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The benefits from publicly funded research

Ben R. Martin & Puay Tang
(SPRU)

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University of Sussex
SPRU – Science & Technology Policy Research

The Freeman Centre, University of Sussex,
Falmer, Brighton BN1 9QE, UK
Tel: +44 (0) 1273 873562
E-mail: b.martin@sussex.ac.uk
http://www.sussex.ac.uk/spru/

THE BENEFITS FROM PUBLICLY FUNDED RESEARCH

Ben R. Martin and Puay Tang

SPRU – Science and Technology Policy Research

University of Sussex

Falmer, Brighton

BN1 9QE, UK

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The Benefits from Publicly Funded Research

Ben R. Martin and Puay Tang, SPRU[1]

1. Introduction

How great are the economic and social benefits that flow from public funding of basic research? This is an important question as society becomes increasingly dependent on the creation and exploitation of knowledge to yield innovations that generate economic and social benefits.

In recent years, the UK Government has increased public spending on basic research in universities and research laboratories. Yet scientists and research funding agencies constantly argue that we should spend even more public money on research. Government, however, faces numerous competing demands for public funding. For some of these, such as health, and education, the economic and other benefits perhaps seem to be more immediate and obvious. Nevertheless, as we shall demonstrate, there is now an extensive body of studies on the economic and social benefits of publicly funded basic research, and we can begin to see some of the benefits that accrue from publicly funded research.

At SPRU (Science and Technology Policy Research), we have systematically reviewed these studies on a number of occasions (Martin et al., 1996; Salter et al., 2000; Salter and Martin, 2001; Scott et al., 2002). In the literature, authors have adopted three principal methodological approaches in attempting to assess those benefits: econometric studies, surveys and case studies. For all three approaches, the results show that the benefits are very substantial, certainly sufficient to justify considerable government investment in basic research. They also show that the benefits come in various forms. As we shall see, we can classify these benefits into seven main mechanisms or ‘exploitation channels’ through which the benefits of basic research may flow to the economy or to society more generally.

In this report, we draw upon previous SPRU reviews[2] and a new review of recent literature, mostly from 2001 to the present.[3] We summarise the evidence on the nature and extent of the benefits associated with each type of exploitation channel. We shall see how the relative importance of each channel varies with scientific field, technology and industrial sector. Consequently, there is no simple answer to the question, ‘What are the economic and social benefits of basic research?’

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[2] The contribution of the various SPRU colleagues who took part in those earlier reviews is gratefully acknowledged.

[3] A search was carried out of the main on-line sources of research articles using key words. In addition, we examined publications that cited Salter and Martin (2001) and other key articles. This yielded some 80 new articles, half of which are cited here.

In what follows, we begin with a conceptual overview of the challenges involved in any attempt to assess the economic and social benefits from publicly funded basic research. Next, we review the findings of previous studies. This is followed by a short summary of the main conclusions. In a final section, we present a number of case studies that illustrate the different exploitation channels and the fact that in most cases exploitation of the results from basic research involves more than one exploitation channel.

2. Conceptual overview

2.1 Beyond the 'linear model'

This report is concerned with the question, 'How do the economic and social benefits from publicly funded research compare with the inputs, in the form of money and people?' To couch the question in this form immediately brings to mind a simple linear model of the relationship between research and innovation (see Figure 1).

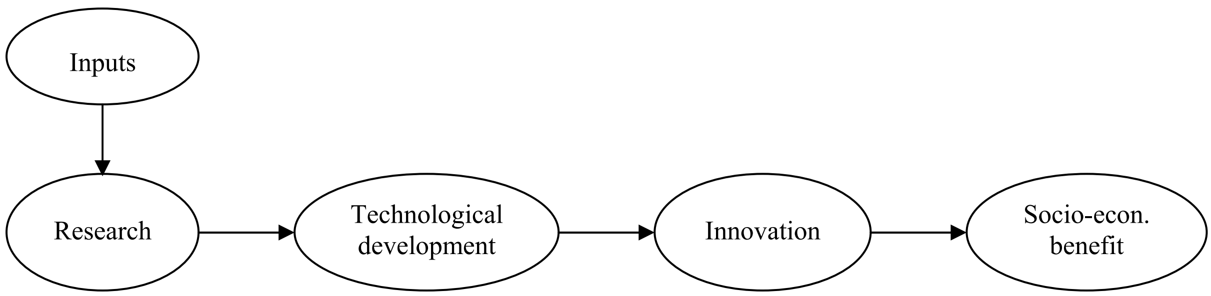


Figure 1: Simple linear ('science-push') model

In this model, the primary output from research is seen as codified knowledge. This knowledge is used to develop new technologies that, in turn, are incorporated into an innovation, which eventually generates some economic and/or social benefit – for example, increased productivity, greater wealth, improved quality of life, or an enhanced environment. If such a model were valid, then in principle one could identify and assess the resulting economic and social benefits, and relate them to the magnitude of the original public investment in the research.

Over the past 30 years, it has become clear that such a simple 'science-push' linear model of innovation is seriously misleading in several important respects. First, the chain of causation is not simply from left to right, as Figure 1 implies. The 'demand pull' for innovations is at least as important as the 'science push'. The model needs to include this and other important feedback loops. For example, new technologies and innovations (derived from a variety of sources, not just from basic research) may be incorporated in new scientific equipment for researchers, while increased economic wealth generates more taxes, which can then be used to increase the public funding of research.

A better representation of the innovation process is an interactive 'chain-link' model (Kline and Rosenberg, 1986). However, in such a model, it is far less clear what is the direction of causation, and hence what particular benefits we can attribute to a specific cause (see Figure 2).

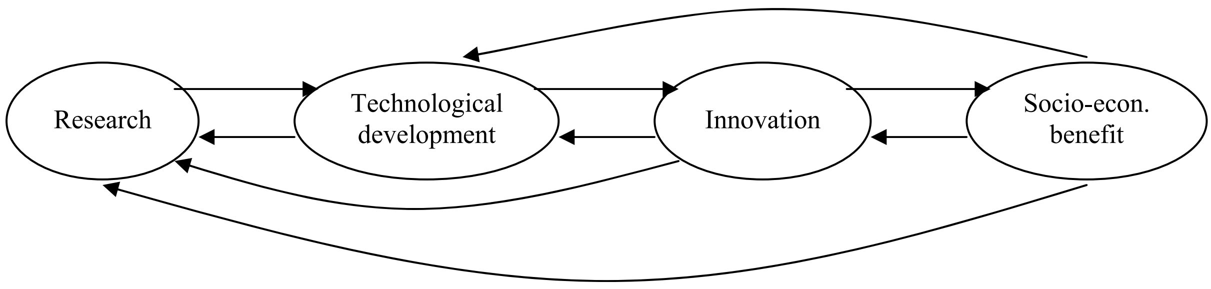


Figure 2: Chain-link model

A second major shortcoming with Figure 1 and the linear model it depicts is that for the elements of 'technological development', 'innovation' and 'economic/social benefits', there are many other important inputs besides those shown. For example, 'technological development' is not just a question of applying new scientific knowledge derived from research – 'trial and error', accumulated experience and tacit knowledge may be just as important.

Similarly, successful innovation depends as much on non-technical inputs (e.g. market research, customer feedback, marketing, organisational improvements) as on the application of new technology. Likewise, a particular economic benefit (e.g. greater wealth) or social benefit (e.g. improved quality of life) will generally depend on a wide range of other factors apart from innovation.

When focusing on a particular socio-economic benefit, it is difficult to establish what portion of that benefit is the result of a particular innovation, what part of that innovation is due to a given technological development, and what proportion of that technological development is the consequence of specific research. This chain of escalating uncertainties makes it extremely difficult to identify what fraction of a specific economic or social benefit should be attributed to a particular set of research activities (see Figure 3). (This 'attribution problem' and its effects have recently been examined by Alston and Pardey (2002), Ekboir (2003) and Morris and Heisey (2003).)

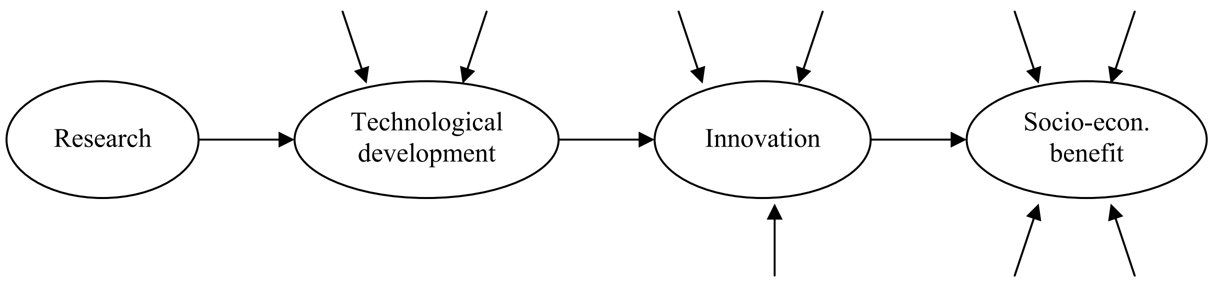


Figure 3: The effects of other factors

A third problem with Figure 1 is that, while the inputs to research are primarily national, the outputs from research are international. Innovation is also increasingly international in scope. An innovation in one country is likely to draw upon outputs from research and technological development in other countries. Hence, the benefits associated with investing in research in Country A are likely to be experienced in many other countries. Conversely, Country A will benefit from the results of research funded and carried out elsewhere. (Indeed, supporting research in Country A is one way to gain access to research in Country B and elsewhere.) It is therefore virtually impossible to relate economic and social benefits in Country A to investments in research in that same country (see Figure 4).

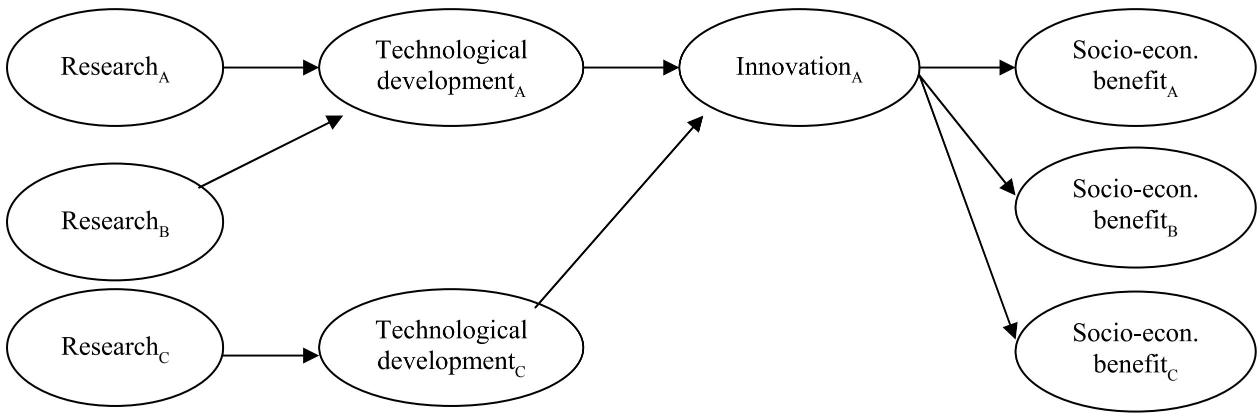


Figure 4: Cross-country effects (where ‘Research$_A$’ means research conducted in Country A, etc.)

