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International Encyclopaedia of the Social and Behavioural Sciences

Organisational and Management Studies

"Research and Development"

by

Keith Pavitt

1. INCREASING DIVISION OF LABOUR IN KNOWLEDGE PRODUCTION AND USE

The growth of Research and Development activities (R & D) reflects the increasing division of labour in the production and use of scientific and technological knowledge - a process foreseen by Adam Smith at the beginning of the Industrial Revolution. Since then, professional education, the establishment of laboratories, and improvements in techniques of measurement and experimentation have progressively increased the efficiency of discovery, invention and innovation (Price, 1984; Mowery and Rosenberg, 1989). Three complementary forms of specialization have developed in parallel, each contributing to the growth of R & D.

1.1 Specialisation by discipline: the growth of science and engineering

First, progress and specialisation in scientific disciplines accelerated in the 19th century with the development of more powerful research tools and techniques. Increasing opportunities for application also led to the emergence of the engineering disciplines: hence chemical engineering in addition to applied chemistry, and electrical engineering in addition to applied physics (Rosenberg and Nelson, 1994). The differences in timing of the emergence of new opportunities for innovation reflected radical but uneven improvements in the knowledge base underlying technological change, and in particular the emergence of new technological paradigms (Freeman et al, 1982, Dosi, 1982).

The mechanical paradigm was the basis of the Industrial Revolution. It did not grow out of contemporaneous scientific advances, but of improvements in the quality of metals and the precision with which they could be formed and machined. These enabled the *design, development and testing* of prototypes of families of machines with greatly improved performance based on materials of homogeneous and predictable quality, and on shapes with compatible sizes. Similarly, the initial improvements in metals processing technologies depended less on scientific understanding than on *development* activities, experimenting with different alloys and processing conditions in pilot plant. Even today, such development activities in prototypes and pilot plant typically account for about three quarters of the R & D expenditures of private business firms and for about two-thirds of total R & D.

1.2 Specialisation by corporate function: the growth of business R & D

The science-based chemical paradigm (based increasingly on synthetic chemistry) and the electrical paradigm (based on electro-magnetism and radio waves) laid the basis for the industrial R & D laboratory, initially in the chemical and electrical firms in Germany and the USA. Many of the initial applications - like the use of techniques of chemical analysis to control the quality and composition of materials in the increasingly large-scale processing industries - were relatively mundane, but very profitable in reducing costs. Management progressively learned that the science-based technological opportunities were applicable over a range of existing and new product markets, and therefore opened up opportunities for what is now called 'related' product diversification. Mowery and Rosenberg (1989) have described the spread of the establishment of R & D laboratories in the USA from the chemical industry to other sectors, and from larger to smaller firms. Similar processes have been at work in Europe (Caron et al., 1995; Nelson, 1993) and more recently in East Asia (Odagiri and Goto, 1996).

Thus, in addition to the benefits of the cognitive division of labour into more specialized fields, the functional division of labour within business firms also augmented the rate of technical change. Corporate R & D laboratories and similar groups devoted full-time to inventive and innovative activities provided an effective method for creating, combining and co-ordinating increasingly specialized knowledge. They provided improved and specialized instrumentation, which enabled firms to monitor and benefit more systematically and effectively from advances in specialized academic disciplines. They also created skills in the development and testing of laboratory concepts and prototypes, and the translation into commercialized products. Firms were able to experiment with a wider range of products and processes than had previously been possible when constrained by established products and production lines. In fields rich in technological opportunity, firms have in consequence become multi-product as well as multi-technology.

Technological paradigms have been associated with the emergence of large dynamic firms that have been successful in exploiting the new opportunities. The largest R & D spenders today are in companies that grew with the emergence of the mechanical (and automobile), chemical and electrical-electronic paradigms. Aerospace is a special case, having been technologically force-fed, especially since World War Two, by government R & D subsidies and procurement linked to military requirements. The fastest growing R & D spenders today are those closely associated with ICTs and software technology.

