the pursuit of commercial R&D targets. Approximately an equal amount is spent through the Ministry of Science and Education, which tends to fund more basic research.

Founded in 1976, ETRI is the largest government funded research organisation in South Korea. It is located in Daejon Campus, where it has 11 lab buildings over a surface of 342,814m$^2$. Other facilities are located in Seoul, Gwnagju, Deagu, Bejing and Silicon Valley. Its activities are organised within the following research divisions: broadcasting and telecommunications convergence (incl. mobile telecommunications, network technologies, broadband wireless, radio technology), software and content, IT convergence technology (RFID/USN, u-robot, u-computing, c-Service platform, telematics, postal technology) and convergence components and materials (advanced solar cells, new device/materials, optical/RF devices, SoC). The institute employs about

1,950 people (figure as of January 2009), approximately 92 per cent of whom are research staff. Of these, 40 per cent have PhDs and 57 per cent hold an MSc.

ETRI's mission includes the promotion of technology commercialisation and adoption, intellectual property management and licensing, and broad technological support to industry. Figure 5 charts total R&D expenditure from 2003 to 2007. The latest available figures (2007) indicate investment for about 0.45 trillion KRW over more than 300 projects. In 2007 outcomes from R&D expenditure have been quantified as a total of 2,747 patent applications, supporting 377 knowledge exchange cases and generating licensing revenues, generally non-exclusive to extend spillovers to all Korean firms, for approximately 59 billion KRW. Overall, between 2003 and 2007 ETRI was responsible for 48 per cent of all the patenting from government labs and 76 per cent of the total income from related royalties.

**Figure 5: Total R&D expenditure and royalty revenues 2003-2007 (KRW100 million)**




*Data Source: ETRI 2008.*

Over the years, ETRI has played special emphasis on the strategic use of technical standards as a source of competitive advantage in global markets. Among its most notable achievements are the telephone switching system TDX (1986) developed with Korea Telecom and Samsung Electronics, DRAM (1988) developed with Samsung Electronics and Hynix, CDMA (1996) developed with SK Telecom, KTF and LG Telecom, WiBro (2004) developed with KBS, MBC, POSDATA and Samsung Electronics. ETRI has been a very active participant in international standard settings organisations. Since 1998 the Institute has made more than 850 submissions for standard specifications. It has acquired more than 120 international standard patents, among which also the MPEG, and has around 40 international standards technologies. This is a part of a business strategy that starts from shortlists of technological opportunities and moves on to market and technical evaluation of applications, which are then selected out and developed. A marketing strategy is finally structured and implemented. The licensing of locally developed or acquired technologies is particularly important as a means to diffuse technological know-how and facilitate technology commercialisation.

While much of history of success of the institute is related to joint activities with Korean largest firms, increasing emphasis has been placed on support for SMEs through a number of schemes. These might involve the provision of skilled R&D staff to interested firms, access to specialised consulting services, rental of testing facilities and equipment and the funding of development and early commercialisation of technologies with the view to conclude the knowledge exchange process upon completion of the development programme. ETRI can also decide to give advance notice of its latest R&D results to SMEs to favour their early involvement in associated market niches.

ETRI has also been under increased pressure to generate income through contracts from industry. One of the difficulties appears to be the perception that it operates quite far from market applications and progress is slower than in large companies' R&D divisions. The traditional model of economic development based on imitative strategies and reverse engineering is no longer sufficient to sustain industries that have caught up with US and Japanese leading firms. As a consequence a stronger focus on creativity is emerging in the Korean innovation system. Universities have become competitors, and not only collaborators, of ETRI by virtue of their superior competence in fundamental research. Moreover, large firms have grown to such extent that they no longer need to rely on government agencies and public labs to build up or upgrade the foundations of their technological know-how. They can choose to co-operate directly with universities, where staff costs are lower than ETRI and job security higher. ETRI itself can operate as contractor of research and subcontracts, for example, more basic research to universities and the production of prototypes to other companies, including foreign companies. In this respect, ETRI still acts as a vehicle for targeted government spending in its competence area.