Fourthly, the time-scale from research to innovation and socio-economic benefits may be very long – sometimes many decades. Therefore, one cannot assess the full impact of research until many years later (Ekboir, 2003). Attempts at an early assessment (e.g. at time t_1 in Figure 4 below) will capture only the short-term benefits from research, ignoring longer-term and perhaps more substantial benefits that only become manifest much later (at time t_2). If the results of that premature assessment are then incorporated into subsequent science policy, this is likely to distort future research, resulting in an over-emphasis on those areas or types of research that yield short-term results.

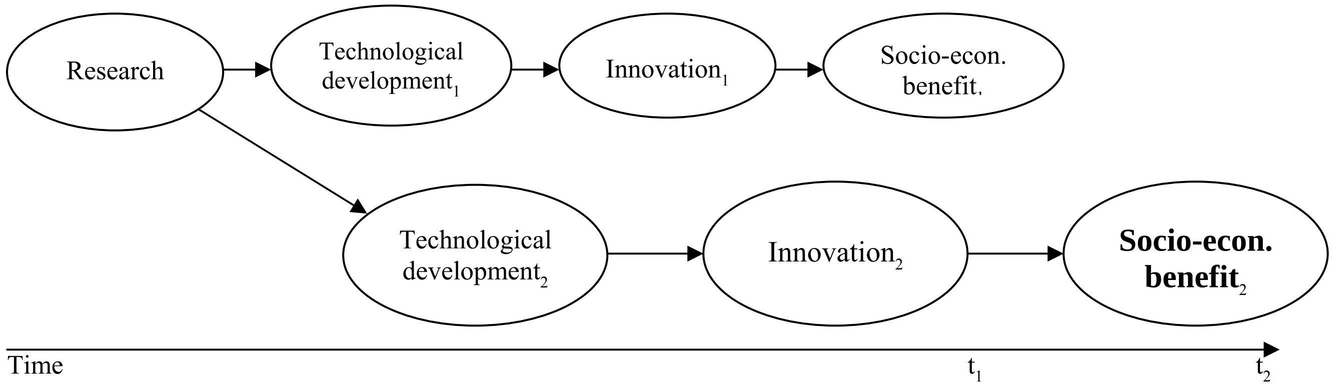


Figure 5: Effects of assessing the benefits prematurely

Fifthly, there are intrinsic limits to the extent to which the assessment of benefits from research can be quantified. There are no perfect measures of the outputs from research from research or from technological development, only a number of imperfect or partial indicators (e.g. scientific publications, citations, patents, licensing revenue, spin-off companies). Moreover, for many of the eventual non-economic benefits (e.g. improved quality of life, better environment), it is often impossible to quantify the effects. Therefore, attempts to add up all the economic and social benefits and to relate them to the initial investments in research are doomed to failure. Indeed, quantified approaches inevitably tend to focus on the direct and more easily measurable contributions, to the detriment of the longer-term, more qualitative and less direct (but often nonetheless very important) benefits from research.

Lastly, in the simple linear model illustrated in Figure 1, it is assumed that the output of research is new scientific knowledge in a codified form. (Indeed, this assumption lies at the heart of the traditional 'market failure' rationale for public funding of basic scientific research.) Yet, as many authors have shown over the last 20 years, tacit knowledge (embodied in trained people) is equally important (Rosenberg, 1990; Pavitt, 1991 & 1998; Hicks, 1995). In addition, there are several other important mechanisms or channels through which benefits flow from research to the economy and society, as we describe below in Section 2.3.

2.2 Methodological approaches to assessing the benefits from research

Despite these severe conceptual and methodological problems, there have been numerous attempts to assess the economic and social benefits from research. These have been extensively analysed in previous SPRU reviews (Martin et al., 1996; Salter et al., 2000; Salter and Martin, 2001; and Scott et al., 2002). Three main methodological approaches have been adopted in these assessments of the benefits from research – econometric studies, surveys and case studies.

Econometric studies

Econometric studies generally involve the analysis of large databases using statistical techniques. As we shall see in Section 3 below, these studies suggest that the economic benefits from research are very substantial, especially in the case of biomedical research. This body of literature also points to the importance of 'spillovers' from research and of localisation effects. However, as noted above, there are numerous empirical difficulties in measuring scientific knowledge and its contribution to technical change and to economic or social welfare, in particular the problem of tracing the extent to which the results from research are used in any particular innovation.

Surveys

Surveys have been conducted, for example, of industrial R&D managers in the United States, Europe and elsewhere, to estimate how much research contributes to new products and processes. The results reveal that the importance of science varies across industrial sectors, and that the links between science and technology are subtle, indirect and varied. However, such surveys have various limitations; in particular, they focus mainly on large firms and they rely on the views of their R&D managers, whose knowledge may be incomplete or whose views may be biased.

Case-studies

Case-studies attempt to trace all the historical antecedents to an innovation including indirect links to science such as those based on skills, equipment and networks. Case studies can also reveal how these links evolve over time. However, case-studies face numerous problems. They focus mainly on successful innovations and ignore the failures. They provide an incomplete picture of the varied nature and extent of the links between research and application. It is also difficult to generalise beyond the specific cases studied.

The main findings from both surveys and case-studies are discussed in Section 5 below, grouped under the different types of 'exploitation channel'.

2.3 Different channels through which benefits from research flow into the economy

In the past, the output from research tended to be seen simply in terms of 'knowledge', which was then applied in the development of a new technology and, in turn, to an innovation. However, the surveys and case-studies reviewed below show several, relatively distinct mechanisms or 'channels' through which benefits from research flow into the economy and society:

Channel 1: increase in the stock of useful knowledge;

Channel 2: supply of skilled graduates and researchers;

Channel 3: creation of new scientific instrumentation and methodologies;

Channel 4: development of networks and stimulation of social interaction;

Channel 5: enhancement of problem-solving capacity;

Channel 6: creation of new firms;

Channel 7: provision of social knowledge.

We examine the main findings with regards to each of these seven 'exploitation channels' in Section 4 below.

3. Main findings from econometric studies

3.1 R&D and economic growth

As noted above, econometric studies of the benefits from research generally involve the statistical analysis of large databases. Early work focused on demonstrating that a significant proportion of economic growth should be attributed to technological change rather than to changes in labour or capital (e.g. Solow, 1957; Abramowitz, 1986). Later work used models derived from 'new growth theory' (Romer, 1990) to show that technology plays a substantial role in the growth of firms (Verspagen, 1993).

In addition, there have been numerous attempts to measure the economic impact of publicly funded research and development (R&D), all of which show a large positive contribution to economic growth. For instance, the studies cited in OTA (1986) and Griliches (1995) spanning over 30 years of work find a rate of return to public R&D of between 20 and 50%. More recent examples of such studies include Bowns et al. (2003), who evaluate the economic benefits from publicly funded R&D programmes in the UK, and Dalton and Guei (2003), who calculate that the economic benefit associated with publicly funded research on new genetic varieties of rice is many times greater than the annual investment in that research. Another recent study finds that R&D investment, as a whole, and higher education R&D investment, in particular, are positively associated with innovation and economic growth in peripheral regions of the EU, although the strength of this association varies with the socio-economic characteristics of each region (Bilbao-Osorio et al., 2004).

3.2 Rates of return from publicly funded basic research

As regards the benefits specifically from basic research, the main contribution is that by Mansfield (1991, 1995 & 1998). He focused on the impact of recent academic research, which is mostly basic in nature, carried out over the previous 15 years. He asked R&D managers in US firms to assess what percentage of their new products and processes depended on academic research. In his first study, Mansfield (1991) concluded that approximately 10% of innovations could not have happened, at least not without a significant delay, without the academic research. He estimated the rate of return from academic research to be 28%. In a follow-up study, Mansfield (1998) found that academic research was increasingly important for industrial innovation. A growing proportion of innovations depended on the results of basic research, while the time to go from basic research to innovation was decreasing.

Beise and Stahl (1999) later confirmed Mansfield's results for a much larger sample of firms in Germany. More recently, Tijssen (2002) has produced evidence that 20% of private sector innovations are based to some extent on public sector research. And in the biomedical industry, Toole (1999) has shown that a 1% increase in the stock of public basic research ultimately leads to a 2.0%–2.4% increase in the number of commercially available new compounds, and that firms appropriate a return on public science investment of between 12% and 41%.

3.3 Patents and their growing reliance on the results of publicly funded science

Further confirmation of Mansfield's findings comes from work by Narin and his colleagues at CHI Research (1997), who showed that patents for inventions draw significantly on the results of publicly funded basic research. Three-quarters of the scientific papers cited in US industrial patents are from public research (see McMillan and Hamilton, 2002). The CHI researchers demonstrated that the knowledge flow from public research to industry has apparently increased rapidly over recent years. They also show that there are variations in the science-intensity of patents across technologies and industrial sectors. Moreover, the way that firms draw on publicly funded research varies widely, depending to differing degrees on the exploitation channels examined below in Section 4.

3.4 'Spillovers' and localisation effects

Another substantial body of economic work focuses on the 'spillovers' from public funding into industrial R&D. ('Spillovers' occur when at least some of the benefits from research accrue to other parties than the organisation that undertook the research.) For example, Jaffe (1989) demonstrated that there are significant spillovers from university research to industrial R&D for firms in the region. This finding has since been confirmed by several other authors (e.g. Acs et al., 1991; Feldman and Florida, 1994, Mansfield and Lee, 1996; Anselin et al., 1997).

Analysis by Hicks and Olivastro (1998) shows that company patents tend to cite results of scientific research by local, publicly funded research institutions. Numerous other studies also point to the importance of geographical clusters and spillovers from publicly funded research (e.g. Saxenian, 1994; Storper, 1995 & 1997; Autio et al., 2004; Bonte, 2004; Coronado and Acosta, 2005; Goldstein and Drucker, 2006), although Audretsch and Stephan (1996) are less convinced about the specific importance of proximity. Proponents of 'new growth theory' see such spillovers as an important mechanism underlying growth patterns (e.g. Romer, 1994; Grossman and Helpman, 1994).

In summary, econometric studies suggest that research yields substantial economic benefits. However, as we noted above, there are numerous empirical difficulties in measuring scientific knowledge and its contribution to technical change and to economic or social welfare. In particular, there are problems in tracing the extent to which the results from research contribute to any particular innovation.

4. Different types of exploitation channel

4.1 Increase in the stock of useful knowledge

Although publicly funded research yields benefits well beyond production of new knowledge, this remains one of the main exploitation channels for converting the fruits of research into innovations that benefit society. The literature identifies two types of research-based knowledge – codified and tacit. Codified knowledge comes in a written form and is the more visible of the two. Tacit knowledge refers to the skills, know-how and experience brought to any task by those carrying it out and is thus embodied in people, who carry it around with them when they move.

The traditional justification for public funding of basic research is based primarily on this 'Channel 1' exploitation mechanism. According to the 'market failure' rationale for public funding of research, basic research expands the pool of scientific knowledge available to firms and other 'users' who can draw on this freely in their technological activities. However, this argument underplays or ignores at least three things.

First, firms and other users need to expend considerable effort to exploit this scientific knowledge. In particular, they generally need a threshold level of internal research effort in order to develop the tacit knowledge and provide the 'absorptive capacity' (Cohen and Levinthal, 1989) needed to identify and assimilate potentially exploitable scientific knowledge created elsewhere. (For example, Caro et al. (2003) have recently demonstrated that university patents only stimulate interaction with those firms that have a certain level of 'absorptive capacity' to exploit the results of research conducted by others.) A similar effect can be observed at the country level; Griffiths et al. (2004) show that, within a given industry, countries lagging further behind the productivity frontier catch up particularly fast if they invest heavily in R&D.