1.3 Specialization by institution: the growth of academic research

In the 19th century, de Tocqueville forsaw that the dynamics of capitalist competition would greatly stimulate the development of innovative activities that showed the prospect of a commercial return. He also argued that public authorities would need to support complementary public research of a more fundamental nature, in order to avoid diminishing returns, to open up new opportunities, and to provide trained researchers. This has happened too. In all advanced countries governments have become the main source of the funding of research activities, and related post-graduate training, in universities and similar institutions. Corporate R & D laboratories have come to depend increasingly on a supply of scientists and engineers aware of the latest research results, and trained in the latest research techniques (Salter and Martin, 2001)

1.4 R & D and modernisation

This historical pattern of specialisation and growth in knowledge production has been broadly repeated in the processes of modernisation of late-coming countries, and is observable in countries at different levels of development today: R & D expenditures as a percentage of Gross Domestic Product (GDP) increase with GDP per head, both in specific countries over time, and in cross sections of countries at any point in time. In successful modernising countries, R & D is preceded by systematic business investments in improvement-generating activities: in particular, in production engineering, quality control and design activities, initially making minor modifications and improvements, and later becoming the basis for indigenous innovative activities (Lall, 1992; Bell, 1984). At this stage, business-funded R & D increases rapidly, accompanied by the growth of university-based research in underlying disciplines, with both reflected in the growth in the numbers of international patents and scientific papers. This pattern can be observed most clearly in both South Korea and Taiwan over the past 20 years.

The centrally planned Soviet model of modernisation, practised in the former USSR and imposed or adopted elsewhere, gave high priority to R & D. By the late 1950s and early 1960s, R & D expenditures in Central and Eastern European countries were apparently higher than those in Western Europe and the USA. Certain Western observers therefore concluded that the Soviet system was superior in promoting R & D and technical change. However, Soviet economic performance subsequently deteriorated, and it later become clear that a very high proportion of Soviet R & D was oriented towards weapons development, and that the government-established R & D laboratories established for each industry were decoupled from the requirements of producers and consumers (Hansen and Pavitt, 1987). The major reductions in R & D activities since their collapse in 1989 can be seen as painful adjustments to make R & D activities - and the underlying activities in production engineering, quality control and design - become an integral part of a process of economic modernisation (Dyker and Radosevic, 1999).

The Soviet system also had inadequate linkages with technical advance in the rest of the world economy. One important feature distinguishing today's modernising countries from those of the 19th century is the availability of more productive technologies in more advanced countries. Countries successful in assimilating these more advanced technologies have had two characteristics (Hobday, 1995): *first*, strong linkages with the more advanced countries' technology whether through inward direct investment (e.g. Singapore), inward technology licensing by locally owned firms (e.g. Japan, S. Korea), or subcontracting agreements from advanced country to local firms (e.g. Taiwan); second, the development of local, change generating activities, culminating in R & D activities, that were essential inputs to effective imitation, as well as to innovation (Cohen and Levinthal, 1987).

2. MEASUREMENT OF R & D ACTIVITIES

2.1 Patterns of R & D Activity

By the beginning of the 1960s, initiatives by the US National Science Foundation and the Organisation of Economic Cooperation and Development (OECD) had established common definitions of R & D activities, and led to the collection by governments of systematic data on R & D activities. These have since been complemented by privately funded surveys comparing the R & D activities of individual business firms. They show the following common and largely invariant features of R & D activities.

- In industrially advanced countries, business and government are the main sources of funds for R & D activities. Business funding is in general larger, and spent in-house mainly on *applied research and development* activities. Government funding is divided between *basic research* performed mainly in university-type institutes, and various types of R & D associated with health, the environment, defence, and the support of industry and agriculture. This R & D is performed mainly in the laboratories of government agencies and business firms.
- In the industrially advanced countries, the share of GDP typically spent on R & D varies between 1.5 and 3.0% of Gross Domestic Product (GDP), compared to 0.5 and 1.5% in the newly industrialising countries, and less than 0.5% in the rest. The share of national R & D funded and performed by business firms tends to increase along with GDP per head.
- More than 60% of all business-funded R & D is typically performed in the chemical, electrical-electronic and automobile industries. The largest individual corporate spenders on R & D are the world's leading automobile, electrical and ICT (information and communication technologies) firms.