Emphasis seems, however, to be shifting from a licensing-based to a spin-off model of revenue generation for the original know-how produced or acquired-and-recombined by the Institute. This is paralleled by increased focus on the role of ETRI in supporting SMEs, which is proving difficult. ETRI backs spin-off companies with IP, technical staff and R&D support. It can also generate demand for the new companies by purchasing technical services from the company or by securing government contracts. Part of the internal process of venture selection involves ETRI showcasing technologies that might be ready for market exploitation. Teams formed with ETRI staff can take up these ideas and negotiate with the Institute requirements for starting up new business and shares of returns. When revenues are generated from, for example, stock market flotation of start-ups, these are reinvested in new spin-offs.

## 9. Technology development in intermediate research organisations: opportunities and risks

The cases of the Fraunhofer Society, IMEC, the Holst Centre, ITRI and ETRI share a number of fundamental objectives, among which the development and exploitation of new technologies through an infrastructure bridging the needs of applied research with those of technology commercialisation. There are of course significant differences between the models of knowledge exchange and technology development adopted by these organisations. There are differences in age, size, focus, management style, policy contexts and – importantly – histories of industrial development. But it is also clear that these organisations, all of which increasingly operate with an eye on international technology markets and global R&D, face some similar challenges: for example, the problem of institutional renewal, the balance between short and long-term targets, the management of intellectual policy, changing policy expectations and evolving relationships with universities. It is also interesting to observe the fundamental role of government grants and procurement policies in the early development of all these organisations, which would not have survived their first years of operation had they adopted the 50-50 or 60-40 ratios of public to private funding they all mention as their strategic objectives.

Institutional change is typically slow in large organisations, and intermediate research laboratories are no exception. This makes it difficult to redeploy resources when technological and business opportunities shift over time. It can also be difficult to manage changes in strategic direction at the level of the research division or group when the underlying contractual arrangements do not favour short-term flexibility but instead continuity over time. A certain level of ‘slack’ is therefore inevitably built in the mechanisms of evolutionary change and short and long-term objectives are integrated in a broader portfolio approach to R&D.

The scale of operations is an important determinant of the capacity to move fast towards the market once exploratory phases of technology development produce output with well defined commercial applications (ITRI is probably the best example). However, size and age of a large organisation, with the rigidities that go with it, might be unsuitable for rapid innovation. Large organisations might have a natural propensity towards slow, adaptive and typically incremental change. Among other factors, this has serious implications for the sectoral distribution of technological opportunities, which we know is not only uneven but also a function of different R&D search regimes (compare, for example, the pharmaceutical sector with semiconductors).

There is another aspect of importance: the balance between cutting-edge research and the provision of services that do not require the ‘globally optimal’ level of expertise, but simply the provision of sound and reliable inputs which would not be available to client firms if an infrastructure of intermediate research organisation did not exist or was not accessible. It must also be recognised that client firms of different sizes have different resources and uneven absorptive capacity. One of the problems of the newer organisations, or of some newer divisions within existing organisations, is the difficulty of engaging with small and medium size enterprises even if satisfactory outcomes are achieved for large firms, including the attraction of high levels of foreign direct R&D investment to the region.

The context in which intermediate research organisations operate matters greatly. One of the major changes that have occurred over the last two decades involves the role of universities. In all the countries where we conducted fieldwork for this research evidence was strong that expectations placed upon universities were growing both in terms of involvement with industry and direct commercial exploitation of research. Overlaps seem to be increasing between the area that has traditionally been the remit of intermediate research laboratories and that of higher education institutions. Instances of increased competition were frequently mentioned in the course of our fieldwork. The shift of some businesses towards R&D services sourced from universities has generally been motivated by the need to access competences in fundamental problem-solving that are seen to be superior to those of intermediate research labs, irrespectively of the university's capacity to directly exploit the market potential of technological breakthroughs. The later can be provided by the – typically large – client firm.

In decreasing order, costs of R&D services differ between private R&D providers, intermediate research labs and universities. Variations seem to be consistent across countries and so seem to be incentives to R&D staff in the different organisations. Risks and rewards are a function of the nature and duration of contractual arrangements and range from the protected status of near-civil servants to the less secure position of scientists and engineers working in market-driven private organisations. This clearly has important implications for the skills profile and the potential for skills upgrading in the models of knowledge exchange adopted by intermediate research laboratories.