Secondly, it may be decades before the commercial application of scientific knowledge becomes apparent. And thirdly, as we noted in Section 2.1 above, there is a two-way flow of knowledge and information between public or 'open' science and private R&D (Meyer-Krahmer and Schmoch, 1998; Gelijns and Thier, 2002).

Nevertheless, there is evidence that firms draw substantially on new scientific ideas (Narin et al., 1997). Publicly funded basic research often stimulates and enhances R&D performed by firms (Nelson and Rosenberg, 1994), as well as expanding the range of technologically exploitable opportunities (Klevorick et al., 1995). A recent OECD report (OECD, 2006) explores this issue of how publicly funded research can stimulate additional R&D efforts by industry, for example, encouraging firms to engage in more collaboration in R&D projects. One study reviewed in the OECD report indicated that existing partnerships were intensified and new ones initiated as a result of government funding. Another showed that many consortia and joint projects were formed directly as a result of government funding, and that collaboration often continued beyond the participation in a government-funded project (ibid.).

Knowledge generated by basic research can improve the efficiency of technological development (Mowery, 1995; Dasgupta and David, 1994) or increase the returns from applied R&D (Steinmueller, 1994). The PACE survey of large European companies (Arundel et al., 1995) shows that firms rely heavily on scientific publications as a primary source of information on publicly funded research. Publications expand the opportunities available to companies to access the scientific knowledge and skills created by public investment in basic research.

The benefits of biomedical research

Since the previous SPRU review, there has been significant new work on the benefits from biomedical research. For many years, the seminal contribution in the field was a study by Comroe and Dripps (1976). They analysed the scientific publications drawn upon by major clinical advances in cardiovascular medicine, and claimed that 62% of the key articles were the result of basic research. Their methodology was later challenged (Smith, 1987) on the grounds that it was too subjective. Now, Grant et al. (2003) have re-examined the study and concluded that the approach was indeed unreliable. Instead, they use an alternative, bibliometric methodology to trace backwards the origins of five major clinical advances, finding that a much smaller percentage (between 2 and 21%) of the research underpinning these was basic.

The same group of authors has developed techniques for tracing the impact of biomedical research, showing how it can lead to health gains in terms of reduced mortality and morbidity (Grant et al., 2000; Hanney et al., 2003a & 2004). In addition, they have carried out a critical review of the international literature on the economic value of health research (Buxton et al., 2004). On the basis of this, they point to four main types of benefit:

- direct cost-savings from new or less costly medical treatments;
- the value to the economy of a healthy workforce (e.g. from avoiding lost production);
- gains to the economy in the form of product development, employment and sales;
- the intrinsic value to society of the health gains, as estimated by placing a monetary value on human life.

Some of the most significant studies of the economic benefits of biomedical research have been carried out in the US. For example, Silverstein et al. (1995) identified substantial cost-savings attributable to medical research in the form of savings from hospitalisations avoided, from productive work gained, and from medical procedures not required as a result of drugs or technologies arising from research. They estimated that for every dollar invested in research, there has been a return of at least three to one from these cost-savings.

Reports prepared for the Lasker Foundation (Lasker, 2000) and for Australian Society for Medical Research (Access Economics, 2003), various studies reported in a book edited by

Murphy (2003), and work by Murphy and Topel (2003) all report very substantial returns from medical research, typically of between three and eightfold, depending on the area of medical research (see also the review in Rosenberg, 2002). Very recently, Johnston et al. (2006) have calculated that medical research trials funded by the US National Institutes of Health at a cost of $335M are likely to yield a new benefit to society after 10 years of $15.2B.

4.2 Supply of skilled graduates and researchers

Many studies suggest that 'Channel 2' – the recruitment of skilled graduates – represents the most important mechanism through which firms derive economic benefits from basic research (e.g. Gibbons and Johnston, 1974; Martin and Irvine, 1981; Roessner et al., 1998; Zellner, 2002 & 2003). New graduates entering industry bring with them:

- knowledge of recent scientific research;
- the skills needed to perform research and to develop new ideas;
- the ability to use knowledge in new and powerful ways (Senker, 1995);
- skills in using advanced instrumentation and techniques (see Section 4.3 below);
- the ability to solve complex problems (as described later in Section 4.5).

They acquire these by being taught by university faculty who also carry out research, mostly publicly funded. While some recent policies have encouraged students to spend part of their time at university working on projects in industry, where they may acquire useful industrial experience and practical skills, one needs to ensure that this does not come at the cost of acquiring these other, more generic and long-lasting skills.

Although the numbers are smaller, the movement of trained researchers (with postgraduate degrees or perhaps further postdoctoral research experience) between universities and industry is also important. They, too, embody knowledge and skills but to a much greater extent. The considerable benefits involved in such cases in biotechnology have been extensively studied (in particular by Zucker and Darby and colleagues, 1996, 1998b, 2001 & 2002b). Another recent study demonstrates the substantial socio-economic benefits accruing from basic research through the embodied knowledge transfers associated with the migration of scientists into the commercial sector (Zellner, 2002 &2003).

4.3 Creation of new scientific instrumentation and methodologies

Researchers continually develop new equipment, laboratory techniques and analytical methods to tackle specific research problems. Hence, the development of new research instrumentation or scientific methodologies is often a key output from basic research (Rosenberg, 1992). Again, this is an area where there is a two-way flow between basic researchers and the users of the results of research in industry and elsewhere, with the former taking advantage of new tools developed by the latter to expand their research.

There have been few attempts to assess the benefits that arise from advances in research instrumentation or techniques. For example, innovation surveys rarely include the impact of instrumentation developed by publicly funded scientists, perhaps because survey respondents in industry are unlikely to know the origins of these. Nevertheless, historians of science and others have identified many examples of scientific instrumentation or research methodologies bringing benefits to industry, for example, electron diffraction, the scanning electron microscope, ion implantation, synchrotron radiation sources, phase-shifted lithography, and superconducting magnets (OTA, 1995).

In some industrial sectors (e.g. semiconductors), scientific instruments play a similar role to industrial capital goods (Rosenberg, 1992). Analysis of university licensing shows that firms tend to license mainly research tools and techniques from universities (Nelson et al., 1996). Similarly, the PACE survey (Arundel et al., 1995) reveals that companies rate instrumentation as the second most important output of publicly funded research, especially in sectors like pharmaceuticals, electrical engineering and aerospace (see also Klevorick et al., 1995).

4.4 Development of networks and stimulation of social interaction

One characteristic of 'open science' is that publicly funded researchers are part of an 'invisible college' (de Solla Price, 1965), an international network of scientists studying the same specialty, reading the same journals, attending the same conferences and so on. Through these networks, scientists can quickly and effectively contact acknowledged experts on a particular issue to obtain from them information or advice. Industrial researchers who form links with publicly funded scientists can 'plug into' these networks and hence derive benefits from them (Darby et al., 2003). Informal interaction is an important means for firms to keep up with publicly funded research, while good personal relations between firms and public sector scientists are often the key to building the trust and understanding vital for successful collaboration. Again, the importance of the tacit dimension of knowledge emerges from this research. Some analysts argue that the density of these network interactions is itself a good indicator of the vibrancy of a regional or national innovation system (Cooke and Morgan, 1993).

Although the economic benefits of networks may be difficult to measure, surveys (e.g. Arundel et al., 1995) show that companies find these informal interactions an effective means of learning about the latest research and acquiring scientific knowledge, as well as obtaining access to scientific instrumentation (Faulkner and Senker, 1995). Government funding for research is vital in supporting the development and extension of such networks, creating new forms of interaction between different actors in the national system of innovation (Lundvall, 1992) and thereby generating new scientific and technological options (Bozeman and Rogers, 2001; Murray, 2002; Petit, 2004). Without this ability to tap into 'knowledge networks,' industry would tend to 'use up' existing scientific and technological options. Over time, the variety of options available to firms would consequently decline (Callon, 1994).

4.5 Enhancement of problem-solving capacity

Publicly funded research and researchers also contribute to the economy by helping industry and others to solve problems. Many firms in technologically demanding industries face complex technological challenges, the solution of which often entails combining a variety of technologies in complex ways. Publicly supported research provides an extensive pool of resources for solving problems from which these firms may draw. In particular, graduates trained by researchers in science and engineering are often very adept at tackling and solving unfamiliar problems. Studies such as those by Vincenti (1990) and Patel and Pavitt (1995) found that firms benefit appreciably from the recruitment of trained problem-solvers such as these. More recently, Zellner (2003) demonstrated that, rather than applying the latest theoretical insights, scientists who migrate to industry mainly transfer elements of knowledge that underlie complex problem-solving strategies in basic research. Likewise, the Yale survey of US companies (Klevorick et al., 1995) and the PACE survey of European firms (Arundel et al., 1995) point to the importance of problem-solving capabilities as an important form of economic benefit from basic research.

4.6 Creation of new firms

Scientific research is often seen as a way of spurring the growth of new firms. Researchers and students can spin out of universities to exploit new ideas and technologies by establishing start-up companies, thus transferring skills, tacit knowledge, problem-solving abilities and so on from academia to a commercial environment.

In the US, the success of Route 128 (MIT) in Boston and of Silicon Valley in California (Stanford) has shown that leading research universities can stimulate regional and firm growth, as has the development of new 'high technology' firms around Cambridge University in the UK. In addition, location in a science park, often next to a university, can be advantageous for new small firms (Storey and Tether, 1998).

Some of the most influential work on the creation of new firms and their interactions with universities has been carried out by Zucker and Derby and their colleagues (e.g. 1996, 1998a & b, 2001, 2002a and b). In a series of studies, they have compiled extensive evidence that leading research universities and academic 'stars' have been crucial in the creation of biotechnology start-ups, with the commercialisation of biotechnology being heavily dependent on the underlying (publicly funded) science. More recently, they have recorded similar effects starting to emerge in nanoscience and nanotechnology (Zucker and Darby, 2005). A number of other authors have confirmed their results. For example, in a recent paper, Fontes (2005) has shown that, in the biotechnology sector, spin-offs play a particularly valuable role in the access, application and dissemination of knowledge produced by universities.

Despite these success stories, the evidence on the relationship between new publicly funded research and firm growth remains somewhat mixed. Although the correlation between university research and the creation of new firms is strong in some sectors, in others it is not statistically significant (Bania et al., 1993). Moreover, simple counts of the numbers of university spin-offs can be misleading as an indicator of knowledge transfer, since many have low growth rates and remain small, while others fail (Massey et al., 1992). One reason for this is that academics tend to make poor entrepreneurs (Stankiewicz, 1994), so control is often passed to experienced managers before the firm becomes successful.

4.7 Provision of social knowledge

While the focus of this overview up to now has been on the scientific and technical inputs to innovation, few problems can be solved on the basis of scientific and technological knowledge alone. In many new technologies, innovators also face non-technical challenges that involve social choices. For example, businesses in the health sector have to contend with large regulatory hurdles.

Environmental problems, health-care improvements and innovation within firms can all benefit from research on the social aspects of technical change. In particular, firms have a growing need to understand the social and regulatory pressures that often influence whether or not an innovation will succeed. Examples such as the controversy over GM food and the widespread hostility to nuclear energy demonstrate that public reactions can strongly affect the diffusion and acceptance of new technologies and of innovations. More recently, nanotechnology has come under the spotlight.

Many of the benefits that flow from publicly funded natural science and engineering are mirrored in the social sciences. The social sciences have provided the basis for such public goods as national statistics, censuses, economic models and large parts of the toolbox of the modern management of economies, all of which contribute in fundamental ways to the innovation process. Indeed, the entire way in which society views itself and attempts to develop policies for the improvement of society is inextricably linked to developments in the social sciences.

