The Economic Returns to Basic Research and the Benefits of University-Industry Relationships

A literature review and update of findings

Report for the Office of Science and Technology*

by
SPRU - Science and Technology Policy Research

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Executive Summary

Context. In order to identify appropriate levels of investment in public sector research, it would be useful to be able to identify the rates of return to public research and to identify the benefits of the relationships between public research and the private sector. It is in this context that this report has been requested by the UK Office of Science and Technology.

An intuitive approach. It is intuitively attractive to think of the main output of research to be new and freely available information, which is then taken up and used by industry in innovation. In particular, new scientific information leads to new technologies. This simple 'linear model' indicates that it should be possible to calculate the returns to public research.

Innovation is not linear. Innovation processes are not that simple, however. They are non-linear, complex and involve a range of interactions with public research. For these reasons and others, some argue that it is impossible to calculate rates of return for public research, and those that try need to interpret their results with great care. To build a full picture of the relationships between public research and innovation requires an understanding of the many benefits of public research for the economy – not just the provision of new information – and the specific mechanisms or channels through which these benefits come about.

A more realistic approach. This review builds on a wide literature that goes beyond the intuitive approach to examine in detail the complex relationships between research and innovation, science and technology. The existence of this rich set of relationships means that the returns to basic research are probably much higher than those imagined by using the intuitive linear approach. However, paradoxically it also makes it more difficult to calculate convincing and analytically rigorous quantitative figures for the returns to basic research.

Calculating the returns. Attempts to calculate the returns to public research have generally resulted in high rates of return – from 20-50% and higher. The report reviews recent literature in the field, showing the diverse economic sectors and country circumstances in which studies have been conducted. Most find substantial returns.

Limits to quantification. However, attempts to calculate the economic returns to public research have faced strong methodological criticism. There now seems to be a wide acceptance of the limits to quantification. As a consequence, few studies now attempt to calculate a rate of return, but some try to give an idea of more specific partial measures, such as measures of the elasticities of public and private R&D – i.e. what effect does public research have on key variables such as private research.

It is therefore important to analyse the other ways in which research benefits the economy:

Creating strategic value. By enhancing capabilities in the economy – and it is important not to forget the vital linkage between research and the supply of skilled graduates – research underpins the knowledge absorption capabilities of the private sector. By creating and maintaining variety, research maintains the diversity of science and technology options vital to a flexible innovation system faced with uncertain future demands and opportunities.

Analysing channels. So far as we know, this review is the first attempt to bring together all the recent evidence about the great many channels of communication between the research sector and the private sector. Firms see many of these as important mechanisms for deriving value from public research. Information on many of the channels remains sparse. This restricts the ability of policy decisions to proceed on the basis of evidence.

Many benefits. Such evidence as does exist, however, demonstrates the many ways in which research benefits the economy, albeit in ways that are difficult to quantify in economic terms. This leads us to conclude that the benefits of public research are probably significantly higher than narrow calculations of the returns to public research would suggest.

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1 Background

In the study of technology transfer, the neophyte and the veteran researcher are easily distinguished. The neophyte is the one who is not confused

(Bozeman 2000).

The relationships between public research and innovation are recognised to be an increasingly significant topic in the emerging knowledge economy. However, this is an area beset by high levels of complexity and a surprisingly small amount of empirical research.

This is a field where it is easy to be misled by simplistic ideas, or to become confused by such data as does exist and the conflicting interpretations that can be taken from them. As this review will show, even now eminent commentators and analysts are still grappling with some of the most fundamental dimensions of the relationships between research and innovation, science and technology.

In this report, we shall try to achieve greater clarity without doing injustice to the topic by over-simplification.

1.1 The brief, and aims of the report

The main aim of this report is to provide up to date information on academic and policy analysis of the returns to academic research. Specifically, the brief of this project was:

'to carry out a concise and up to date survey of the literature on:

- economic returns to academic research, and
- university-industry relationships.'

Two reviews on these issues have previously been conducted by authors at SPRU, as shown below. Those reports covered the literature up to and including most of 1999. This report therefore built on these reports by reviewing evidence published since that time – principally 2000 and 2001.

The report is underpinned by a search of literature and on-line sources. Appendix A gives a list of all of the sources searched. It should be noted that despite the growing importance of the need to analyse and understand the relationships between public research and innovation, this is an area still characterised by only patchy empirical research. Hence, a significant proportion of those sources searched produced little or no *new* material. This observation underlies a recommendation made in the final section – that effective government policy in this area would benefit from being underpinned by a much stronger research base than currently exists.

1.2 Antecedents

The two previous reports by SPRU have also investigated this topic:

- The first review was conducted for the UK Treasury in 1996: '*The Relationship Between Publicly Funded Basic Research and Economic Performance*' (Martin, Salter et al. 1996).
- The second report was commissioned by the Committee of Vice-Chancellors and Principals and the Higher Education Funding Council for England in 2000: '*Talent, not Technology: Publicly Funded Research and Innovation in the UK*' (Salter, d'Este et al. 2000).

2 An intuitive approach

In the context of limited resources for supporting basic research, and the need to justify the expenditure of these resources, a growing number of policy-makers and academic analysts have become interested in understanding the relationships between basic research and economic activity.

Much of this analysis has been underpinned by an attractive intuitive approach to understanding these relationships.[1] This approach is characterised by several logical and sequential steps:

- First, science is mainly seen as a source of new information about how the world works.
- Second, because this information is published openly in the usual academic way, it is 'free to all comers' – a low cost input into economic processes.
- Third, the link between science and technology is obvious: scientific information is used in the creation of new technologies, which are then used in economic activity.
- Finally, given this role of science in the creation of economic returns, it becomes attractive to try to quantify the amount of economic benefit that can be attributed to the basic science elements.

This way of seeing science-technology-economy linkages is so intuitively obvious that for a long time it was simply assumed to be a valid approach. Unfortunately, it contains within it a series of misleading and incomplete 'mindsets and myths', the limitations of which have only become apparent with more in-depth investigations in recent years.[2]

This review, and previous reviews at SPRU and elsewhere, goes well beyond the intuitive approach to show that the relationships between research and economic activity are much richer and more complex than the simple linear model would suggest. This means that the returns to basic research are probably much higher than those imagined by using the intuitive approach. However, paradoxically it also makes it more difficult to calculate convincing and analytically rigorous quantitative figures for the returns to basic research.

In order to understand why the intuitive approach is limited in its ability to describe the value of research to the economy, it is necessary to consider the nature of innovation in the modern economy. This is the task for the next section.

3 Innovation in the modern economy: beyond the intuitive approach

The fundamental role of innovation and technical change in fostering firms', industries' and countries' capabilities for wealth creation is by now widely recognized. Innovation is at the heart of attempts to improve productivity and to deliver new products and services. Policy makers need to know how best to facilitate the unfolding of sound innovative strategies.

The literature that analyses national systems of innovation (NSI) stresses that the innovative performance of a country, and thus its growth potential, depends upon the development of a balanced 'system' of knowledge production and distribution (Nelson 1993; Lundvall 1992).

The emphasis placed by these and other authors on the specific role played by 'knowledge' in the process of innovation and economic growth has become even more central since the emergence of

[1] This traditional approach is also referred to as the '''linear model'. See Steinmueller Steinmueller 1994 and Cohen et al Cohen, Nelson and Walsh 2001 for further discussion of the origins and short-comings of this approach.

[2] See Steinmueller Steinmueller 1994 for a brief review of the first critiques from the sociology of science.

the so-called 'knowledge-based economies' (OECD 1996: 7). The increasing emphasis on attempting to understand the flows and relationships that link the many actors involved in the innovation process is consistent with much research that has shown innovation to be the outcome of a complex, non-linear and highly uncertain process. The 'intuitive', or linear, approach has repeatedly been found to be at odds with compelling empirical evidence (Nelson 1962; Rosenberg 1994; David and Foray 1995; Freeman and Soete 1997).

However, despite these more sophisticated insights the rhetoric of the linear model continues to influence thinking. A good deal of the linear model's appeal is due to its simplicity: scientists discover the fundamental laws; engineers apply them to produce the means of material progress. The former strive for understanding; the latter for marketable results. Science is explorative; engineering synthesises solutions within the boundaries of what is already known.

This report, as the SPRU reports that preceded it, relies on a more realistic, albeit more complex, analysis of the innovation process. In particular, we draw on a wealth of evidence that points to the interdependencies and feedback loops that link the various stages of this process – basic research, development activities, engineering efforts, commercialisation.

The linear intuitive approach is thus subject to substantial limits:

- It does not allow for the fact that technology often leads science: basic science is often not the source for new ideas, but is used to understand new technologies and complete new projects.
- It overlooks the fact of industry publications – industry is doing science too.
- It overlooks the need for capability and capacity at the industry end for university-industry relationships to work (see section 5.2 below).
- It obfuscates variability in university-industry relationships between industry sectors, and in the overall magnitude of, and the mechanisms through which knowledge transfer occurs.
- It ignores the many 'non-linear' channels by which knowledge and benefits arise from university-industry relationships.