The purpose of this paper is not a systematic quantitative comparison of the performance of the different institutes, but it is apparent from the qualitative evidence we have seen that in the long-run intermediate research organisations have generated substantial total direct and indirect returns to national economies. There are instances where they have been responsible for the emergence of whole value chains and industrial ecologies which would not arguably have come into existence without their activities. Returns have surely been uneven in time and across areas of research areas. If we take short-term venture capital returns from direct exploitation of IP through new firm formation, these are not very high. However, if we extend the time horizon in our analysis and consider, for example, the spin-offs generated by ITRI over a period of approximately thirty years, the results are very substantial. In addition, the support to R&D capacity, the role in technical training and the development of applied engineering skills and resources (incl. testing) has been fundamental in the growth of innovation system of the longest-lived intermediate research organisations we have presented in the previous section.

## 10. Conclusion.

In the first part of this paper we discussed features of both the UK economy and its innovation system which raise particular challenges when it comes to designing policies that will facilitate the generation of higher returns from the development and exploitation of the UK science and technology base. In the light of that discussion a number of non-mutually exclusive policy responses are possible in addressing the challenge Government to fund the exploratory development stage within start-ups and other SMEs.

1. In the US, the Small Business Innovation Research (SBIR) programme and other federal government procurement based R&D funding programmes achieve this on a significant scale;
2. Government can attempt to make it easier to undertake this activity within universities, for example, by funding the appointment of more engineers and scientists from industry to work alongside academics[28];
3. Government can support the development of some form of "Intermediate Research Laboratories", with a more commercial, mission driven modus operandi through government (and possibly private sector) funding. These can enable work in selected fields to take place without the conflicting pressures of publishing and teaching explicit in academic research and act as attractors for leveraged private sector funding.

Our attention in this paper has focused on the third proposal The key question here is whether at this stage in the evolution of the UK economy, and in particular with the political desire to rebuild the country's industrial base and create a more balanced economy, there is potential value in adopting some form of Intermediate Laboratory model as one of the tools to achieve this.

With this objective in mind, we reviewed some important variants of the intermediate research organization model of knowledge exchange and profiled the way in which they operate as well as key trade-offs we observed in their funding, governance structures and strategic orientation. This does not mean to say that this is an exhaustive account of all possible models, but we are confident that the sample we have investigated well represents the key options and highlights factors where crucial decisions have to be made if this model is to be adopted in – and *adapted to* – the UK science and technology policy framework.

There are a number of important organizational design and financing issues to be considered if a model is to be developed that best fits the UK innovation system. They include:

a. Size of investment required to make a difference
b. Life-expectancy of the organisation

c. Sectoral focus
d. Incentives (including salary levels and cross-institutional labour mobility)
e. Resistance to policy fads and changes of focus
f. Legal status and governance and exploitation of IP
g. Nature of relationships with the client base and academia

While there is much to be learned from overseas models both in terms of their successes and their weaknesses, the devil is in the detail and each institution has features rooted in its own innovation system setting.

During the remainder of the project we will be investigating these issues in greater depth.

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## Endnotes

[1] On these two points, see the discussion in Antonelli and Teubal (2006).

[2] The innovation and R&D management literature has been particularly active in research on knowledge exchange but there is no agreement on the relative effectiveness and efficiency of solutions as diverse as changes to patent policies, direct subsidies or, for example, the creation of science parks.

[3] The following two papers have just been published which summarise the latest thinking about technology transfer: Wright et al. (2008) and Bekkers and Bodas-Freitas (2008).

[4] Further fieldwork is in progress or in the planning stage in Germany, Japan and the USA.

[5] Among their core activities are "Translating and managing the integration process of 'raw' knowledge into applications in a way understood by management; working with universities; developing ideas and competences into a form attractive to second stage funding; optimizing contract spin out and licensing activities; auditing organisations to uncover exploitable innovation assets; raising R&D capability in low R&D organisations" (p. 4). In the course of the research 46 RTOs were consulted as well as one group of 90 firms that used the services of RTO and a group of 60 firms with similar characteristics that did not.

[6] In terms of R&D expenditure, the sector is estimated to generate about 6-8% of the total UK private extramural expenditure on R&D, excluding Qinetiq.

[7] Answers also included various grant schemes as well as a number of active industry-university links in the US. These are obviously very important in the current developments of micro and nano-electronics research and markets, but are quite different models and cannot be considered in this study.