There are, as yet, few studies providing empirical evidence on benefits in the form of providing social knowledge (although one recent example is Otronen, 2004). Nevertheless it appears that quite a high proportion of research institutions collaborate with industry for the purpose of "analysing the environment/framework for innovations" (Fritsch and Schwirten, 1999). There are also indications that arts and humanities are becoming more important to innovation, especially in the 'creative industries', where design and architecture, for example, can play a key role.

In the case of the social sciences, it is clear that they also make a significant contribution to government policy. Health policy (see, for example, the review in Hanney et al., 2003b), social policy and education policy have all been influenced by the research of academics and other publicly funded social scientists. In our own field of science and technology policy, there are numerous examples where concepts or tools developed by science policy researchers have influenced decision makers. These include the notion of a 'national system of innovation', the development of science and technology indicators and of methods for research assessment, and the use of Technology Foresight not only to identify priorities but also as a means to help 'wire up' the national system of innovation (Martin and Johnston, 1999).

4.8 Assessment of the SPRU framework and earlier reviews

The earlier SPRU reviews of the economic benefits from publicly funded research have since been subject to detailed scrutiny in an article by McMillan and Hamilton (2003). These researchers draw upon an extensive body of empirical work relating to biomedical research to test the SPRU framework (based on the various exploitation channels) and the conclusions drawn from it. On this basis, they arrive at the following conclusions:

- Public funding, particularly of universities, generates scientific publications that are a substantial portion of the science base drawn upon by the biomedical industry.
- Public funding of university research also generates patents, but the process has shifted over time. In the past, highly cited university patents were mostly springboards for industry commercialisation. Now, universities directly seek the financial benefits from

these innovations. As a result, universities patent much more frequently, but those patents generate fewer citations on average.

- There are spillovers from the public sector to the private sector. However, private firms must have sufficient internal capability (or 'absorptive capacity') for the process to work effectively. The results from publicly funded science are public, but they are not 'free' in terms of the cost involved in using them.
- The movement of trained scientific personnel from academia to industry is vital in the technology transfer process.
- Universities have played a substantial role in the emergence of the American biotechnology industry, which has created new jobs and companies, wealth and drugs.

McMillan and Hamilton conclude that "the public funding of basic research has had, and continues to have, a significant impact in many venues. The effect is found in the emergence of recent biotechnology companies, the development of new drugs from the big pharmaceutical houses, and basic research that industry utilizes in its technological efforts."

Despite this positive assessment of the earlier SPRU work, it is clear that the framework based on the seven exploitation channels may somewhat oversimplify the complex interactions between publicly funded research and its impact on the economy and society. In particular, there may well be other significant channels besides those identified above. For example, the support and development of truly outstanding research groups or institutions can act as a 'magnet' that attracts multinationals to invest in the locality, thereby adding to the GDP. In addition, we perhaps need to give more attention not just to new spin-off companies but also to 'semi-mature' companies, some of which – five, ten or more years after their creation – are publicly floated, thereby raising tens or even hundreds of millions of pounds. Although the numbers of such instances are relatively small, their economic significance may well be greater than that of new start-ups. (For instance, a recent article in *The Financial Times* reported that in the past three years 26 such companies have floated in the UK, with a combined value at their initial public offering of £1.3 billion – see Boone, 2006.) However, there seems to be little literature on either the 'magnet' effect or on the relationship between research, 'semi-mature' companies and economic impact. These are two areas where further research is clearly needed.

5. Conclusions

Any attempt to assess and quantify the economic and social benefits from publicly funded research is beset by problems. Some of those are conceptual (related to the shortcomings of the linear model) and others methodological (in particular, identifying what proportion of the socio-economic benefits from an innovation is attributable to research). Nevertheless, as SPRU's previous reviews have documented, and as this study further illustrates, a growing body of empirical work demonstrates that those benefits are substantial. Moreover, the benefits seem to be increasingly important as we move into a more knowledge intensive and competitive era.

This report shows how the benefits from publicly funded research come in a variety of forms, flowing through a variety of channels and over differing timescales. Case-studies and surveys suggest only some of the benefits flow through 'Channel 1' – i.e. in the form of new useful knowledge that is directly incorporated into a new product or process (Feller at al., 2002) – although this varies with scientific field, technology and industrial sector. Hence, attempts to assess the socio-economic benefits of basic research that focus solely on ‘Channel 1’ will inevitably underestimate the total benefits.

There is much evidence that ‘Channel 2’ – the recruitment of trained graduates and researchers – is more important to industry. Moreover, analysis of the licensing of university patents suggests that companies rate instrumentation as the second most important output of publicly funded research (i.e. ‘Channel 3’). In addition, surveys of industrial R&D managers show that companies find that acquiring access to the networks created by publicly funded researchers provides an effective means of learning about the latest research and acquiring scientific knowledge (‘Channel 4’). Those surveys also point to the importance of problem-solving capabilities as an important form of economic benefit from basic research (‘Channel 5’).

Some of these exploitation channels, and the benefits that they deliver, are harder to quantify than ‘Channel 1’, at least within a reasonable timescale. Consequently, it is not possible to make a formal, rigorous comparison of the relative importance of the different channels. Nor is it possible to provide a simple, quantitative answer to the question of how the overall level of benefits from basic research compares with the level of public investment in such research. Moreover, if one were to rely solely on quantified approaches to assessing the benefits from publicly funded research, one would almost certainly underestimate the full range and extent of the benefits. It is significant that, according to a survey, firms investing in university research do not attempt to make any cost-benefit analysis of this investment on the grounds that it would be too complex and costly (Feller et al., 2002).

Quantitative studies inevitably tend to focus on the more easily measurable exploitation channels. There is, therefore, a danger that the findings of such studies, if taken in isolation, may distort science policy, to the detriment of future research and the longer-term economic and social benefits. However, the studies reviewed here provide incontrovertible evidence of substantial benefits flowing to the economy and society through these other exploitation channels.

Lastly, in recent years much science policy has focused on the ‘science push’ aspect of innovation rather than ‘demand pull’. Yet many of the economic benefits from basic research depend as much, if not more, on the approach that companies take to innovation as on the strength of the science base. In other words, these benefits depend on whether firms adopt a positive and far-sighted approach to drawing on the results of research through all the various channels we have identified. Government policy needs to reflect this fundamental point and to find effective ways of influencing the thinking of companies accordingly.

Case Studies

1 Autosub – getting accurate data on melting sea ice

Exploitation channels: (3) scientific instrumentation; (1) increasing stock of useful knowledge; (5) increased capacity for problem-solving

This case study is about a successful outcome of oceanographic research conducted at the National Oceanography Centre at the University of Southampton. It involves an unmanned underwater autonomous vehicle called A*utosub*, which carries onboard a wide assortment of biological and chemical sensors to provide scientists with the capability to monitor the oceans in distinctly more novel ways than those undertaken by conventional research ships that study the oceans. A*utosub* is a pioneering vehicle as none has ever previously undertaken work under the Antarctic ice-sheet. The vehicle was awarded 'Millennium Product' status by the UK Design Council and is displayed in the Wellcome Wing of the Science Museum.

The novelty of Autosub

Autosub is an Autonomous Underwater Vehicle (AUV). AUVs are unmanned and free-floating submersibles that are programmed to conduct missions without communication from the surface. They also carry their own power supply and in this way are different from Remote Operated Vehicles (ROV) that are operated and powered from a surface ship via a tether. AUVs can survey remote environments that are inaccessible to ROVs and other underwater vehicles at a cost that cannot be matched by traditional research ships.

A major advantage of *Autosub* is that it can collect physical, chemical, biological and geophysical data from the ocean surface to the seabed through the use of a suite of sensors and sampling devices tailored to individual mission requirements. Autosub has conducted a total of 271 missions, with the deepest mission being 1003 meters underwater. The longest mission lasted 50 hours and covered a distance of 262 kilometres.

The innovation: social and economic benefits

Led by Professor Gwynn Griffiths, the project team comprises a multidisciplinary group of oceanographers, geologists, glaciologists, biologists, and engineers from 14 UK institutions. They have been investigating the role of sub-ice-shelf processes in the climate system. The project was funded by NERC to explore the marine environment beneath the floating ice shelves. The project was funded through a grant of £5.8 million.

What are ice shelves? They are the floating edges of ice sheets that cover Greenland and Antarctica, and contain 77 per cent of the world's freshwater and more than 10 per cent of the earth's land area. If ice sheets were to melt completely, the sea level would rise by nearly 80 meters.

Why are ice-shelves important? Ice shelves affect sea levels and climate; they provide a source of icebergs that transport freshwater to the oceans; and they affect the production of sea ice and the formation of bottom waters that influence ocean circulation. With the current anxiety over global warming and the concomitant rising of sea level, *Autosub* has an important role in generating knowledge for scientists and policymakers. The environmental impact from use of such knowledge cannot be underestimated.

Autosub has also assessed the herring stock in the North Sea and mapped the distribution of manganese in Scottish sea lochs. Elevated concentrations of manganese may cause water supplies to fail the EU standards for drinking water, resulting in discolouration of water and increased treatment costs.

Halliburton Subsea has licensed *Autosub* technology for use in the oil, gas and subsea cable markets. Halliburton, based in Texas, is one of the world's largest providers of services and products to the oil and gas industries.

Picture 1. Autosub (permission granted for use of image)

2 Caries management – an easier and safer way to oral hygiene

Exploitation channels: (3) scientific instrumentation; (6) spin-off

IDMos Plc is a technology spin-off from the University of Dundee, which has developed a revolutionary system for detecting and monitoring early dental decay – the Caries Management Support System (CMS System). The company was formally established in 2001 and floated on the Alternative Investment Market (UK) in November 2004, raising about £5 million from this, and another £2.3 million from a second stock placing the following year. Additional investment of close to US$1 million was also provided by Dentsply, a US dental equipment distributor with operations in 120 countries.

The social benefit of preventative dental care is obvious – to improve oral healthcare and to avoid the need for fillings. The CMS is reputed to be satisfying an unmet clinical need and has the potential to reduce the cost of an escalating national dental bill.

The novelty of the CMS System

IDMos was founded following research investigating the detection and monitoring of dental decay. The research was undertaken by Professor Peter Bruce and Dr Alasdair Christie at the Universities of St. Andrews and Dundee, respectively. The CMS System, which resulted from eight years of research, comprises a base system, integral analysis software and a disposable sensor. It enables dental practitioners to distinguish accurately between stages of dental decay, including decay in the early, reversible stages, and provides a high level of detection accuracy and sensitivity. This level of accuracy is purportedly unavailable from existing commercial techniques, such as X-rays and probes, which have limitations regarding accuracy and safety that the CMS System directly addresses. Moreover, the frequent use of X-rays is discouraged because of the radiation effect, whereas the CMS System does not entail the use of such rays. Research and development and other costs have absorbed most of IDMos' investment to date, but the system will be commercially available at the end of 2006. Unfortunately, owing to current funding mechanisms in the UK dental market, IDMos may find it difficult to sell the system first in the UK.

The innovation: social and economic benefits

A distinct social benefit to the public and an economic benefit to the national health bill is the potential enhancement of public health through preventive decay management. Preventive decay enhancement is likely to prove more cost-effective than restorative procedures. Given the global trend toward the preventive management of dental decay, the CMS System is clearly positioned to exploit this change.

Two major US dental teaching hospitals have expressed their intent to adopt the CMS System to train dental graduates in preventive techniques. Furthermore, discussions with distributors are being finalised for sales in California, Florida and New York. IDMos has also targeted Germany, France and Scandinavia.