Section 4.2 below argues that existing attempts at measuring economic returns to basic research are based on the linear model of the innovation process. The implicit model underpinning measurement methodologies is thus far removed from what we now know to be the empirical reality of the complexity of the innovation process, thus subjecting such measurements to substantial difficulties.

To summarise, in order to understand the full impact of university research on the economy, it is necessary to go well beyond the intuitive approach to develop a more complete understanding of the relationships between public research and innovation. Furthermore, measurement methodologies are mostly based on the linear model and are thus subject to substantial difficulties.

In the next section the discussion thus first provides a review of the various attempts to measure the returns to public research. Thereafter we review the current literature on these complex relationships, the various benefits of research to the economy, and the channels through which these benefits are realised.

4 Measuring and quantifying the returns of basic research to the economy

The linear model of the relationship between science and innovation suggests that science contributes knowledge for application in the innovation process. Social investments in science can thus be expected to increase social welfare and ‘if such returns are traced, we will be able to account for the return on scientific investment’ (Steinmueller 1994). While the identification and characterisation of the flow of benefits from public research is in itself useful, numerous attempts have been made to *quantify* the returns from public research. Griliches (1958) pioneered the measurement of social returns to research investment in this way (see Table 1).

A further important early attempt was that of Mansfield who, by generalising from a random sample of seventy-six American manufacturing firms, estimated the rate of return from total academic research in the US to be 28% for the fifteen year period under consideration (1991: 10). However, attempts to estimate the return to public research have been criticised as subject to substantial problems. In his later work Mansfield (1998) subsequently declined to estimate comprehensive economic indicators, such as the social rate of return.[3]

We now review the literature on the returns to basic research, including the latest published findings. However, readers should note that a range of eminent economists have argued that in order to be able to use the results of such studies, it is important to understand the difficulties associated with measuring the economic returns to research, and the limits to this approach. We therefore conclude this section with a review of these factors.

4.1 Review

This section provides an overview of recent efforts to quantify returns to research. As has been explained above, this literature has for the purposes of analysis been constrained to the linear model; Steinmueller (1994) makes the point that, although this does not allow for complete measures, it is done simply so that there is something that can be measured.

First we provide a short overview of the research, including recently published results. Thereafter we provide more detailed summaries of a selection of important recent papers presenting results of modelling and quantification efforts.

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[3] In his 1991 study using a sample of 76 US firms in seven industries, Mansfield obtained estimates from company R&D managers about what proportion of the firms’ products and processes over a ten-year period could not have been developed without inputs from academic research. He found that 11 per cent of new products and 9 per cent of new processes could not have been developed without a substantial delay in the absence of the academic research, these accounting for 3 per cent and 1 per cent of sales respectively. He also measured those products and processes developed with ‘substantial aid’ from academic research over the previous 15 years; 2.1 per cent of sales for new products and 1.6 per cent of new processes would have been lost in the absence of the academic research. Using these figures, Mansfield estimated the rate of return from academic research to be 28 per cent (*ibid*., p. 10). His 1998, follow-up study found that:

- academic work was becoming increasingly important for industrial activities;
- 15 per cent of new products and 11 per cent of new processes could not have been developed (without a substantial delay) in the absence of academic research;
- innovations that could not have developed without academic research accounted for 5 per cent of total sales for the firms; and
- the time delay from academic research to industrial practice has shortened from seven years to six.

4.1.1 *Overview*

Table 1 shows the latest available information from peer-reviewed journals on the rate of return from publicly funded R&D, starting with the original contribution from Griliches. It should be noted that only one recent paper has attempted to calculate a rate of return: other papers reviewed below do not provide an estimate of this measure so are not included in this table.

TABLE 1: PUBLISHED ESTIMATES OF RATE OF RETURN TO PUBLICLY FUNDED RESEARCH AND DEVELOPMENT

Studies	Subject	Rate of return to public R&D
Griliches (1958)	Hybrid corn	20-40%
Peterson (1967)	Poultry	21-25%
Schmitz-Seckler (1979)	Tomato harvester	37-46%
Griliches (1968)	Agricultural research	35-40%
Evenson (1968)	Agricultural research	28-47%
Davis (1979)	Agricultural research	37%
Evenson (1979)	Agricultural research	45%
Davis and Peterson (1981)	Agricultural research	37%
Mansfield (1991)	All academic science research	28%
Huffman and Evenson (1993)	Agricultural research	43-67%
Cockburn and Henderson (2000)	Pharmaceuticals	30% +

Compiled following Salter and Martin (2001).

Source: Griliches (1995), OTA (1986), and further additions by ourselves. Salter and Martin point out that many of these authors caution about the reliability of the numerical results obtained.

The Strategic Planning and Economic Analysis Group of the US National Institute of Standards and Technology (NIST) has more recently become a large source of economic returns assessments. They have been conducting economic impact assessments of their research funding programmes since 1992. The studies cited in the table in Appendix B are recent economic impact assessments of projects undertaken by NIST Measurement and Standards Laboratories. Tassey (Tassey 1999) provides an overview of their assessment programme and a discussion of the lessons learned about the methodology of their economic impact studies.

They claim that 'Collectively, the entire set of economic impact studies conducted to date demonstrates that the rates of return on NIST infratechnologies consistently match or exceed rates of return to private investment in technology' (Tassey 2001).

As indicated above, there is a range of problems associated with measuring comprehensive economic returns to public R&D, and academic debate about these problems has encouraged researchers to adopt a more modest approach focussing on measuring the relationship between public funding and specific desirable outcomes, such as the level of business R&D and innovation. Table 2 provides a summary of two recent papers (reviewed in more detailed below) providing estimates of partial-indicator elasticities: other papers reviewed in this section do not provide comparable data so are not included in this table. While the figures in Table 1 are average values, Table 2 provides elasticity measures that are of greater use when deciding about increasing or decreasing resource (funding) for public research.

TABLE 2: ESTIMATES OF PARTIAL-INDICATOR ELASTICITIES

Studies	Subject	Finding
Toole (2000)	Pharmaceuticals	Estimate that 1% increase in the stock of public basic research ultimately leads to 2-2.4% increase in the number of commercially available new compounds.
Guellec and Van Pottelsberghe (2000)	All sectors	One dollar of public funding for R&D (including defence) leads to additional business R&D as follows: +$0.70, when allocated to business -$0.44, when allocated to government labs -$0.18, when allocated to universities (The effect is approximately zero when defence spending is removed. See the review in section 4.1.2 below for further explanation of the role of defence spending)

Source: compiled by the authors.

4.1.2 *Recent papers: overview*

The following studies are reviewed in this section.

- In a large German study Beise and Stahl (1999) obtained results similar to Mansfield (1991), with the exception that they did not calculate a rate of return.
- Cockburn and Henderson (2000) report a 30 percent minimum return to publicly funded pharmaceutical research.
- Also working in the pharmaceutical sector, but employing a different approach, Toole (2000) finds that a 1% increase in the stock of basic research ultimately leads to a 2.0% to 2.4% increase in the number of commercially available compounds.
- In an important study using OECD data Guellec and Van Pottelsberghe (2000) produced a range of findings concerning the relationship between the public and private funding of research. The primary concern addressed was whether public funding crowds out private funding of research. In addition to the discussion below see Table 2 for a short summary of the results.
- Also pursuing this line of enquiry, David *et al* (2000) conduct a substantial review of the econometric literature addressing the question of whether public R&D is a complement or a substitute for private R&D.
- In a French study Autant-Bernard (2001) finds that public research increases private innovation directly, and indirectly by increasing private research. These effects are geographically localised.
- Tijssen (2001) aimed to identify the degree to which innovations are 'science dependent' and found that approximately 20 percent of private sector innovations are partially based on public sector research.

All studies reviewed here (and practically all the studies we are aware of) focus on manufacturing products and processes, leaving innovation in the service sector and the creative industries largely unexamined.

Beise and Stahl (1999)

Following Mansfield (1991), Beise and Stahl investigated the effects of publicly funded research at universities, polytechnics and federal research laboratories on industrial innovation in Germany. The primary aim of their study was to assess the 'economic justification for publicly funded research that directly supports industrial innovations which otherwise would not be developed by private businesses.' Their second aim was to identify the type of public research institutions and the type of firms that are associated with the successful transfer of knowledge from universities to industry, and their third aim was to assess the importance of geographic proximity for the commercialisation of the findings of public research.

While they did not estimate a rate of return their findings were in other respects similar to that of Mansfield's. Their survey of 2300 firms in the manufacturing sector found that one tenth of the firms which produced product or process innovations between 1993 and 1995 would not have done so without public research. This amounts to approximately 5 percent of all new product sales. With the exception of start-ups, they found no higher probability of publicly supported innovations emerging from firms located closer to universities or polytechnics. Firms with higher in-house R&D intensities were found to have a greater ability to absorb the findings of public research.