2.2 The economic determinants and impact of R & D activities

The improved quality of R & D statistics has enabled economists and other analysts to deepen understanding of both the determinants and the economic impact of R & D activities, at the level of countries, industries and firms. A number of analysts have been able to show that - amongst the industrially advanced countries - differences in the levels and rates of growth of national R & D activities have a significant influence on differences in national performance in exports and productivity (Fagerberg, 1987, 1988).

At the industry level, considerable attention has been given to the effects of firm size and industrial structure on R & D activities. Given the dependence of specialisation on scale, the proportion of firms performing R & D increases with firm size. However, there is no clear consensus on how R & D intensity varies with firm size amongst large firms: evidence can be found either way (Cohen, 1995). And although R & D is found mainly in concentrated industries, there is compelling evidence that variations amongst industries in both the degree of concentration and R & D intensity are jointly determined by a third factor, namely, inter-industry variations in the extent of technological opportunities (Levin et al., 1985).

Less progress has been made so far in measuring the effects of differences in R & D expenditures on company performance. This is partly because comprehensive and comparable R & D data at the company level are only slowly becoming available. It is also because of the difficulty of defining a proper measure of corporate performance. Those used include the R & D production function, stock market evaluation, and long-term growth (Patel, 2000).

2.3 Limitations

Sections 3.1 and 3.2 show that statistics on R & D activities can be a useful proxy measure for innovative activities. But they have their limitations, the most often mentioned of which is that they measure inputs and not outputs. Equally, if not more important are the following:

- In large firms, R & D statistics do not measure the often considerable expenditures on complementary activities in production and marketing, that are necessary to transform the outputs of R & D into commercially successful innovations
- In small firms, they do not measure part-time innovative activities, which are particularly important in the machinery and software sectors.

- They capture only very imperfectly the growing volume of innovative activities in software now being performed in firms in service sectors, such as finance and distribution.

Other indicators of knowledge-generating and innovative activities have therefore been developed to complement R & D indicators, the most important of which have been counts of patents, papers, citations and numbers of innovations (Freeman, 1987; van Raan, 1988).

3. SOME CONTEMPORARY DEBATES IN R & D MANAGEMENT

Many of the characteristics and problems of managing corporate R & D have changed very little since the 19th century.

- The need to orchestrate and integrate specialised knowledge and skills across disciplines, professions, functions and divisions.
- The progressive improvement in fundamental scientific understanding, accompanying the increasing systemic complexity of innovations - a process that will continue with the more widespread application of the techniques emerging from ICT (information and communications technologies).
- The difficulty (impossibility?) of making reliable predictions about the success or otherwise of specific innovations, especially major ones.

At the same time, new problems and challenges have emerged.

- With increasing specialisation in both the production of knowledge, and of the components of increasingly complex systems, firms are faced with increasingly difficult choices about what products and knowledge to outsource, and what to retain in-house. An important part of the in-house R & D function is now devoted to the monitoring and co-ordination of innovative and production activities external to the firm.
- In addition to the well established function of supporting foreign production, large firms are performing a growing share of their R & D outside their home country, in order to tap into the increasingly numerous international sources of leading-edge scientific and technical advance. This poses new challenges for managers in integrating skills and

knowledge over long distances (Niosi, 1999), and for national policy-makers in assessing the location of the benefits of public investments in academic research.

- There is some evidence that academic research is becoming increasingly linked to commercial R & D activities. For some, this is the consequence of unwelcome financial pressure from governments on universities to demonstrate short term "relevance" in their research. For others, it is the consequence of fundamental changes in the locus of knowledge production. Other evidence suggests that reductions in the costs of technical experimentation through simulation software now makes it easier for academic researchers to develop and test experimental prototypes.

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Economics of Science

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Economics of Science (4.10.64)

Determining the principles governing the allocation of resources to science as well as the management and consequences of the use of these resources are the central issues of the economics of science. Studies in this field began with the assumption that science was a distinct category of public spending that required rationalisation. They have moved towards the view that science is a social system with distinct rules and norms. As the systems view has developed, the focus of the economics of science has moved from the effects of science on the economy to the influence of incentives and opportunities on scientists and research organisations.