IDMoS' long-term agreement with Dentsply International Inc. also provides a critical and global distribution route to the market for the CMS System. The dental distributor, who designs, develops, manufactures and markets a broad range of dental products, will have exclusive rights to promote, market and sell current and future IDMoS dental products. Dentsply has also committed substantial resources toward the regulatory approval process that the CMS System requires for the US market. In addition, Dentsply will help underwrite the market launch of the CMS System as well as future IDMoS products, such as the 3D CMS System, which is currently undergoing development and testing.

3 Parting the clouds

Exploitation channels: (6) spin-off; (3) scientific instrumentation; (5) increased capacity for problem-solving

"We can't stop the rain but we can part the clouds", claims Dmist, a spin-out company from Manchester University. The company is referring to its patented enhancement technology, which can be used in real time and in natural colour for a broad range of environments where optimum video quality is required, for instance, in poor visibility or illumination. This claimed unrivalled technology is embodied in a product called ClearVue™, which the company sells. This technology provides a cost-effective solution compared to infra-red imaging systems. In 2003, the BBC featured a video of this product that "can see through fog" on its *Tomorrow's World* programme. Dmist conducted pre-sale demonstrations in early 2005 for customers who wished to make early purchases, and has received a positive response from the Ministry of Defence, airports and seaports.

The novelty of Dmist technology

Generally, the technology can be used for CCTV, seaport and surveillance systems. It can also be deployed for military applications and shipping navigation. In addition, medical applications, such as endoscopy, can benefit from this enhancement technology.

As a specific product of this technology, ClearVue™ is a self-contained unit, sitting between a video camera and all major video formats. It works by reversing the deterioration of video images caused by fog, mist, rain, smoke, underwater particles, poor illumination and other environmental visual impediments. Its innovativeness lies in its method of correcting in real time and with no intervention, and with the high speed of data processing, clear images can be produced immediately.

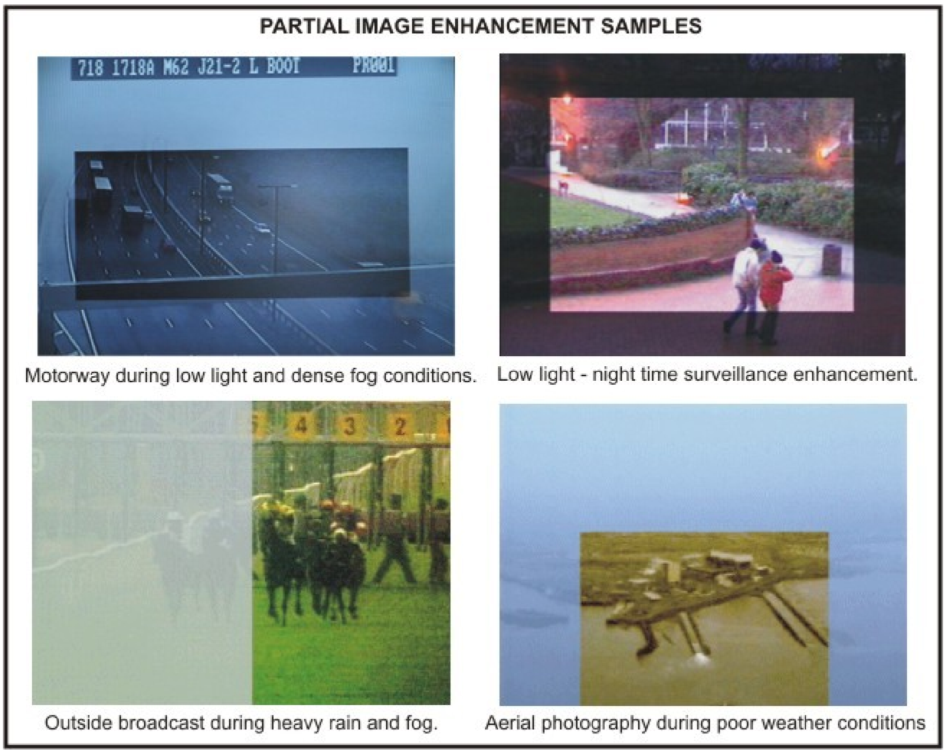
Other distinguishing features of ClearVue™ are that it can be fitted to new and existing camera systems. It also performs well in low light conditions by examining each pixel of an unclear image and correcting it instantly. When a real -ime video feed is not available, ClearVue™ is able to process pre-recorded video tapes and to clean up the video image.

The technology was developed about 10 years ago by Dr John Oakley and Professor Nigel Allinson of the Image Engineering and Neural Computing research group at UMIST. Initially funded by a DTI SMART award to develop a prototype, the project was eventually funded by NESTA, North West Equity, North West Seed and University Ventures Ltd.

The innovation: social and economic benefits

There are more than 500,000 new cameras installed in the UK each year. Despite fears of possible loss of citizen privacy through widespread surveillance, a general anxiety over 'homeland security' and safety is likely to create a large market for Dmist's enhancement technology in the UK and abroad. As noted above, the technology will be able to help police and highway agencies using cameras to monitor traffic flows more effectively. Sales have been made to the UK Highways Agency for traffic monitoring. Environment Canada (a government agency) has also purchased units for trials in Canada. A company in China has bought several units for various applications including maritime and harbour monitoring. The Chinese company has also expressed an interest in visiting Manchester to discuss the possibility of being a distributor for ClearVue™. In addition, an Indian company has expressed interest in the product for use in the railways, coastguard and security forces, as well as in being the distributor. Two British Government security agencies have also loaned ClearVue™ for trials.

According to Dmist, the biggest problem for traffic controllers is monitoring the movement of planes on the ground, particularly at busy airports. For instance, Manchester International Airport has hundreds of cameras to ensure that clear, accurate and timely images are produced to manage aircraft ground traffic and its movement. Poor visibility due to fog is another problem for airports. Twenty six of the world's busiest airports, including JFK in New York, O'Hare in Chicago, Heathrow and San Francisco airport, experience up to 40 days a year of heavy fog. Delays for take-off and landing incur huge costs for airlines and cause aggravation among passengers. Such situations could be ameliorated, in part, with better technology such as that developed by Dmist, given its claim that, even in marginal visibility and light, ClearVue™ may provide maximum performance from the camera system.



Picture 2. Dmist (permission granted for use of images)

4 Innovative software targets the plagiarism menace

Exploitation channels: (1) increasing stock of useful knowledge; (2) training skilled graduates; *(6) spin off*

Established in 2004 by the University of Derby, Innovation 4 Learning (i4L) sells a wide range of e-learning and e-assessment resources to schools and colleges. These are collectively branded as Derby 14-19™. For instance, one of the products aims at tackling the causes of plagiarism instead of merely detecting this form of misdemeanour. Another noteworthy product is the Bioscope ™, a virtual microscope that simulates a real microscope. i4L claims that it is the only product of its kind. Both these products, along with other i4L products, were successfully exhibited at the BETT 2006 educational technology show at London's Olympia in January. The company's clients include the giant retailer New Look, Cambridge Hitachi, the British Museum, and several city councils and health trusts. i4L is a joint venture between the University and Derby City Council Education Service.

The novelty of Derby 14-19TM

PLATO TM is a specific e-learning product aimed primarily at A-level students and undergraduates to tackle the causes of plagiarism. Schools and universities have installed plagiarism detection software. While this is a necessary measure to curb the apparent increase of plagiarism among school and university students, it does not really tackle the core of the problem, that is to "show and tell" exactly what plagiarism is and the forms it may take. PLATO TM (Plagiarism Teaching Online) provides tutorials on what constitutes plagiarism and the proper ways to reference material so as to avoid plagiarism. The product does not assume prior knowledge of plagiarism on the part of users and instead engages them through a detailed visual approach. PLATO TM, unlike automated plagiarism detection software, directly addresses this problem.

Derby University produces Bioscope TM for Hitachi Cambridge/Cambridge Assessment, which is a collaborative venture between Hitachi R&D Division and the Cambridge Centre for Communications Systems Research. This venture develops technological solutions in key areas of network software technology, such as copy protection, network security and architecture. Bioscope TM is a virtual microscope and includes a large number of magnified botanical and zoological microscope slides for biology students. These slides are accompanied by paper-based tasks for students to practice their observation and 'focusing' skills as well as to measure the observed artefact. These tasks, according to i4L, have been included in the current GCSE, IGSCE and O level syllabuses.

The innovation: social and economic benefits

With the widespread use of the Internet and the diverse range of services it provides, plagiarism has been greatly facilitated. There are scores of 'services' that supply articles on virtually any topic, for a fee. While students must surely realise that buying such articles is tantamount to a form of plagiarism, the lack of referencing as an act of plagiarism is not obvious to them, or supposedly not that obvious. Plagiarism, according to the media, is on the increase. While it is not clear if this trend has been exaggerated by the press, there is still sufficient anecdotal evidence to be concerned about this practice. Witness two recent incidents that have received much press coverage – the author Dan Brown of the *Da Vinci Code* fame, and the Harvard student whose book deal has been withdrawn on grounds of alleged plagiarism. If the current curriculum does not include lessons on proper referencing, then it is possible that copying can occur inadvertently. This does not bode well for the education and training of the future knowledge workers on which the economy largely depends.

The obvious economic benefit from this successful exploitation of academic research lies in the growing portfolio of clients that i4L currently enjoys. Its production of Bioscope TM for Hitachi Cambridge also suggests that the company has not only acquired an important global distributor for this product, but also a leading 'transferer' of knowledge generated by Derby University.

5 Raising the ethnic entrepreneurial spirit through networks

Exploitation channels: (4) network and social interaction; (2) training skilled graduates

This case study describes the success of a collaborative effort between De Montfort University and the East Midlands Regional Development Agency (EMDA) and its leading project, the Supplier Development East Midlands (SDEM) project. The close collaboration between the University and EMDA resulted in the establishment of the Centre for Research in Ethnic Minority Entrepreneurship (CRÈME), which is particularly aimed at knowledge transfer and support for ethnic minority entrepreneurship. CRÈME, which has years of research on the issues facing ethnic minority-owned businesses, is leading SDEM and has garnered increasing participation from a large number of these businesses, the majority of them being engaged in the supply goods and services to the public and private organisations. The success of CRÈME has resulted in large part from the active participation of hundreds of corporate sponsors, such as IBM, PepsiCo, Ford Company, Severn Trent Water, British Telecom, JP Morgan, Leicester Football Club and Exxon Mobil. A significant accomplishment of SDEM has been the various contracts awarded to ethnic minority-owned businesses by participating corporations.

The novelty of SDEM

SDEM, funded by HEIF2 and EMDA, aims at supplier diversity. SDEM was a 24-month pilot project, which started in June 2004 with funding from the East Midlands Development Agency and with additional support from HEIF2 from August 2004 onwards. Through the development and establishment of strong partnerships with multinationals and large private-sector organisations, SDEM has effectively facilitated direct interaction between the procurement professionals of participating corporations and innovative ethnic minority-owned businesses, with the aim of concluding procurement contracts for the latter. In addition to the corporations mentioned above are Enterprise Rent-a-car, Capital One, Frank Haslam, Milan and Miller Construction. The latest multinational corporation to join SDEM is ExxonMobil; Malcolm Platt, Global Process Manager of Procurement Global Operations for ExxonMobil noted: “We believe supporting minority-owned businesses builds stronger communities and produces solid business results. ExxonMobil’s US Supplier Diversity Program ensures that qualified minority-owned suppliers are included in our procurement sourcing process. We want to extend this within our Esso UK operations and are pleased to join the SDEM program” (quote supplied by De Montfort Head of External Relations). The total corporate membership has risen from eight in June 2004 to 25 in April 2006.