They note that their work only measured public research-based innovations identified by the firm directly and thus excluded innovations that relied on the public science base more generally. They were also only likely to have measured the short-term effects of public research. It is significant that they conclude that, even if these limitations are taken into account, there is 'not much evidence of publicly funded research in Germany being fully justified by identifiable transfers to industrial innovations.' (1999: 417). The more convincing finding, they argue, is the differences between the effectiveness of technology transfer from the various types of public research institutions. Universities are cited as the most important source of knowledge, closely followed by publicly financed laboratories, while large federal research centres lagged behind. The primary variable determining their success in technology transfer was found to be the degree of movement of qualified academics between the research centres and industry.

Cockburn and Henderson (Cockburn and Henderson 2000)

Cockburn and Henderson review the literature on the impact of public funded research on the performance of the pharmaceutical industry and report on their own earlier research. They find that private sector returns are high, in the vicinity of 30 percent, and that this should be seen as the lower bound. Furthermore, they argue that the biotechnology revolution will result in even higher returns in the future.

In their conclusions they identify as a cause for concern that the delicate balance between non-profit public and for-profit private research is changing. They argue that increasing pressure by both to adjust property rights to increase their ability to capture the returns from public research will reshape the nature of this relationship.

Toole (2000)

Working in the pharmaceutical industry, Toole investigated the impact of public basic research on industrial innovation. He used a production function framework to model the number of new products as a function of research investment in seven technology classes over the period 1978 – 1994 for federally funded basic research conducted in the USA. He found that a 1% increase in the stock of basic research ultimately leads to a 2-2.4% increase in the number of commercially available ethical drugs. His estimates also suggest that the lag between funding and commercialisation is seventeen to nineteen years. He further finds that (for the pharmaceutical sector) the marginal product of basic research is larger than the marginal product of applied R&D.

Guellec and Van Pottelsberghe (2000)

In an important paper Guellec and Van Pottelsberghe investigate the impact of public R&D expenditure on business R&D. The study investigated the aggregate effect of government funding of R&D on business R&D in 17 OECD member countries over the period 1981 – 1996. They identify four possible ways for governments to fund R&D. Governments can:

- fund businesses directly to undertake research (either by means of procurement programmes or as grants);
- provide tax-based incentives for business R&D;
- perform R&D itself in public laboratories;
- fund universities to conduct research.

They point out that while such measures are intended to remedy the problem of incomplete markets and imperfect appropriability of the benefits of privately funded research as identified by Arrow (1962), by leveraging more public and business research, the effectiveness of such funding measures can be challenged on a number of grounds. Public funding could crowd out business funded R&D by increasing demand and thus the wages of researchers. Public funds could also simply replace private funding as business substitute public funding for their own funds. Public funding of projects could also distort resource allocation favouring areas with lower opportunities. The specific focus of the study is thus on the question of whether government funding of public and business R&D leverages more business R&D, whether it also crowds it out, and whether the leveraging effect dominates the crowding out effect.

The major findings of their research are as follows:

- One dollar of public funding provided to firms results in a total of 1.70 dollars of research (the difference being funded by firms themselves, see Table 2 for further results).
- Tax incentives encourage business-funded R&D.
- These measures are more effective if they are stable over time.
- Direct government funding of business R&D and tax incentives are substitutes.
- The direct impact of direct government funding of business R&D is more long-lived than that of tax incentives. (Governments tend to target projects with longer time-horizons than those business prefer when choosing freely under tax incentives).
- The stimulating effect of government funding increases up to a certain threshold and then decreases. For the 17 countries and the period under study this threshold was at about 13 percent of business R&D. Beyond 25 percent, additional public funding is likely to entirely substitute for private funding.
- Publicly funded defence research performed at universities and public laboratories crowds out business-funded research.
- Civilian university research is neutral towards business R&D for the period investigated. While crowding out effects are 'immediately' visible, *positive spillover effects may take time to reach industry and is thus likely to fall beyond the time frame of the study.*
- The transfer of technology from university research is improved when government funding of business research is increased, thereby increasing their ability to absorb knowledge from the public sector.

David *et al* (2000)

In a similar vein David *et al* conduct a substantial review of the econometric literature addressing the question of whether public R&D is a complement or a substitute for private R&D.

They present the following table summarising the distribution of findings on the relationship between public and private R&D investment:

TABLE 3: SUMMARY DISTRIBUTION OF ECONOMETRIC STUDIES OF THE RELATIONSHIP BETWEEN PUBLIC AND PRIVATE R&D INVESTMENT

	Studies reporting 'net' substitution	Total number of studies
Level of aggregation: firm and lower		
Number of studies surveyed	9	19
Based on US data only	7	12
Based on data from other countries	2	7
Level of aggregation: industry and higher		
Number of studies surveyed	2	14
Based on US data only	2	9
Based on data from other countries	0	5
All levels of aggregation	11	33

From David *et al* (2000)

While their findings are inconclusive they do report that

> At this time the econometric results obtained from careful studies at both the micro- and macro- levels tend to be running in favour of findings of complementarity between public and private R&D investments. But, that reading is simply an unweighted summary based upon some 30 diverse studies; it is not a conclusion derived from a formal statistical 'meta-analysis,' and in no sense is it offered here as a judgement that would pretend to settle the issue definitively. (2000: 500)

In addition to the review of the literature this paper provides a useful conceptual framework for approaching the subject.

Autant-Bernard (2001)

Autant-Bernard examines the magnitude of 'public technological externalities' (spillovers) in France. Following Jaffe (1989), she develops a production function model to compare the relationship between business innovation output (measured by patents) and private R&D (measured by internal expenditure on R&D), public research (measured by bibliometric records), geographic unit (indicated by French Department), and scientific coincidence (measured by proximity to the public research profile of Departments). She finds that public research increases innovation directly, and indirectly by increasing private research. These effects are geographically localised.

Tijssen (2001)

Tijssen investigated the use of science in private sector innovations in the Netherlands. The research was based on a nation-wide mail survey amongst inventors working in the corporate and public research sectors enquiring about their own innovations and other related innovations in the market. The statistical analysis employed aimed to identify the degree to which innovations are 'science dependent' and the channels through which science influences the innovation process. He found that approximately 20 percent of private sector innovations are partially based on public sector research. They found citations in patients referring to basic research literature to be invalid indicators of a technology's science base.

4.2 Difficulties with measuring economic returns to academic research

In order to be meaningful the measurement of the economic returns to academic research will have to consider all its costs and returns. As explained in section 3 above, in addition to the direct, tangible products of basic and applied public research many other indirect by-products and benefits arise from it. The wide scope of the benefits, and the many complex and often indirect channels by which they arise, makes it very difficult to measure (David, Mowery et al. 1992). In short, because most measurement attempts are implicitly based on the linear model they fail to capture most of the complex reality of the relationship between science and innovation as suggested by the 'complex' or 'network' models.

One measurement technique uses an econometric 'production function' analysis to measure productivity improvements, and thus the economic return, attributable to public research. Productivity improvements are measured as changes in the ratio of inputs to outputs. Other comprehensive approaches, such as cost-benefit analysis also have to compare inputs with outputs. Yet other approaches have been developed in an attempt to avoid some of the pitfalls associated with the comprehensive indicators such as rate-of-return, or cost-benefit measures. These employ estimates of partial measures, such as the elasticity of specific economic indicators (for example number of innovations, or business R&D spending) in response to increases in public funding of R&D. Measuring outputs and inputs associated with academic research continues, however, to be fraught with difficulty for the reasons outlined above, and explained in more detail now.

4.2.1 Outputs

At least two difficulties arise with measuring new economic outputs that result from academic research (Cockburn and Henderson 2000). Firstly, the market price for new goods or services will inevitably not include the positive (or negative) externalities ('spillovers') that arise.[4] Cockburn *et al* give the example of the distinction between the private benefits to a person to whom a vaccine has been administered, and its social benefits of reducing the overall prevalence of disease and thus the probability that other members of society will contract it.

Secondly, improvement in the quality of a product (its consumer utility) as a result of academic research–based innovations is likely not to be entirely reflected either because the price of the product or service resulting from the innovation does not reflect the full increase in the value (as indicated by consumers' willingness to pay) or because the market basket of goods and services used to assess prices is only periodically updated to reflect new products and services.[5]

[4] Also see Arrow Arrow 1962.

[5] Strictly speaking productivity measures should not be affected by changes in relative prices. In other words, if all that changes is relative prices no productivity improvement should be registered. However, the point here is that if the quality of a product (or service) increases as a result of academic-research-based innovation, for every given unit of output (e.g. apple or laptop computer) a consumer purchases they now receive increased value (e.g. longer shelf life, or greater processing power), which would not be detected by productivity measures. Hollanders and Meijers Hollanders and Meijers 2001 discuss the use of "Hedonic Price Indexes" as an attempt to correct for this problem in the context of the software industry.