There is a productive tension between viewing science as a social instrument and as a social purpose. In the first view, science is a social investment in the production and dissemination of knowledge that is expected to generate economic returns as this knowledge is commercially developed and exploited. This approach has the apparent advantage that the standard tools of economic analysis might be directly employed in choosing how to allocate resources to science and manage their use. In the second approach, science is assumed to be a social institution whose norms and practices are distinct from, and only partially reconcilable with, the institutions of markets. While this second approach greatly complicates the analysis of resource allocation and management, it may better represent the actual social organisation of science and the behaviour of scientists, and it may, therefore, ultimately produce more effective rules for resource allocation and better principles for management. Both approaches are examined in this article, although it is the first that accounts for the majority of the economics of science literature (Stephan 1996).

1. The Economic Analysis of Science as a Social Instrument

In arguing for a continuing high rate of public funding of science following World War II, US Presidential Science Advisor Vannevar Bush (1945) crafted the view that science is intrinsically linked to technological and economic progress as well as being essential to national defence. The aim of 'directing' science to social purposes was already well recognised, and had been most clearly articulated before the war by John D. Bernal (1939). What distinguished Bush's argument was the claim that science had to be curiosity-driven and that, in companies, such research would be displaced by the commercial priorities of more applied research. The view that science is the wellspring of economic growth became well established within the following generation, giving rise to statements like,"Basic research provides most of the original discoveries from which all other progress flows" (United Kingdom Council for Scientific Policy 1967).

The concept of science as a source of knowledge that would be progressively developed and eventually commercialised became known as the 'linear model'. In the linear model, technology is science reduced to practical application. The 'linear model' is an over-simplified representation that ignores the evidence that technological change is often built upon experience and ingenuity divorced from scientific theory or method, the role of technological developments in motivating scientific explanation, and the technological sources of instruments for scientific investigation (Rosenberg 1982). Nonetheless, it provides a pragmatic scheme for distinguishing the role of science in commercial society.

If science is instrumental in technological progress and ultimately economic growth and prosperity, it follows that the economic theory of resource allocation should be applicable to science. Nelson (1959) and Arrow (1962) demonstrated why market forces could not be expected to generate the appropriate amount of such investment from a social perspective. Both Arrow and Nelson noted that in making investments in scientific knowledge, private investors would be unable to capture all of the returns to their investment because they could not charge others for the use of new scientific discoveries, particularly when those discoveries involved fundamental understanding of the natural world. Investment in scientific knowledge, therefore, had the characteristics of a 'public good' like publicly accessible roads. This approach established a basis for justifying science as a public investment. It did not, however, provide a means for determining what the level of that investment should be.

Investments in public goods are undertaken, in principle, subject to the criterion that benefits exceed costs by an amount that is attractive relative to other investments of public funds. To employ this criterion, a method for determining the prospective returns or benefits from scientific knowledge is required. The uncertainty of scientific outcomes is not, in principle, a fundamental barrier to employing this method. In practice, it is often true that the returns from investments in public good projects are uncertain, and prospective returns often involve attributing to new projects the returns from historical projects. Griliches (1958) pioneered a methodology for retrospectively assessing the economic returns on research investment, estimating that social returns of 700% had been realised in the period 1933-1955 from the $2 million of public and private investments on the development of hybrid corn from 1910-1955. Other studies of agricultural innovation as well as a limited number of studies of industrial innovation replicated Griliches' findings of a high social rate of return (see Steinmueller 1994 for references). Mansfield (1991) provides a fruitful approach for continuing to advance this view. Mansfield asked R&D executives to estimate the proportion of their company's products and processes commercialised in 1975-85 that could not have been developed, or would have been substantially delayed, without academic research carried out in the preceding 15 years. He also asked them to estimate the 1985 sales of the new products and cost savings from the new processes. Extrapolating the results from this survey to the total investment in academic research and the total returns from new products and processes, Mansfield concluded that this investment had produced the (substantial) social rate of return of 28%.