An accompanying aim of SDEM is knowledge transfer to ethnic minority entrepreneurs. “Meet the Buyer” events as well as virtual trade shows have been developed and promoted to inform and advise these small suppliers on presentation and marketing. To date, SDEM has signed up more than 250 businesses to participate in the project.

CRÈME is developing a national programme, Supplier Diversity UK, to support supplier diversity. To realise this programme, CRÈME has formed strategic partnerships with Regional Development Agencies, ethnic business support organisations, and formal and informal business networks across the UK. It plans to launch this programme later in 2006. It is reputed to be the first minority supplier development programme. It will be funded jointly by the private and public sector (including EMDA).

The innovation: social and economic benefits

The focus on ethnic minority-owned businesses is opportune at a time of heightened ethnic tension in parts of the UK. Areas with an ethnic concentration are often characterised by poverty and high unemployment, which tend to result in social unrest and disturbance. In such an environment, the promotion of economic opportunities for disaffected ethnic minorities offers “a way out of the ghetto”. In other words, a sense of ownership can contribute to some form of security, responsibility and accountability.

In its first 22 months SDEM has achieved some encouraging results. The total value of contracts awarded by corporations so far has been more than £500,000, while business generated through networking among minority-owned businesses has totalled about £75,000. A further £1.5 million worth of contracts is currently under negotiation. SDEM is also acting as a broker for corporate contracts worth about £1 million to be placed within the next six months. The project team matches these opportunities to the minority-owned businesses engaged in the project and informs the relevant parties of these forthcoming contracts.

SDEM has also benefited the University. It has established and maintained a strong and effective relationship with EMDA and a number of large corporations. Through successful engagement with a large range of businesses in the region, the University now has a platform to support practice-based research and knowledge transfer. Undergraduate teaching has also been enhanced by a large portfolio of empirical research on business management and entrepreneurship.

Picture 3. SDEM (permission granted for use of image)

6 Exercising the easy way

Exploitation channels: (6) spin-off; (2) training skilled graduates; (5) increased capacity for problem-solving; (4) forming networks

Progressive Sports Technologies (PST) is a Loughborough University spin-off specialising in innovative sports and fitness equipment. The company grew out of an idea of doctoral student, Paul Weir, also formerly a personal trainer, who identified a market gap for a multi-function exercise for home and gym use. With a £45,000 grant from the DTI, a £19,000 loan from Loughborough University Enterprises, the University's business support company, and expertise from the UK's largest product design and innovation agency, PDD (in return for an equity stake), PST was formed in 2001. The prototype was perfected in 18 months after extensive market research and simulation. In 2003, PST concluded a £1 million global license with Reebok Fitness Equipment. It is also the preferred innovation partner to Reebok and provides product development input for the giant sports corporation for a large range of equipment. The PST invention is now marketed as the Reebok Deck, which is retailed in JJB, John Lewis and Argos. A £1 million deal was also signed with the UK and Europe's largest health club operator in January 2005. Sales of the product have been made in Russia, Egypt and New Zealand. PST also helps students of Loughborough Sports Technology (an undergraduate programme leading to a BSc) to develop their products for possible commercialisation.

The novelty of PST

PST represents an interesting case because it is a three-person company which has demonstrated that size may not be a hindrance to commercial success with the right kind of skills and support (and perhaps some serendipity). The company comprises Paul Weir, Dr Mike Caine, a lecturer in Sports Technology in Loughborough University, and Jeff Davis, with 20 years of commercial experience in the fitness industry. PST developed from research pioneered in the Loughborough University Sports Technology Research Group, which is reputed to be the world's largest research group of its kind. With this kind of expertise behind it, PST is well positioned to exploit further its early successes. The company is networked globally within the sports and fitness industry, and has already developed a range of product designs. It is also active in regional business networks.

One such successful product is the Reebok Deck, for which the technology has been patented. Its novelty lies in how it has addressed the limitations of cardiovascular and resistance-training equipment, which generally allow only specific activities for each kind of equipment. Instead, Reebok Deck allows multiple activities to be undertaken. It is also compact, and easily transported and stored. This makes it attractive for health club studios that do not have large space for gym equipment. Reebok Deck is particularly suited for the personal market, which is currently booming in the UK, as it is easily portable.

Also patented is the RespiVest, which PST claims to be an innovative sports garment that helps boost athletic performance by restricting the chest during exercise. This effect forces the muscles used during breathing to work harder and become stronger. The company is in current discussion with several major sports brands to commercialise the garment.

The innovation: social and economic benefits

Obesity is a growing concern of the UK Government. Increasing resources are being allocated for exercise facilities and obesity awareness-raising campaigns. An important element in these campaigns is the role of exercise for the health of the nation. That the UK personal training market is growing and the number of gyms proliferating may be indicative of the increasing awareness of the importance of exercise. In these markets, the Reebok Deck has the potential to become a common piece of equipment used by gyms and personal trainers. Arguably, PST innovations such as the Reebok Deck and RespiVest and its partnership with Reebok make the company an increasingly important player in the world of fitness equipment.

The economic returns to PST from its sales and from licensing of its technologies have been impressive. Its speedy conclusion of a licensing contract with Reebok (two years after the formation of the company), its status as preferred partner with Reebok on product development, and its national and international sales are testimony to its success and to the potential economic rewards from the company's past and ongoing research.

PST also contributes to the development and mentoring of would-be entrepreneurs at Loughborough University. In addition, they disseminate their knowledge and experience of creating spin-offs to the wider University audience, to regional business networks, and to others through international conferences and innovation workshops. The company's inventions have been widely covered by the media and the London Science Museum.

Picture 4. Progressive Sports Technologies (permission granted for use of image)

7 New service satisfies the quest for ancestral knowledge

Exploitation channels: (3) new methodologies; (4) stimulating social interaction; (6) spin-off; (7) provision of social knowledge

This case study has been selected because of its interesting and 'non-mainstream' products – tracing one's genealogy. Oxford Ancestors, founded by Professor Bryan Sykes, was formally incorporated as a University of Oxford spin-off in 2001. Following press coverage of his genetic research and publication of his book, *The Seven Daughters of Eve*, Sykes received an overwhelming number of requests from the public for personal DNA analysis services. Sykes had been using DNA analysis to trace important events in human evolution and to show common ancestry among everyone on Earth. By 2002, the company had received more than 10,000 requests for analysis that it had to relocate to larger premises. In 2003, it launched its leading services – Y-Clan™, MatriLine™ Tribes of Britain™ and MyMap™ – to provide its customers with more information about their ancestry and about the UK distribution of surnames.

The novelty of Oxford Ancestors

Sykes and his colleagues at the Institute of Molecular Medicine at the University of Oxford have been studying human evolution and patterns of population origins for more than 10 years. The research focused on using mitochondrial DNA and Y-chromosome DNA, which are inherited down the maternal and paternal lines respectively, to trace ancestry patterns. They were also the first researchers to recover DNA from fossil bones and are at the forefront of human fossil analysis. Sykes was apparently the first scientist to establish a connection between surnames and Y-chromosomes.

A person's maternal ancestry is traced by mtDNA and, although both men and women carry this DNA, only women can pass it on to their children. The MatriLine™ service establishes the personal link between the person and his/her ancestral clan mother. Persons of European descent have a 95% chance of being related to one of the seven clan mothers described in Professor Sykes' book, *The Seven Daughters of Eve*. Those of non-European descent can have their genealogy tracked from the other 29 clans. There are currently 36 identified clan mothers, who cover the whole of humanity. In addition to establishing what particular clan a person belongs to, MatriLine™ is able to provide information about how and when one's ancestral mother lived.

Scientific research throughout the world has shown that all paternal lines are connected somewhere in the past and so paternal ancestry is traced by the Y-chromosome or yDNA. Only men have this, which they inherit from their fathers and pass on to their male children. Y-Clan™ analyses a man's yDNA to establish the link between the man and his ancestral clan. There are currently 15 identified and named clans that cover the whole of humanity and these represent the major human Y-chromosome haplogroups. In many countries, sons inherit their father's surname. This allows a man to investigate his paternal lines; for instance, he can compare his genealogy with those of other men with the same surname to reveal if he shares a genetic connection.

The innovation: social and economic benefits

The overwhelming response that Oxford Ancestors has received for their products indicates the enormous interest among members of the public in finding out about their genealogy. Testimonials on the company's website (http://www.oxfordancestors.com/testimonials.html) show that sales have been made across the UK, the US, Australia and New Zealand. While some may perhaps be sceptical of the 'social value' of knowing our genealogy, the testimonials received amply illustrate this value.

[From the US] "*I noted that you took an additional week to report on my wife's ancestry (Ina - Ed). That was actually reassuring; I concluded that you were re-checking your results to rule out error. Your letter says: 'Yours is a DNA sequence which is very rare among native Europeans'. Indeed. My wife is descended from Native Americans; Mexican, in the case of her father, the California coastal Chumash in the case of her mother. If you had categorized her as a descendant from one of the Seven Daughters of Eve, I would likely have challenged your results.*

In short, I believe you have passed the test. You conducted your tests honestly and reported your results. I feel that I have gotten my money's worth. Thank you very much."

[From Scotland] "*Through the MatriLine database I contacted one of your customers. Through searching both our lines it turns out we are 4th cousins once removed. Without having our DNA done we would not have found each other, so again thanks.*"

[From London] "*Thank you for sending me the results of my Tribes of Britain Ancestry test. I must say that I am now feeling very 'Nordic' and have taken to eating more fish and longing for the open seas. This is really a most fascinating project and many of my friends and relatives are intending to find out if they too are a Viking.*"

[From New Zealand] "*I feel I belong to something bigger than myself and I am not just hanging here, and that my ancestors got through all the trouble, diseases and the perils of life for me to be able to exist. Thank you.*"

8 Reducing the risk of problem-solving and decision-making

Exploitation channels: (3) new methodologies; (5) increased capacity for problem-solving; (1) increasing stock of useful knowledge; (2) training skilled graduates

InforSense describes itself as an "integrative analytics company", spun out of research carried out at Imperial College. The company "provides a software platform for integrative analytics", which enables researchers to analyse, visualise and integrate data from diverse sources while at the same time facilitating collaborative work. Applications of InforSense products have a wide range of applications in an equally broad variety of industries. InforSense products are used in pharmaceuticals and biotechnology companies, financial and healthcare services, research institutes, automotive and aerospace industries, and for various purposes related to environmental monitoring. The company's flagship product is KDE™, which is sold around the world. The company is privately owned. Its European headquarters are in London and the US headquarters in Cambridge, Massachusetts. The CEO of InforSense is Professor Yike Guo.