4.2.2 *Inputs*

A range of factors make it hard to measure new knowledge flowing from academic research as inputs to new products or processes.

Firstly, it often takes a considerable time before new scientific knowledge has a tangible economic effect. For instance, Adams (1990) found evidence that it takes on average twenty years for basic research to produce tangible economic results. A further complicating factor is the numerous channels by which public research influences private sector productivity (Cohen, Nelson et al. 2001; David and Hall 2000; Bozeman 2000). This makes it much harder to identify and assess all the relevant factors, particularly when benefits occur through systemic and indirect channels. It also compounds another difficulty – identifying all the relevant academic inputs to new products (Adams 1990; David, Mowery et al. 1992).

Cockburn also points out that knowledge spills over to other sectors that are not viewed as the primary beneficiary of the original scientific research and that these secondary benefits are often not identified and counted (Cockburn and Henderson 2000). The fact that the nature of knowledge and benefit flows between public research and the private sector are not linear, but bi-directional further complicates the measurement of academic knowledge inputs to private sector innovation.

David *et al* (1992) point out that it is often very difficult to attribute new products to specific new basic research findings. They argue that in addition to the direct use of basic research in new processes or products, research output could be used by further research activities, which would then ultimately contribute to industrial innovation. Research could also contribute to the improvement of products that were primarily based on other scientific or technological discoveries. Furthermore, usually further complementary investments in applied research and development are required in addition to the basic research to bring a product to commercial fruition, which, if excluded from the measurement would lead to an overestimation of the returns.

David *et al* (1992) further point out that new scientific and technological knowledge arising from public research creates option value – another conception of the ideas of variety or diversity discussed earlier – which is generally ignored by conventional measures.

4.2.3 *Other difficulties with measuring returns*

Together this long, complicated and delayed link between academic research and economic returns makes it very difficult to accurately identify and measure all the inputs and outputs. Furthermore, David *et al* (1992) point out that comparing inputs with outputs assumes that no alternative could have resulted in the economic returns attributed to the product or service associated with the basic research in question.[6] They explain that 'most economists find this assumption to be an uncomfortable one inasmuch as there are few new products or processes completely lacking substitutes' (1992: 77).

Studies which use productivity growth as an indicator of social returns to research investments are subject to a number of difficulties. Adopting a high level of aggregation in their analysis they rarely control for inter-industry differences in technological opportunity and appropriability. Furthermore, such studies do not reveal how the economic returns are realised and thus do not enable a comparison of the productivity impact of research in different scientific disciplines (1992: 77).

A further point to keep in mind is that most measures estimate average rates of return, while marginal rates of return are required for the purposes of resource allocation decisions.

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[6] In other words, it assumes that the entire expenditure on the input was necessary to achieve the output and that it was thus not redundant to any degree.

5 University–industry relationships

As indicated by the discussion about innovation processes, the relationship between public research and the economy is much more complex than suggested by an intuitive linear approach. In order to *understand* the returns to public research, we need to analyse the character of the relationships between universities and firms. By reviewing the evidence in this section, we show that public science is part of a larger network of knowledge creation and results in many more benefits than simply providing new information.

Previous reviews have found that the conduct of public research produces a number of ***benefits*** to the economy, and to innovation in particular. Some of these benefits are tangible outputs of public research, while some are in the form of ***sources of strategic value.*** These benefits and sources of strategic value, and the relationships between firms and public research that produce them, come about through various ***channels*** (as noted by eminent authors such as David and Hall 2000 and Cohen, Nelson et al. 200).

Some of these relationships and benefits are direct, while some are indirect. Equally, some are deliberately brought about by government policy or the decisions of researchers, universities or firms, while some are unplanned or unpredictable. These distinctions provide a useful framework for viewing the topic, but they also point to a common warning in the literature: that because of the often indirect, unplanned and long-term nature of the benefits of research, measuring and even understanding these benefits is a difficult task (see Georghiou and Metcalfe 1993; Luukkonen 1998; Luukkonen 2000).

As analysts' understanding of the relationships between universities and industry has improved over the years, it has become clear that the relationships develop within an ***institutional framework,*** which could either support and stimulate its development or impede it. Governments have sought to bring about institutional 'framework conditions' that are favourable to industry-university relationships and that encourage the development of channels through which these relations can develop. A recent study investigated the nature of framework conditions in eight EU states and the USA and Japan (Institute of Technology and Regional Policy, Research et al. 2001). It pays special attention to the following types:

- 'Legislation and the regulatory framework with respect to the different channels of industry science relations;
- Instutional settings in public science, including incentive systems and institution-specific barriers;
- Public promotion programmes and other policy initiatives aimed at stimulating industry science relations;
- Intermediary structures implemented to foster interaction between industry and science.' (2001: 10)

This study also reviews and assesses the measures taken by each country to improve their institutional framework conditions. There is still controversy about the effectiveness of some of the measures taken, and this report is not intended as a review of these.

In the rest of this section, we therefore review the following:

- the seven benefits of public research (section 5.1);
- the sources of strategic value (section 5.2); and
- the channels through which these benefits flow, and through which universities and firms interact (section 5.3).

5.1 *Science and the economy: scoping the benefits*

Previous SPRU reviews found seven benefits from public research for innovation. Rather than re-rehearse the evidence for each here, we refer the reader to those reviews (Martin, Salter et al. 1996; Salter, d'Este et al. 2000; and also Salter and Martin 2001). The benefits are:

1. Producing new scientific information
2. Training skilled graduates
3. Supporting new scientific networks and stimulating interaction
4. Expanding the capacity for problem-solving
5. Producing new instrumentation and methodologies/techniques
6. Creating new firms
7. Providing social knowledge

Recent work has continued to confirm the existence of these benefits. For example, over 20% of industrial R&D managers report using instruments and techniques generated by public research in their own projects within the previous three years (Cohen, Nelson et al. 2001). On university spin-offs, Pfirrmann adds data about in Germany (Pfirrmann 1999), while Chiesa adds data from a survey in Italy and reviews recent literature (Chiesa and Piccaluga 2000).

Several other benefits have also been cited by firms in recent research, such as enhanced credibility for firms using independent testing facilities at universities, and enhanced commercial credibility through being linked with a university (see Rappert, Webster et al. 1999). However, here the evidence is limited at this stage so we do not develop them fully here.

As the benefits cut across many of the channels discussed in the next section, much of this evidence is picked up there. However, one of the seven benefits merits special attention, and recent literature has also highlighted the existence of an eighth benefit.

5.1.1 *The seventh benefit: further evidence*

At the time of the last review, the seventh benefit was a new addition to the previous list. It was recognised that there is a growing need for firms to have knowledge about the social and regulatory pressures which will partly determine whether innovations succeed or fail. For instance, public reactions to new technologies can affect their trajectories (see GECP 1999). Public research already provides some of this information. Since that time, one paper has reviewed arguments in this area (Scott 2001), noting early statements by several high-profile authors (Giddens 1987; Gibbons, Limoges et al. 1994) but also finding that mainstream empirical innovation research still seems to ignore these benefits. However, some evidence on the use of social knowledge is beginning to emerge. For example, Fritsch and Schwirten found that about 45% of research institutions had collaborated with industry around the ‘analysis of environment/framework for innovations’ (Fritsch and Schwirten 1999). Unfortunately, they do not discuss this result in the text.

5.1.2 *A new benefit: Access to unique facilities*

The new addition to the list of benefits is where industry gains access to unique facilities held and developed at universities. It is distinct from the creation of new instrumentation, where that instrumentation and associated techniques become widely disseminated for use and development in industry (Arnold and Thuriaux 2001). This is confirmed by other recent evidence from in-depth studies of links between university spin-off firms and universities (Rappert, Webster et al. 1999), and by survey evidence in Germany, where it was found to be the ‘most frequent type of relations between firms and science (30%)’ (Kaufmann and Todtling 2001).

5.2 *Research as a source of strategic value*

As well as providing the tangible benefits outlined above, publicly funded research is also a source of strategic value by helping to improve the system-wide:

- capability (such as qualitative research skills)
- variety (the creation of options and diversity)

5.2.1 *Research as Capability*

Knowledge and research skills can be seen as capabilites embodied in researchers and the institutional networks within which they work. Scientific knowledge requires a substantial capability on the part of the user – both in research and in the application of knowledge, as acknowledged in a recent policy statement by the European Commission (European Commission 2000b). Conceição and Heitor note that 'good ideas are useless if the skills needed to use them do not exist'.(Conceição and Heitor 1999). The importance of firm-level capability for innovation is now widely recognised and its assessment is becoming a standard research task, as witnessed by various recent studies (Bowonder and Richardson 2000; Kaufmann and Todtling 2001).