[8] This section is based on official documents from the Fraunhofer Society, including the latest Annual Reports and original interview materials gathered through a CBR site visit to the Institute for Integrated Circuits (IIS) and the Institute of Integrated Systems and Device Technology (IISB) in Erlangen on the 11th July 2008. This material has been integrated with information and discussion of the Fraunhofer model in Schmoch (1999), Beise and Stahl (1999) and Harding (2002).

[9] Data as of 2008 (German Federal Ministry of Education and Research)

[10] Other independent technology intermediaries include the von Helmholtz Association, the Leibniz Foundation, the German Federation of Industrial

Research Associations. The Max Planck Society plays instead a more important role in fundamental research (total budget 2008: approximately 1.3bn euros). The recent report "Research at a Glance: The German Research Landscape" (2008) by the Federal Ministry of Education and Research presents a useful overview of these organisations.

[11] The source of these figures is the Society's Annual Report 2008, p.13-16.

[12] The IIS is part of the larger Microelectronic division of the society. This groups together 11 institutes and 2 guests organisations where developments of micro and nanoelectronics are distributed. The latest figures for this Division on the year 2008 indicated a total budget of about 244 million euros, 53% of which from industrial contracts, 22% from basic funding and the remaining 25% from other projects and revenues.

[13] This section is based on official documents from IMEC (including recent Annual Reports) and original interview materials gathered through a CBR site visit to Leuven on the 29th May 2008. This material has been integrated with information and discussion of the IMEC model in Helleputte and Reid (2004), Moray and Clarysse (2004) and Bijnens and van Petegem (2007).

[14] See Moray and Clarysse (2004) for more details of the national R&D context.

[15] A discussion of these points can be found in Helleputte and Reid (2004).

[16] The role played by IMEC in development and testing of new semiconductor manufacturing technologies seems to be fundamental. This requires a very different model to other sectors as it is so expensive. Secondly, it requires considerable investment in process equipment and a relatively 'open' approach to R&D by companies participating in a structured collaborative manner. For these reasons alone, it seems unlikely that Europe could afford more than one or two of such centres.

[17] Ryckaert and van den Broeck (2008) discuss these programmes in some detail in relation to the broader IPR model developed by the Centre.

[18] TNO is the largest Dutch independent R&D organization providing research services to public and private clients in the Netherlands and abroad. It has five core research areas: Quality of Life, Defence and Public Safety, Science and Industry, Built Environment and Geosciences and ICT and Services.

[19] Cases available at http://www.holstcentre.com/en/PartneringinResearch/WhyPartnersJoin/Knowhow.aspx.

[20] For an examination of ITRI's technology transfer externalities, see Chu et al. (2009); for an institutional analysis of the development of Taiwan's industrial technology strategy and Hsinchu industrial districts, see Hsu and

(2001) and Hsu (2004) respectively. Of great interest is also Mathew's (2002) analysis of Taiwan's R&D consortia.

[21] At the time ITRI already employed more than 3,000 people, but half of them were active in established sectors. These generated about two thirds of contract revenues.

[22] Interestingly, 15 years later ITRI took the lab back from the company and converted it into a nanotech lab.

[23] UMC, for example, co-funded the country's first TFT-LCD fabrication facility.

[24] For this reason in 2004 they introduced a Creativity Lab to improve the connection between technology and potential demands ("linking technology to lifestyle") and sharpen the focus on new client-end applications. ITRI has also introduced an Innovation Projects scheme whereby members of staff can use up to 10 per cent of their time to work on their own ideas irrespectively of the current projects and independently from their line managers. They are allowed to form their own teams and submit research proposals without supervisors' permission.

[25] The incubation unit was founded in 1996. It forms a division in its own rights and employs 40-50 members of staff between engineers, lawyers and administrators.

[26] The institute offers a highly integrated environment covering activities from IC design to MEMs. When a company becomes a client at ITRI it gets 25% (year1), 15% (year 2) and 5% (year 3) facilitation rental rate for the use of local facilities. Within 18 months the firm can apply to join the ITRI incubator and ITRI can exercise the option of investing in the company, even though this option is established by gentlemen's agreement and not by contract.

[27] Choung and Hwang (2000) contains an interesting comparative institutional analysis of South Korea's and Taiwan's national innovation systems.

[28] The Integrated Knowledge Centres Initiative in one attempt in this direction.