The novelty of InforSense software

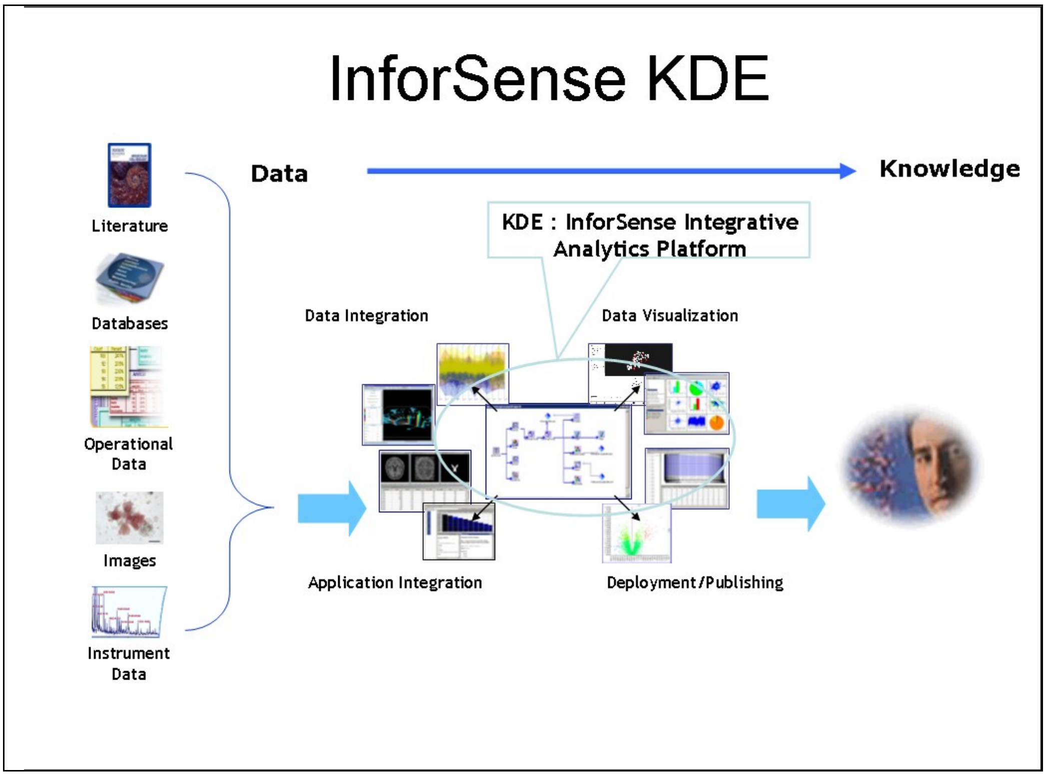
The flagship product is KDE™ (Knowledge Discovery Environment). The software is used, amongst other things, as a decision-making tool in any area of business or research that has to make difficult decisions based on complex data. It also has the ability to boost the productivity of scientific research through its capacity to integrate and analyse a diverse range of data. Importantly, it supports effective collaborative working, not uncommon, for instance, in the field of life sciences. The software is scaleable, can be customised, does not require coding, and is flexible for iterative and scientific research. Importantly, the software has been useful in translational medicine (i.e. the translation of research from the bench to the bedside), but equally significantly it allows results from “the bedside to the bench” to be integrated, analysed and used in further research. The software is built to industry standards; this facilitates integration of other analytic tools and data formats, thereby allowing the creation of a single informatics platform.

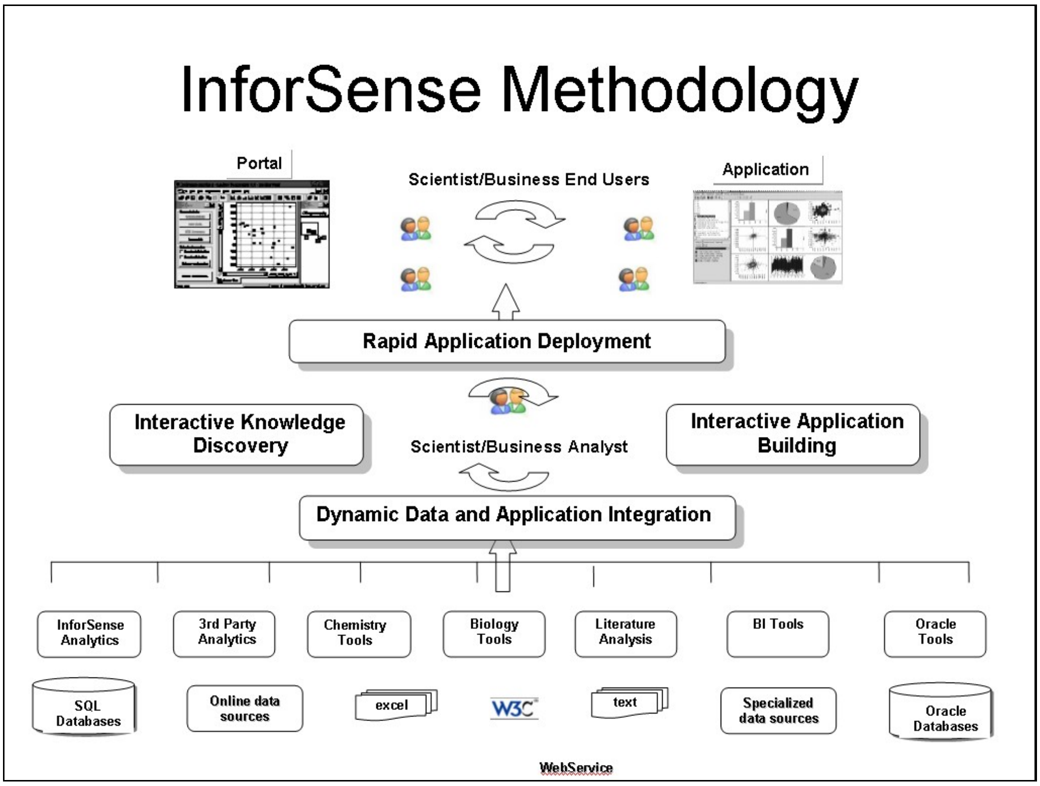
The innovation: social and economic benefits

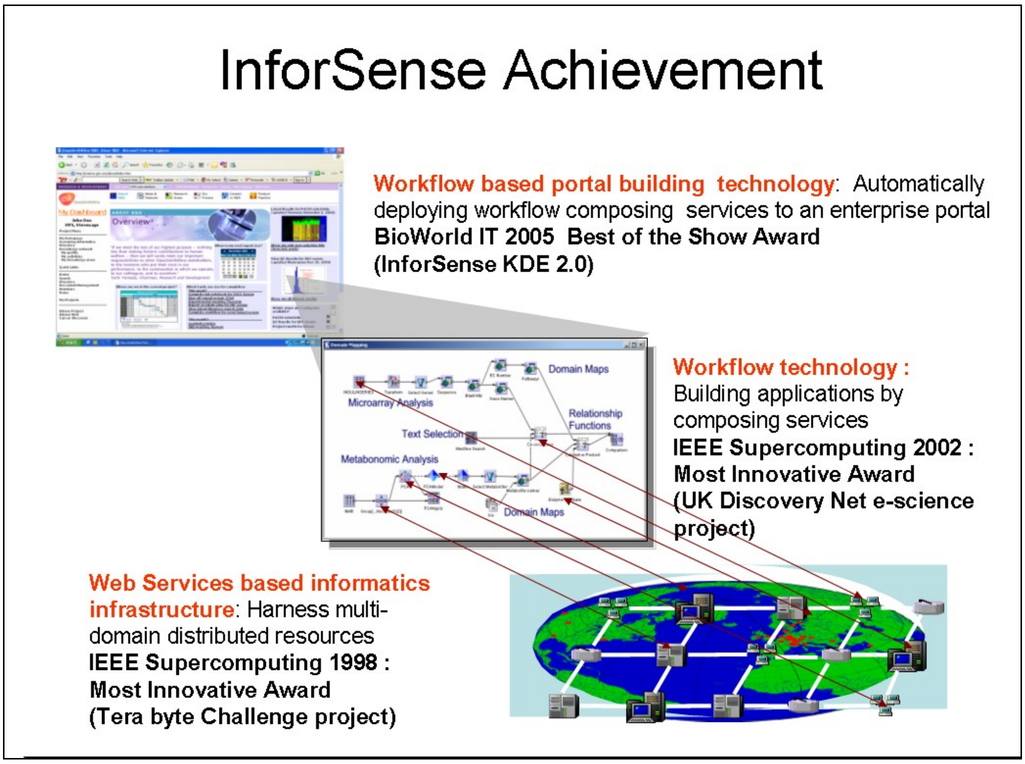
In 2002, InforSense software won the “Most Innovative Data Intensive Application” at the SuperComputing 2002 event in the US. As noted above, the software enables the orchestration of all the tasks involved in increasingly complex decision-making processes using multiple data sources and tools. Combined with the easy identification and extraction of knowledge needed to make better-informed decisions faster, with increasingly scarce resources, KDE™ offers a significant advantage to businesses and research.

In 2005, the Windber Research Institute (WRI), a world-class biomedical research facility in Switzerland, licensed InforSense technology to provide an informatics platform for translational medicine. This particular biology platform will be jointly developed by WRI and InforSense, with the aim of developing an integrative decision support system to enhance patient care. The resulting platform will be deployed to share the research throughout the Institute and to help a quicker translation of research into real decisions for patient care.

InforSense has a large portfolio of customers around the world, including leading corporations such Bayer and AstraZeneca, the US National Cancer Institute, and the Shanghai Public Infrastructure for Research and Development Services. The company also has distribution deals in Europe and Japan and is co-selling its products with IBM Europe. In addition, it has a joint venture with Shanghai Centre for Bioinformatics Technology and IBM China to create a laboratory to conduct research in bioinformatics and applications.


InforSense KDE
Data
Knowledge
Literature
Databases
Operational Data
Images
Instrument Data
KDE : InforSense Integrative Analytics Platform
Data Integration
Data Visualization
Application Integration
Deployment/Publishing


InforSense Methodology
Portal
Scientist/Business End Users
Application
Rapid Application Deployment
Interactive Knowledge Discovery
Scientist/Business Analyst
Interactive Application Building
Dynamic Data and Application Integration
InforSense Analytics
3rd Party Analytics
Chemistry Tools
Biology Tools
Literature Analysis
BI Tools
Oracle Tools
SQL Databases
Online data sources
excel
W3C
text
Specialized data sources
Oracle Databases
WebService



Picture 5. InforSense software (permission granted for use of images)

9 Charting a clearer course to improved productivity

Exploitation channels: (2) training skilled graduates; (5) increased capacity for problem-solving; (3) new methodologies; (1) increasing stock of useful knowledge

The Statistics and Mathematics Consultancy Unit (SMCU) is a business unit of the University of Durham. It offers statistical and mathematical advice and analysis for a wide range of industrial, commercial, academic and institutional clients. SMCU also offers short courses in statistical techniques and practice, which are tailored according to the company's requirements and the level of training required by each member of its staff. Statistical and mathematical consultancy is generally regarded as an esoteric field of business; indeed, to offer consultancy in the statistical and mathematical fields is not a business that immediately jumps to mind. Yet SMCU's portfolio of businesses illustrates the range of applications that the Unit has offered. We have selected SMCU to show that not only the 'hot' domains such as Information and Technology and biotechnology research can be successfully exploited. SMCU is registered with the DTI as a Centre of Expertise in Manufacturing.

The novelty of SMCU

SMCU, an integral part of the Department of Mathematical Sciences at the University of Durham, is staffed by consultancy staff and by other statisticians and mathematicians working in the Department. All participating staff are active researchers and lecturers, and they offer a very wide range of expertise in a number of fields. This arguably is not novel in itself; what is interesting is the range of applications that SMCU has developed for businesses and for advancing the state of knowledge in many fields of study. The following examples demonstrate the application of mathematical sciences to businesses.

In the first, SMCU helped to improve dramatically the manufacturing performance of a company. Continuous improvement by manufacturing companies is widely advocated by business management experts as a means to develop a competitive edge. In particular, companies need to make their products better (higher quality, fewer rejects) and cheaper (faster production, lower waste). SMCU applied an experimental design methodology to this particular company's production lines and succeeded in reducing wastage from 18 per cent to 3 per cent, while simultaneously improving throughput by 30 per cent.