5.2.2 *Variety*

Public funding for research plays an important role in supporting the creation of diverse options. Variety is a vital feature of flexible innovation systems. The value of variety or diversity becomes clear when the problem of uncertainty and ignorance is considered. Society is subject to uncertainty about future opportunities and threats. Variety is widely regarded as a desirable attribute in the context of an uncertain future (see Stirling 1998 for a review of the literature on diversity).

Recently, Conceição and Heitor's research has led them to conclude that the variety of demands being placed on universities is a reason to believe that the higher education system itself also needs to be diversified (Conceição and Heitor 1999). Similarly, Kaufmann and Tödtling's research led them to argue that 'crossing the border to science, in particular, increases the diversity of firms' innovation partners and respective innovation stimuli which, in turn, improves the capability of firms to introduce more advanced innovations' (Kaufmann and Todtling 2001: 791). They conclude that 'It is of crucial importance that the systemic diversity is maintained in order to improve the innovative performance of the involved firms. As a consequence, attempts to reduce barriers blocking cooperation between institutions belonging to the two systems should not try to make all the operating principles of science-linked organizations similar to those of the business sector' (ibid: 802).

5.2.3 *Capability and variety – capacity in an innovation system*

Capability and variety combine to determine the capacity within a firm or innovation system. An influential study suggested that R&D undertaken within firms has two functions: it allows firms to create new knowledge, but it also enhances their ability to assimilate and exploit existing external knowledge. The authors refer to this 'second face of research' as the firm's 'absorptive capacity' (Cohen and Levinthal 1989). Various studies have begun to use the notion of capacity (Kinder and Lancaster 2001), or confirmed the need to assess the absorptive capacity of firms (McMillan, Narin et al. 2000).

In summary, these themes of capability, variety and capacity outline the main sources of strategic value provided by public research.

5.3 Channels of communication between universities and the economy

In order for the benefits of university research to be expressed in the economy, the university research system has to be connected with the economy. Much of the economic literature assumes that such connections come about as a result of 'spillovers' – side effects or 'externalities' of public research.

This idea has been criticised by a number of authors for tending to 'black box' the specific mechanisms through which knowledge can flow (David and Hall 2000; Breschi and Lissoni 2000). The specific mechanisms of linkage need to be analysed (Rappert, Webster et al. 1999). The literature reveals a variety of channels – formal and informal, direct and indirect, deliberate and unplanned – through which these connections come about (Cohen, Nelson et al. 2001; David and Hall 2000; Bozeman 2000; Faulkner and Senker 1994; Faulkner and Senker 1995). Channels also can be characterised in terms of whether their effect changes over time and whether they are affected by geographic proximity. For example, Arundel and Geuna have investigated the effects of proximity between public research organisations and firms (Arundel and Geuna 2001). They show that the larger the investment in higher education R&D and the higher the number of publications produced in a country, the higher is the importance assigned to national sources of public research by the largest R&D intensive EU firms.

In this section we review the evidence discussing channels of communications, dwelling especially on the recent evidence.

The principal channels identified in the literature can be grouped as:

- Codification/artefacts: publications, patents, prototypes
- Cooperation: joint ventures, personnel exchange
- Contacts: meetings and conferences, informal interaction, science parks, industrial liaison offices, and funded networks
- Contracts: licenses, contract research, consulting.

We will analyse the latest information on each of these channels in turn. Other links identified only recently, or for which there is only limited evidence include those found in a study of the links between university spin-off firms and universities (Rappert, Webster et al. 1999):

- Contacts: customer links (universities as customers), sponsored university posts, studentships, part-time teaching
- Contracts: universities using equipment in spin-off firms, product testing, business support.

As can been seen, these links potentially provide benefits in both directions, indicating yet further evidence of the complexity of university-industry relations. Again, while the limited amount of evidence indicates that there are significant factors here, it restricts our ability to provide more in-depth analysis at this time.

5.3.1 Codification/artefacts

A first group of channels can be thought of as those that involve the transmission of ideas, information, and designs by means of codification (normally in the form of documents, but also by means of artefacts). These channels include publications, patents and prototypes.

5.3.1.1 Publications

According to the linear model, public research produces information which then feeds into industry and benefits processes of innovation. The recent consensus about the limitations of the linear approach does not mean that this function is no longer significant – merely that it is inadequate to describe the whole range of benefits and relationships. Publications remain an important channel for the communication of new information generated by public research, and a range of studies continue to add to our understanding of the significance of publications as a channel for such communication between research and a range of industries.

Cohen, Nelson and Marsh have recently found that nearly 30% of R&D managers in industry cited publications from public research as a useful input into their projects within the past three years (Cohen, Nelson et al. 2001), in industries as varied as petroleum, pharmaceuticals, aerospace, communication, and semiconductor industries (ibid: 11-12). Similarly, Arundel and Geuna (2001) found that publications are the methods to obtain the results of public research most frequently cited as important. Interestingly, firms in low-tech sectors give their highest score to publications more often than firms in medium and high-tech sectors.

Firms also use publications as a method of detecting expertise within public research organisations. Subsequent direct contact with the researchers can augment and facilitate the use of the published information.

By publishing in the scientific literature themselves, firms and syndicates also use scientific publications to signal their needs for fundamental research (see for example Slangen 2000).

5.3.1.2 Patents

If universities are producing useful knowledge, and are to be encouraged to commercialise this knowledge, they need to have incentives to do so and the ability to protect their intellectual property. So runs the argument behind the establishment of legislation such as the 1980 Bayh-Dole Act in the US, under which universities and other research institutions are able to patent their own inventions (Mowery, Nelson et al. 2001a). Patents also help to signal university expertise, encouraging fruitful relationships with industry.

By analysing the publications cited in patents, researchers have been able to build up a picture of the use of academic output in innovation activities (Tijssen 2001). The existence of a patent does not necessarily mean that the invention will be used in a successful innovation and are likely to signify causal links in only a limited number of cases (Tijssen 2001: 39). Nevertheless, the patterns of publications cited in patents have been used by authors as a proxy indicator of university-industry links. For example, Narin and colleagues find that patents are citing publications almost as quickly as the scientific literature (Narin, Hamilton et al. 1997) and that these links grew three-fold in recent years. Mowery and Sampat give some useful background history of patenting in the US (Mowery and Sampat 2001b).

Some research certainly confirms the importance of patents as a means of knowledge communication between public research and firms, with one survey finding 50% of R&D managers in the pharmaceutical industry reporting patents to be at least a moderately useful source of information for their projects within the past three years (Cohen, Nelson et al. 2001). McMillan and colleagues find that biotechnology firms cite public research in 83% of their patents, compared to 79% of pharmaceutical firms (McMillan, Narin et al. 2000).

5.3.1.3 Prototypes

The production of prototypes valuable for industrial innovation is a benefit of public research that has received little attention in the literature, and no focused research of its own that we are aware of. However, some survey-based research has found some evidence that prototypes can be a significant channel/benefit of public research in some industries. One survey of industry R&D managers asked them to report how many R&D projects made use of prototypes (among other things) generated by public research (Cohen, Nelson et al. 2001). They found that although across all industries, the 'weighted average for the percentage of R&D projects using prototypes generated by public research is only 8.3%' in three industries – glass, TV/radio and motors/generators – 20-35% reported their use. Further, 10-20% reported their use in three other industries – drugs, machine tools and aerospace (ibid: 11). As reported by Jensen and Thursby, there is also a close link between prototypes and the licensing of university technology (Jensen and Thursby 2001).

5.3.2 Cooperation

The second category deals with channels that essentially involve cooperation between universities and industry. At present this includes joint ventures and personnel exchange.

5.3.2.1 Joint ventures

Recent commentators note that the management of R&D is increasingly about 'managing knowledge rather than simply managing its generation. Better management of knowledge is a key success factor for industry competitiveness' (Liyanage, Greenfield et al. 1999). This includes the management of 'knowledge external to the firm, and …knowledge transfers across research links' (ibid). One way of enhancing such knowledge transfers is through cooperation and joint ventures (OECD 1998), particularly when complex innovative activities reduces the likelihood that all necessary capabilities will be found in-house (Meeus, Oerlemans et al. 2001). Feller has found that 'university-industry cooperative R&D programs have become the dominant form of industry support of academic R&D' (Feller, 1997 in Behrens and Gray 2001: 180). Firms also cite access to public funds through joint research as one benefit of collaborating with universities (Rappert, Webster et al. 1999). Rahm and colleagues provide a thorough comparative review of R&D collaboration in the US, UK and Japan (Rahm, Kirkland et al. 2000), while a report of the US National Science Foundation also gives much useful information, including the state of play in developing indicators in the field of strategic research parnerships (National Science Foundation 2001).

A range of recent studies has sought to clarify the character and extent of collaborations between public research providers and commercial organisations. These include:

- the value of such collaborations for small start-up firms (Tapon, Thong et al. 2001)
- surveys in: specific areas of commercial activity such as software engineering (Mead, Beckman et al. 1999); and geographical regions (Fritsch and Schwirten 1999; Fritsch and Lukas 1997)
- case studies of specific collaborations and university-industry networks in the field of IT (Acampora 1999; Fuertes, Herrera et al. 1999); paper recycling (Hardie, Leichtle et al. 1999); electric gun development (Kolkert and Jamet 1999); the metals industry (Degischer, Prader et al. 2001; Conard 2001; Wolf 2000); mining (McAllister, Scoble et al. 1999); aerothermodynamics (Muylaert, Kordulla et al. 2001); wind profiler radars (Nash and Oakley 2001); the use of artificial intelligence in the oil and gas industry (Neuroth, MacConnell et al. 2000); the development of curricula in the pulp and paper industry (Paris and Yelon 1999); innovative learning technologies (Pea, Tinker et al. 1999); trucking operations (Taylor, Meinert et al. 1999); and energy use in the sugar industry (Urbaniec, Zalewski et al. 2000) among others.
- cases where a lack of effective networking is: preventing the efficient flow of information and is therefore leading to commercial problems (Barja and Toranzo 1998); or inhibiting the design of effective and relevant curricula (Barnes 1999; Ducrotoy, Shastri et al. 2000; Kramers 1999; Wolf 2000); or limiting the effective functioning of European science and technology policy (Grande and Peschke 1999).

There is also a small but significant literature which investigates the unintended negative consequences of cooperative research. Behrens and Gray review this literature, and were only able to find four empirical research reports – 'as opposed to opinion or theory pieces' (Behrens and Gray 2001). Their survey-based research on graduate students found no reason to believe that industrial links were threatening academic freedom. However, others have found more cause for concern (Geuna 2001).

Recent analysis provides some intriguing insights. An investigation into the effects of university collaboration in Advanced Technology Programme projects in the US found, on the basis of a survey (which the authors acknowledge to be relatively small and needs to be interpreted with caution) that projects with university involvement tend to be experiencing more problems than other projects along two dimensions:

- acquiring and assimilating basic knowledge for the project's progress
- delays in commercializing the technology than expected at the start.

But far from interpreting this 'to mean that university involvement is creating research problems…We eschew that interpretation and conclude, albeit cautiously, that university involvement is creating a greater awareness of research problems than would otherwise be the case. We base our interpretation on the fact that ATP-funded projects with university involvement are less likely to terminate early compared to projects without university involvement' (Hall, Link et al. 2000).

Similarly, analysts in Germany have concluded, on the basis of a large survey of firms, that collaborations with universities 'stimulate or enable firms to introduce more advance innovations … 'pure' science seems to be more effective in stimulating advanced innovations than applied research focusing on commercialization' (Kaufmann and Todtling 2001).

Analysis of scientific publication trends has continued to demonstrate the growing significance of co-authorship between researchers in universities, firms, government departments and other organisations such as hospitals (see Okubo and Sjoberg 2000 for evidence from Sweden). Other authors have used similar data for Canada to show a near doubling between 1980 and 1995 in the collaborative publications produced by universities and government, and universities and industry. But rather than finding that the increasing diversity of co-authors is a sign of a reduced significance of universities, these analysts argue that universities are increasingly significant players in the publication of scientific papers (growing from 75% in 1980 to 82% in 1995): 'Universities are thus more than ever at the heart of the system of knowledge production' (Godin and Gingras 2000).

Adams and colleagues find Cooperative Research and Development Agreements (CRADAs) to be the main channel through which federal labs 'increase the patenting and R&D of industrial laboratories' (Adams, Chiang et al. 2000). They find that 'with a CRADA, industrial laboratories patent more, spend more on company-financed R&D and spend more of their own money on federal laboratories'. They conclude that 'these results are consistent with the literature on endogenous R&D spillovers, which emphasizes that knowledge spills over when recipients work at making it spill over'. Since CRADAs are legal agreements, they may be beneficial 'precisely because of the mutual effort that they require of firms and government laboratories'. It is worth noting that attempts to quantify the direct benefits of CRADAs have been criticised as unreliable. Citing Ham and Mowery (Ham and Mowery 1998), Bozeman notes: 'most of the benefits accruing are 'indirect and generic'. Thus, the transfer recipients indicated that 'the CRADA contributed to their overall technical capabilities, rather than benefiting any single product'(p670)' (Bozeman 2000).

5.3.2.2 Personnel exchange

The value of personnel exchange between universities and industry is sparse, but has been picked up by Fritsch and Schwirten, who find that in a selection of German research institutions, around 30% have seconded personnel into industry, while 10-20% of firms have seconded personnel to a variety of research institutions (Fritsch and Schwirten 1999). Some of this was related to ensuring job opportunities for students.

5.3.3 *Contacts*

A common theme in the literature is that interactions between public researchers and their counterparts in firms are required in order to build strong relationships and effective communication: 'The most important channels for accessing public research appear to be the public and personal channels (such as publications, conferences and informal interactions), rather than, say, licenses or cooperative ventures' (although these authors do also acknowledge the importance of consulting) (Cohen, Nelson et al. 2001: 3),.

These contacts can be brought about through a number of mechanisms, some deliberate and some which arise as a systemic consequence of high levels of funding for public research. Firms realise the benefits of being located in areas where such interactions can come about, and authors such as Pavitt have cited the ability to attract large firms to locate as one reason for funding high quality academic research (Pavitt 2000). In this section, we review the recent evidence on the various channels for establishing contacts between public sector research organisations and firms.

5.3.3.1 Supporting new scientific networks and stimulating interaction

Networks and informal interaction are both a channel and a benefit of the public funding of research: they mostly come about as a natural side effect of the funding of public research, although the establishment of professional research networks is also sometimes assisted with deliberate funding from research and other organisations. Networks and informal interaction serve as a vital channel for the flow of ideas and information.

A growing number of researchers find informal interaction and networks to be vital in the exchange of knowledge (Foray and Lundvall 1996; Luukkonen 1998; OECD 1998; Miyata 2000). Conceição and Heitor note the 'very recent appearance of attempts to analyse the economic implications of learning processes that result from social interaction' (Conceição and Heitor 1999). One reason for keeping contacts between universities and firms, even when there is no immediate benefit, is to maintain the goodwill that is essential to 'aid future linkage and recruitment' (Rappert, Webster et al. 1999). Similarly, networks that linked university spin-off firms with universities was beneficial for personal social reasons and 'keeping staff happy'. This is similar to Florida's perspective that knowledge workers 'want to be around other smart people' (Florida 1999).

The importance of social networks has been picked up by research into the international movement of highly skilled labour. For example, research on Mexican and Indian workers in Silicon Valley found that 'The recruitment and hiring of these workers underscore the importance of the operation of social networks. They either worked for subsidiaries of US companies located abroad or were students at US universities'. (Alarcon 1999).

Networks are often 'heavily influenced by proximity and by social and cultural factors (e.g., Pavitt 1998), and constitute an important factor in the geographical constraints on technological innovation (e.g. Jaffe 1989)' (Tijssen 2001). Fritsch and Schwirten found personal contacts to be very important in relationships among universities and firms: around 80% of survey respondents mentioned informal contacts as important, while nearly 40% of initial contacts came about through personal links (Fritsch and Schwirten 1999). Other research has focused upon the role of product developers within firms, and has confirmed the significance of their contacts with others involved in R&D, education and technology transfer (Balthasar, Battig et al. 2000).

5.3.3.2 Science parks

Part of the argument for science parks is provided by the idea of 'localised knowledge spillovers'. The key argument in this literature is that firms operating near sources of knowledge such as universities can 'introduce innovations at a faster rate than rival firms located elsewhere' (see relevant reviews by Martin 1999; and Feldman 1999). Breschi and Lissoni provide an overview of the developing literature in this field, as represented by 'influential case studies on hi-tech clusters in the US (Saxenian 1994; Storper 1995) or industrial districts, learning regions and 'milieux innovateur in Europe (Cossentino, Pyke et al. 1996; Camagni 1991; Camagni, 1995, see also Phelps 1992 for a critical survey)'.

Science and technology parks can also provide specific support services needed by new firms, such as coaching in key capabilities, advice from trusted sources, and access to sources of help in areas such as finance (von Waldkirch 2000). By setting up specific locations with suitable infrastructure and attractive environments, governments can attract industrial firms, and the staff that underpin their success, to locate near science parks.

However, not all authors are uncritical of the science park approach. As Phillimore writes: 'Science and technology parks have been criticised for relying on an outdated, linear, model of innovation, which assumes that scientific knowledge can be transferred unproblematically from a research university to an adjacent Park for development' (Phillimore 1999). Phillimore assesses the interactions going on between firms on science parks and researchers, and concludes that 'there is more interaction occurring than might be estimated using the traditional evaluative model'.