In another example, SMCU helped a local company optimise its warehouse operations. This company has 3500 products, of which around 600 per day may be manufactured. Therefore sufficient space was needed to hold enough stock of each product so that orders could be met, either from stock or newly scheduled production, with only a small probability of running out. SMCU modelled the demand for products, taking into account possible production schedules, and advised on stock levels for each product, with a range of stock out probabilities to be decided by managers.

SMCU is working with another company to provide forecasts of financial series, such as commodity prices. Such forecasts are often based on a number of factors, typically data and expert judgments. Using Bayesian statistics, SMCU is able to provide forecasts that reputedly take better account of the variety of underlying factors and their compatibility, in particular to understand more clearly the uncertainties attached to them and then to calibrate new data for use by the company.

This consultancy work in collaboration with Energy Scitech Ltd concerns Bayesian approaches to very complicated stochastic systems, for example the modelling of leak detection for pipeline networks and history matching for oil reservoirs. The consultancy was based on an EPSRC research grant, entitled *Bayes linear forecasting and decision-making for large-scale systems in the petroleum industry*. SMCU aims at further commercialising other aspects of that research.

The innovation: social and economic benefits

Apart from the demonstrated economic benefits that SMCU has helped create for companies from application of its research, it also undertakes several projects to advance the state of knowledge in many fields that have potential economic and social value. An interesting example is its research in bird survival. Based on Bayesian graphical modelling, the research aims to analyse the survival distribution for birds, whether this changes over time and whether bird survival is associated with climatic change.

Conducting collaborative work with colleagues in the Centre for Applied Social Studies at Durham University and social scientists elsewhere, SMCU provides statistical expertise underpinning a variety of projects relating to social policy decisions that require extensive survey work. For instance, SMCU has participated in projects addressing care of people with mental health or learning disability problems. The Unit also helps to design the studies, provides advice on the choice of statistical instruments to be used for the projects, and assists with the analysis of the resulting surveys.

10 Adding meaning to content

Exploitation channels: (4) forming networks and stimulating social interaction; (1) increasing stock of useful knowledge;(7) providing social knowledge

PocketVisions is collaboration between film-makers and anthropologists from University College London. This venture demonstrates that innovative use of academic research need not only have a financial imperative underpinning its use. It also perhaps reinforces the familiar argument that commercial applications are not always evident from academic research. PocketVisions holds regular documentary screenings (about 30 weeks a year) of international award films in London from up-and-coming film-makers as well as established producers, such as Ken Loach. In conjunction with these screenings are debates with the film-makers. PocketVisions was created in 2005 and will be taking up residence at the British Museum in January 2007.

The novelty of PocketVisions

The special dimension of PocketVisions is its origin – it was conceived by researchers in anthropology, a discipline where research is not widely regarded as commercially viable compared to other disciplines such as IT or biotechnology. Channel 4's *Four Docs* describes the company's selections: "The docs [documentaries] selected have often emerged from anthropological fieldwork, which gives a really interesting perspective that goes beyond the film-making itself and into the social meanings and ethics of documentary interviews and investigation… PocketVisions is carving a very unique space for itself." (http://www.pocketvisions.co.uk/pv/?page_id=12). Discussions with an often diverse and passionate audience followed the screenings. (*Four Docs* is a broadband channel designed by Channel 4 as a place for users to showcase their documentaries of just four minutes each. Practical advice and guidance from experts on producing a film are provided on this channel. Documentaries are uploaded to the site, and opinions and views are shared with other aspiring film-makers.) PocketVisions constantly seeks out new films to screen. Feedback from past screenings from directors has indicated the value of its services as a way of previewing films.

The innovation: social and economic benefits

A main benefit from PocketVisions' activities lies in the cultural network it has created among aspiring film producers and the public. These activities do not clearly produce a product *per se*; however, it provides a service and forum for discussions with experienced critics, academics and film-makers, in which ideas are exchanged for either new documentaries or improvement of existing films, and information is passed or acquired. For instance, PocketVisions in partnership with Black Cultural Archives, Black World and Film London, presented in mid-2005 *Africa Mine*, a programme of modern, classic and art-house films. This programme explored Africa through the eyes of Africans, alongside "visions of the continent packaged primarily for western viewers" (http://www.pocketvisions.co.uk/pv/?p=56). As is the practice of PocketVision, The screenings were followed by panel discussions and meetings with the film-makers, media professionals and experts from Africa. In April 2006, the company screened *Wal-Mart: the high cost of low price*, a documentary described by the Los Angeles Times as "An engrossing, muckraking documentary … but if you're expecting an angry diatribe, you're going to be disappointed" (http://www.pocketvisions.co.uk/pv/?cat=10). This feature-length film was about how Wal-Mart's aggressive business practices assail American lives and values.

In many ways, PocketVision is illustrative of the importance of networks "for tapping into the intelligence of others", as argued by Salter and Martin (2001, 525). While this venture is not yet reaping the financial returns of some of the spin-offs discussed above, the use of its academic research and expertise in anthropology perceptibly contributes to the cultural and social fabric of London and elsewhere.

11 Flexible tool for all formats

Exploitation channels: (6) spin-off; (5) increased capacity for problem-solving; (2) training skilled graduates

Transitive Corporation was founded in 2000 by Alasdair Rawsthorne, a University of Manchester lecturer in Computing Science. The company exports computing technology to Silicon Valley. Its leading product, QuickTransit^{TM}, allows any software application to run on any processor and operating system, thereby tackling the problem of hardware/software dependency. This product is now included in every system of Silicon Graphics work-stations, from desk-side visualisation systems to high-end supercomputers. The crowning glory of Transitive Corporation was in June 2005 when Apple's Steve Jobs demonstrated Transitive's part (through licensing) in Apple's much heralded plans to migrate from PowerPC to Intel CPU chips. The company has also received much attention in the international media and accolades from the trade press. For instance, the Wall Street named Quick Transit^{TM} as the runner-up in the software category of the newspaper's second annual Global Technology Innovation Awards for 2005. Transitive employs more than 40 home-grown graduates at the company's offices in Manchester and Silicon Valley. The R&D is done in Manchester.

The novelty of Transitive technology

Transitive spent about three years on research in the School of Computing Science, developing the technology into a robust, commercial and industrial software base, and completing the necessary features for sale. This research eventually formed the foundation of the QuickTransit^{TM} product. Betting on its potential, Manchester Technology Fund invested £0.2 million and Pond Venture Partners of London and Silicon Valley £1.8 million to support the research and development. Transitive subsequently raised more than $20 million in the US. Development contracts were signed in 2001 and 2002 with early customers acting as technology partners. In 2003, the company was ready to market its product. The first major deal was with Silicon Graphics.

The unique patented feature of Transitive's hardware visualisation technology is that it allows software developed for one platform to run on any other without any source code or binary changes. This results in minimum disruption in performance when programs are ported on to different chip architectures. The technology claims to reduce dramatically software developers' costs, risk and time to market of supporting multiple hardware platforms. It also facilitates the migration to new platforms and increases the choice of software available on hardware platforms. The versatility of Transitive's software underpins Apple's choice to use Transitive's technology in its recent move to Intel. It also spurred Intel's collaboration with the company (see below).

The innovation: social and economic benefits

Apple's new Intel-based machines use the Quick Transit™ translation technology, which enables these new machines to run applications written for the PowerPC platform. Having benefited indirectly from the Apple deal, Intel considered the possibilities of what QuickTransit might do to bolster Intel's competitive position. This led the company to announce in March 2006 that it would be funding the development of QuickTransit variants. It aims to apply Transitive's QuickTransit™ technology to Intel-powered servers and Xerox processors.

To date, Transitive have agreements with six of the world's largest computer companies to write customer software support for their platform. Independent Software Vendors have also supported Transitive's technology and many are collaborating with the company to write customised software as well. Together with its numerous awards, Transitive's grasp of cutting-edge computing technology has placed it in the 'big league' of enterprise technology. *InfoWorld*, a leading computer magazine in the US, named Alasdair Rawsthorne the *InfoWorld* 'Innovator of the Year' in 2005; these awards are to recognise individuals whose expertise and vision help drive the future of computing technology. The 13 September 2004 edition of Wired.com, a leading e-magazine (also available in hard print) for computer buffs, stated that QuickTransit™ was "A Step Towards Universal Computing".

That the R&D is done in Manchester is noteworthy. This implies, first, that there is not an inevitable brain drain from Manchester to Silicon Valley, and secondly, that scientific training and knowledge are continually added to the national pool of expertise.

12 Ensuring that land-usage is safe

Exploitation channels: (5) increased capacity for problem-solving; (1) increasing stock of useful knowledge; (3) new methodologies

Working as a researcher in a project examining land restoration for British coal after his PhD in soil physics from Newcastle University, Dr Robin Weir identified a viable business opportunity for soil-related industrial applications of academic research. In 2000, he established Soil Environment Services Ltd. The company has offered consultancy services throughout the UK, including assisting small and multinational corporations in the assessment of land quality. For instance, the venture tested industrial waste products to provide the kind of information that the Environment Agency required before recycling the waste from agricultural fertiliser.

The novelty of Soil Environment Services

Soil Environment Services Ltd is a 'graduate consultancy business' as opposed to a 'spin-out', a differentiation that Newcastle University makes between the two kinds of businesses. A differentiating characteristic perhaps lies in the fact that the former continues to be funded by the public sector through small and large grants for research as well as through consultancy services.

Soil Environment Services Ltd undertakes major infrastructure impact assessments, agricultural land classification, contaminated land risk assessments, composting planning applications and mineral extraction soil planning schemes. For instance, soil erosion assessment may require specialised investigation and research techniques to solve a particular problem. A typical scenario, according to Soil Environment Services, is for litigation to prove a soil has been badly managed and resulted in erosion. Land risk assessment involves the quality of the soil that may have been vulnerable to soil movement during wet conditions or contamination. An example of testing soil strength is that involved in testing heavy vehicles, such as the new Ministry of Defence Terrier armoured vehicle.

Land use, currently a universal problem, is closely associated with ecological and environmental concerns. For instance, the spreading on land of compost, water treatment sludge, or any other industrial or farm by-products, are all considered forms of ‘land treatment’ that can receive exemptions under UK environmental regulations. Spreading waste directly on land requires nutrient balance assessments to determine the beneficial properties of a particular compost or organic material to be used on the land.

Shortage of soils is often addressed by the use of synthetic soil (with the use of combined soil-forming materials). A wide range of mineral soil-forming material and organic matter is now available for the production of synthetic soils for land restoration. UK Waste Management Licensing regulations require that agricultural or ecological benefit should be proved. This requires testing and research to satisfy both the regulatory authorities and to provide the site operators with practical achievable procedures and goals. Similarly, contaminated land risk assessments are done in conjunction with soil forming materials assessment to identify any risks to plants, human health or controlled waters from contaminating materials.

The innovation: social and economic benefits

Land reclamation, land testing and land use, including green-field and brown-field surveys, involve a combination of economic and social issues. Soil Environment Services’ clients include the English Partnerships Coalfields Regeneration Programme, for whom the company has managed soil and management strategies for a number of its sites, such as the Monkton and Lambton coke foundries, and the Corby iron foundry and industrial waste site. Other clients are BP, BAE Systems, Tarmac, George Wimpey, The Countryside Agency, Newcastle Airport and the Dale National Park.

In the provision of its services, Soil Environment Services collaborates with universities and multinational companies. The company is also funded by central government grants for very small projects involving further research on soil management.

Picture 6. Soil Environment Services (permission granted for use of image)

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