The recent literature on science parks can be characterised as follows:

- Single case studies, typically reporting successes, setting out the benefits of the science park approach, and providing a (usually) uncritical summary of information about the case in question (Brown 1999; Buratti and Penco 2001; Efferth 2000; Lee and Yang 2000; Ongini 2001; Petroni and Verbano 2000; Shin 2001; von Waldkirch 2000).
- Empirical studies that have sought to test hypotheses about the role of science parks in creating employment or boosting the profitability of firms in the parks (Doloreux 1999; Lofsten and Lindelof 2001; Shearmur and Doloreux 2000; Phillimore 1999; Felsenstein 1994). Many of these find rather negative or inconclusive evidence for such benefits, but conclude that 'location in a science park …does confer status and prestige and these indirectly promote technology transfer and information flows' (Bozeman 2000). Others have sought to study the character and extent of the linkages between firms located on science parks and local academic institutions, finding evidence for a range of formal and informal contacts (Quintas, Wield et al. 1992). However, only a surprisingly low percentage of firms on science parks could be classified as 'university spin-offs'.
- Studies of a more critical kind, which seek to assess science parks in terms of their success record but also their wider benefits to the economy – some see science parks as having a negative impact by concentrating, rather than distributing, the skills needed in the knowledge (Massey, Quintas et al. 1992; Shearmur and Doloreux 2000). Others seek to characterise the type of region and other factors (such as low level of innovations from local university research) which determine the success of science parks (Miyata 2000).

In conclusion, the evidence about the effectiveness of science parks as a channel for linking universities to the economy is still relatively sparse. The literature in this field is particularly beset by the small amount of empirical research that has been conducted.

5.3.3.3 Industrial liaison offices and technology transfer institutions

Despite their existence in some universities since the 1970s, very little research has been conducted into the role and value of industrial liaison offices (ILOs). Only two articles were found in a search of 'web of science', and these similarly pointed to a lack of work in this area (Jones-Evans, Klofsten et al. 1999; Jones-Evans and Klofsten 1998).

They find that various authors have begun to define the various roles that ILOs can or should undertake: some interpreted narrowly – primarily as a switchboard – and others more broadly – by helping two-way communications between universities and the outside world such as, for example, identifying curriculum development needs. However, they find 'little information to suggest that ILOs are undertaking a pro-active role…and that, at most, industrial liaison offices at higher educational institutions are merely providing marketing services for their parent organisation' (ibid 49). They note evidence that contacts between researchers and their business counterparts are mostly undertaken directly, perhaps because of ‘unsatisfactory earlier experiences with comparable institutions’ (ibid: 49). However, they also note that university technology transfer activities are ‘most effective when resources go to activities that are carried out in close cooperation with external actors and when the clear purpose of those activities is to satisfy real needs’ (Jones-Evans and Klofsten 1998).

Other research conducted through surveys has picked up similar results: research in Germany found that only 4% of initial contacts came about through technology transfer institutions, a category that includes but also goes well beyond ILOs (Fritsch and Schwirten 1999). Kaufmann and Tödtling found similarly poor results for technology transfer organisations in Germany, with only around 5% of firms citing them as partners (Kaufmann and Todtling 2001). They take this to mean that ‘Many firms able to introduce advanced product innovations do not seem to need mediation’ (ibid: 801). Another study found that ‘successful institutions at the interface between science and industry do not consider themselves to be an institution for transfer but a network manager’ (Balthasar, Battig et al. 2000).

These analysts conclude that given the right level of resources, and effective links to other commercialisation activities such as patenting and licensing, ILOs could play a vital role in enhancing the mutual understanding and cooperation of university and industry but that their role is currently very limited.

5.3.4 Contracts

Formal contractual links between public sector research organisations and firms are an important category of relationships. In this section, we review the latest evidence about the variety and magnitude of such relationships and their success or otherwise.

However, before proceeding it might be useful to reflect on some of the wider debates in this area. There remains an important source of disagreement in the literature around one fundamental question: are public sector research organisations most effective when they are mainly involved in basic research, or should they also get involved in applied research and development? As several recent contributions by eminent analysts have pointed out, by emphasising the role of universities in basic research, US science policy since 1945 has tended to overlook the ‘direct contribution of universities to technical advance in industry’ (Crow and Tucker 2001; see also Nelson 1997 and).

These authors argue that this has caused a confused situation, where ‘universities have undermined efforts to support applied research and at the same time their funding quests have led to a rich mix of applied research despite the system’ (Crow and Tucker 2001: 2). They note that the architect of this situation, Vannevar Bush in his influential book ‘Science, the Endless Frontier’ (Bush 1945), deliberately ‘chose to de-emphasize the university as a performer of anything other than basic research…in the face of conservative elements concerned with the ‘crowding out’ effect of public investment in applied research’ (Crow 2001: 3). This position was also a convenient means of arguing autonomy for universities. The success of this argument ‘has left little room for understanding the variety of ways in which university research supports industrial development…Despite the reality that…universities were involved in industrially relevant research, this has never been thought through in terms of a coordinated technology policy’ (ibid:8). Applied research has succeeded ‘despite the system, not because of it’ (ibid: 8).

These sorts of confusions are apparent in the literature about contractual relationships between public sector research organisations and industry. Despite evidence that such links are growing, analysts still continue to conclude that universities should restrict themselves to basic research (see for example Miyata 2000). Against this, some argue that far from ‘knowledge spillovers’ being an accidental by-product of basic research in the public sector, many ‘are actually well-regulated knowledge flows between academic institutions (or individuals therein) and firms. A large amount of the knowledge flowing this way has much more to do with enhancing the innovation appropriability strategies of local companies (by speeding up the development phases of new products and services) rather than innovation opportunities (by providing them with new ideas)’

(Breschi and Lissoni 2000). The job for analysts should perhaps be to assess the effectiveness of university involvement in basic *and* applied research: the latter seems to receive much less attention than the former (Crow and Tucker 2001).

Similarly, Cohen, Nelson and Walsh found that public research played 'a slightly more important role overall as a knowledge source for R&D project completion rather than for project initiation, with 36% of respondents reporting public research as a source of knowledge for this former function versus 32% for the latter. This suggests that, at least as often as not, public research provides the means to achieve some technological goal…' (Cohen, Nelson et al. 2001: 8-9). These scores exceed 50% for a range of significant industries including food, drugs and aerospace.

5.3.4.1 Licenses

When university research leads to technical innovations, one route to commercialisation is to license the technology to other firms, rather than try to exploit the technology in a direct way. This is a recent university activity, and evidence about its impact is limited. The key questions here are: which areas of university research are most likely to lead to licensing potential, how can universities best organise their licensing activities, and how much revenue from licenses can be expected? Some caution is needed, as some argue against the formalisation of university-industry links (Rappert, Webster et al. 1999): 'large firms resist university control over intellectual property in order to control the rights for themselves' (ibid: they cite Webster and Packer 1996), (while) smaller firms opposed this as it reduced the flexibility, informality and trust-based nature of their relationships with their university counterparts'.

Pharmaceuticals and biotechnology seem to be the areas with the most licensing activity at present (Miyata 2000). Miyata also suggests that while an exclusive license 'may result in greater license revenues… (an) unexclusive licensing policy may…enhance competition among licensees, …and thus (lead to) a greater amount of license revenue' (ibid: 422, brackets added). This author found that around 50% of licensees are small firms (less that 500 employees), 40% are large firms and 10% are start-ups, although these percentages vary by university type. Similarly, a survey in the US found that 35% of R&D managers in the pharmaceuticals sector had found license agreements with public research organisations to be at least moderately useful for their projects in the past three years (Cohen, Nelson et al. 2001). Other industries reporting at least 10% include steel (18%), cement (30%), medical equipment (17%), glass (17%), petroleum (11%) and food (11%).

These authors that have investigated university licensing have found that while they can in certain notable cases provide useful income for the university, they are unlikely to form a significant proportion of their total budget in the foreseeable future.

5.3.4.2 Contract Research

It is easy to overstate the value of industry funding for university research. Recent figures for the US show that such funding has remained stable at around 6% of total funding since 1985, similar to the figure for 1960 although higher than the intervening years when it was closer to 3% (Miyata 2000). Funding from non-profit organisations is higher at around 7%, while university internal funds have grown from 10% in 1960 to around 18% in 1995. Local government funding has fallen consistently over the years from 13% to around 7%, while federal government funding has remained constant at around 60-65%.

Miyata finds that 60% of US industry funding for university research is for basic research. However, he cites other authors who found the proportion to be 41%, with applied research accounting for 43% and development 16% (Cohen, Florida et al. 1994). Citing Cohen et al, one reason offered for the 'large share of basic research at universities … is that university personnel conduct development which is close to commercialization off-campus by establishing their own start-up firms, so on-campus research remains basic research' (Miyata 2000; Cohen, Florida et al. 1998). Yet again, establishing cause and effect is not a simple task.

5.3.4.3 Consulting

Until recently, little research has been conducted on the role and value of university-based consulting as a channel of communication between universities and industry. This has recently been confirmed by pilot research by one of the authors of this report: among interviewees involved in organising some of the most successful university consulting units in the UK, all but one reported that they had never before been contacted by researchers investigating this issue (and the one who had was contacted by a researcher not focusing specifically on consulting).

However, consulting has begun to be mentioned by analysts who have studied university-industry relationships by means of surveys and case studies. As stated by Cohen and colleagues: 'The relatively high score for consulting underscores the importance of this little-studied vehicle through which public research impacts industrial R&D. Both more and less R&D intensive industries consider consulting to be important' (Cohen, Nelson et al. 2001). They later note that, on the basis of the evidence, they consider consulting to be one of the most important channels of information flow between public research and industry (p.29).

Similarly, in older evidence, Rahm found that, based on a survey of 1000 academics across 100 top universities, 75% of those engaged in 'technology transfer' activities were involved in consulting. Even among those researchers not classified as being active in technology transfer, Rahm still found that 26% were involved in consulting (Rahm, 1994 #2 cited in Bozeman 2000). In a study of university-industry links in three German regions, Fritsch and Schwirten found that nearly 80% of universities and other research institutions were involved in consulting and report-writing activities (Fritsch and Schwirten 1999). Poti provides some evidence for the significance of university consulting in a survey of innovation activity in Italy (Poti 1998), while Lee also finds evidence for this in the US (Lee 1996), and Klofsten and Jones-Evans find evidence in Sweden and Ireland (Klofsten and Jones-Evans 2000).

In the UK, Howells and colleagues found university consulting to be an important channel for linking with firms. Their analysis dwelled principally on the factors motivating and inhibiting consultancy links, but they omitted to give any data on the prevalence and significance of consulting (Howells, Nedeva et al. 1998). Others find substantial evidence of consulting links between university spin-off firms and universities (Rappert, Webster et al. 1999).

5.4 Conclusions: channels of communication

In conclusion, a range of channels for communication exist between public research and the private sector. The focus on channels has become more significant since the production of the last review, hence the emphasis in this report. So far as we know, this review is the first attempt to bring together all the recent evidence about these channels.

By enhancing the capabilities in the economy – and it is important not to forget the vital linkage between research and higher education teaching, which in turn ensures a flow of skilled graduates into the economy – public research underpins the capabilities of the private sector. By creating and maintaining variety, public research helps maintain the diversity of options vital to a flexible innovation system.

The existence of a great many channels of communication between the research sector and firms, and the evidence that firms see many of these as important mechanisms for deriving value from public research, would indicate that this line of enquiry could be fruitful for future. Evidence on many of the channels remains sparse, especially for those identified only recently. This restricts our ability to inform policy decisions.

Such evidence as does exist, however, demonstrates the many ways in which research benefits the economy, albeit in ways that are difficult to quantify in economic terms. This leads us to conclude that the benefits of public research are probably significantly higher than narrow calculations of the returns to public research would suggest.

6 Appendix A: Sources searched

http://meritbbs.rulimburg.nl/rmpdf/rmlist.html

http://www.business.auc.dk/druid/wp/wp.html

http://les.man.ac.uk/cric/papers.htm

http://www.rand.org/

http://www.isi.fhg.de/homeisi.htm

http://www.step.no/

http://www.google.com with relevant key words

SPRU resources including the Electronic Working Paper Series at www.sussex.ac.uk/spru

Stanford Institute of Economic Policy research

OECD online sources

US National Bureau of Economic Research

US National Institute of Standards and Technology (NIST)

Web of Science with relevant key words and phrases

Last two years of the following journals:

American Economic Review

Economics of Innovation and New Technology

Industrial and Corporate Change

International Journal of Industrial Organization

Journal of Applied Economics

Journal of Industrial Economics

R&D Management

Research Policy

Review of Economics and Statistics

Science and Public Policy

Scientometrics

Technology Analysis and Strategic Management

Technovation

Weltwirtschaftliches Archiv

7 Appendix B

TABLE 4: OUTPUTS AND OUTCOMES OF NIST LABORATORY RESEARCH

Industry: project	NIST OU[1]/Year	Output	Outcomes	Measures[2]
Semiconductors: resistivity	EEEL/1981	Test methods	Increase productivity	SRR: 181% BCR: 37
Semiconductors: thermal conductivity	EEEL/1981	Materials properties test methods	Increase R&D efficiency lower transaction costs	SRR: 63% BCR: 5
Semiconductors: wire bonding	EEEL/1981	Test methods	Increase productivity increase R&D efficiency	SRR: 140% BCR: 12
Communications: electromagnetic interference	EEEL/1991	Test methods	Lower transaction costs	SRR: 266% BCR:
Semiconductors: electro migration	EEEL/1992	Test methods	Increase R&D efficiency transactions costs	SRR: 117%
Photonics: optical fiber	EEEL/1992	Test methods (acceptance)	Lower transaction costs	SRR: 423% BCR:
Automation: real-time control systems	MEL/1995	Generic architecture	Increase R&D efficiency	SRR: 149% BCR:
Energy: electric meter calibration	EEEL/1995	Test methods (calibration)	Lower transaction costs	SRR: 117% BCR: 12
Communications: ISDN	ITL/1995	Interoperability standards	Lower transaction costs	SRR: 156% BCR:
Computers: software conformance	ITL/1995	Test methods (acceptance)	Lower transaction costs	SRR: 41% BCR:
Photonics: spectral irradiance	PL/1995	Test method (calibration)	Increase productivity lower transaction costs	SRR: 145% BCR: 13
Construction: building codes	BFRL/1996	Technical basis for standards	Energy conservation energy cost savings	SRR*: 57% BCR:
Construction: roofing shingles	BFRL/1996	Materials properties	Increased durability	SRR*: 90% BCR:
Construction: fire safety evaluation system	BFRL/1996	Technical basis for standards	Lower compliance costs	SRR*: 35% BCR:
Automation: machine tool software error compensation	MEL/1996	Quality control algorithm	Increase R&D efficiency increase productivity	SRR: 99% BCR: 85
Materials: thermocouples	CSTL/1997	Standard reference data (calibration)	Lower transaction costs increase product	SRR: 32% BCR: 3

			quality	
Pharmaceuticals: radiopharmaceuticals	PL/1997	Standard reference materials	Increase product quality	SRR: 138% BCR: 97
Photonics: optical detector calibration	PL/1997	Standards and calibration services	Increase productivity	SRR: 72% BCR: 3
Chemicals: alternative refrigerants	CSTL/1998	Standard reference data	Increase R&D efficiency increase productivity	SRR: 433% BCR: 4
Materials: phase equilibria for advanced ceramics	MSEL/1998	Standard reference data	Increase R&D efficiency increase productivity	SRR: 33% BCR: 10
Semiconductors: software for design automation (IGBT semiconductors)	EEEL/1999	Software model	Increase R&D efficiency increase productivity	SRR: 76% BCR: 23 NPV: $10M
Pharmaceuticals: cholesterol measurement	CSTL/2000	Standard reference materials	Increase productivity decrease transaction costs	SRR: 154% BCR: 4.5 NPV: $3.5M
Photonics: laser and fiberoptic power and energy calibration	EEEL/2000	Calibrations	Increase productivity decrease transaction costs	SRR: 43%-136% BCR: 3-11 NPV: $48M
Electronics: Josephson voltage standard	EEEL/2001	Standard reference materials	Increase R&D efficiency Increase productivity Enable new markets	SRR: 877 BCR: 5 NPV: $18M
Chemicals: srms for sulfur in fossil fuels	CSTL/2000	Standard reference materials	Increase productivity reduce transaction costs	SRR: 1,056% BCR: 113 NPV: $409M
Communications: security (data encryption standards)	ITL/2001	Standard; conformance test methods/ services	Increase R&D efficiency Enable new markets	SRR: 267-272% BCR: 58-145 NPV: $345M-$1.2B
Communications: security (role-based access control)	ITL/2000	In progress		SRR: BCR: NPV
Chemicals: National Traceable Reference Materials Program (NTRM)	CSTL/2000	In progress		SRR: BCR: NPV:
Manufacturing: standards for product data exchange (STEP)	MEL/2001	In progress		SRR: BCR: NPV:

[1] **NIST Laboratories (OUs):**
EEEL: Electronics and Electrical Engineering
MEL: Manufacturing Engineering Laboratory
CSTL: Chemical Science and Technology Laboratory

PL: Physics Laboratory
MSEL: Materials Science and Engineering Laboratory
BFRL: Building and Fire Research Laboratory
ITL: Information Technology Laboratory

[2] **Measures:**
SRR: social (internal) rate of return
SRR*: social (implied) rate of return
BCR: benefit-cost ratio
NPV: net present value

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Source: (Tassey 2001)

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