The preceding discussion could lead one to conclude that the development of a comprehensive methodology for assessing the rate of return based on scientific research was only a matter of greater expenditure on economic research. This conclusion would be unwarranted. Efforts to trace the returns from specific government research efforts (other than in medicine and agriculture) have been less successful. The effort by the US Department of Defense Project Hindsight to compute the returns from defence research expenditures not only failed to reveal a positive rate of return, but also rejected the view that "any simple or linear relationship exists between cost of research and value received," (Office of the Director of Defense Research and Engineering 1969). Similar problems were experienced when the US National Science Foundation sought to trace the basic research contributions underlying several major industrial innovations (National Science Foundation 1969). In sum, retrospective studies based upon the very specific circumstances of 'science enabled' innovation or upon much broader claims that science as a whole contributes a resource for commercial innovation seem to be sustainable. When these conditions do not apply, as in the cases of specific research programmes with uncertain application or efforts to direct basic research to industrial needs, the applicability of retrospective assessment, and therefore its value for resource allocation policy, is less clear.

More fundamentally, imputing a return to investments in scientific research requires assumptions about the 'counter-factual' course of developments that would have transpired in the absence of specific and identified contributions of science. In examples like hybrid corn or the poliomyelitis vaccine, a reasonable assumption about the 'counter-factual' state of the world is a continuation of historical experience. Such assumptions are less reasonable in cases where scientific contributions enable a particular line of development but compete with alternative possibilities or where scientific research results are 'enabling' but are accompanied by substantial development expenditures (David, Mowery, and Steinmueller 1992; Mowery and Rosenberg 1989; Pavitt 1993).

For science to be analysed as a social instrument, scientific activities must be interpreted as the production of information and knowledge. As the results of this production are taken up and used, they are combined with other types of knowledge in complex ways for which the 'linear model' is only a crude approximation. The result is arguably, and in some cases measurably, an improvement in economic output and productivity. The robustness and reliability of efforts to assess the returns to science fall short of standards that are employed in allocating public investment resources. Nonetheless, virtually every systematic study of the contribution of science to economy has found appreciable returns to this social investment. The goals of improving standards for resource allocation and management may be better served, however, by analysing science as a social institution.

2. Science as a Social Institution

The economic analysis of science as a social system begins by identifying the incentives and constraints that govern the individual choices of scientists and this may reflect persistent historical features of science or contemporaneous policies. Incentives may include tangible rewards such as monetary awards, intangible, but observable, rewards such as status, and less observable rewards such as personal satisfaction. Similarly, constraints should be interpreted broadly, including not only financial limitations but also constraints stemming from institutional rules, norms and standards of practice. The following simplified account suggests one of several ways of assembling these elements into a useful analytical framework.

Becoming a scientist requires substantial discipline and persistence in educational preparation as well as skills and talents that are very difficult to assess. Scientific training may be seen as a filter for selecting from prospective scientists those who have the ability and drive to engage in a scientific career. In addition, the original work produced during research training demonstrates the capacity of the researcher and provides a means for employers to assess the talents of the researcher (David 1994). Analysing science education as an employment filter is a complement to more traditional studies of the scientific labour market such as those reviewed by Stephan (1996). The employment filter approach may also waste human resources by making schooling success the only indicator of potential for scientific contribution. If, for example, the social environment of the school discourages the participation or devalues the achievement of women or individuals from particular ethnic groups, the filter system will not perform as a meritocracy

The distinctive features of science as a social system emerge when considering the incentives and constraints facing employed scientists. Although there is a real prospect of monetary reward for outstanding scientific work (Zuckerman 1992), many of the incentives governing scientific careers are related to the accumulation of professional reputation (Merton 1973). While Merton represented science as 'universalist' (open to claims from any quarter) the ability to make meaningful claims requires participation in scientific research networks, participation that is constrained by all of the social processes that exclude individuals from such social networks or fail to recognise their contribution. The incentive structure of seeking the rewards from professional recognition, and the social organisation arising from it, is central to the 'new economics of science' (Dasgupta and David 1994).

The new economics of science builds upon sociological analyses (Cole and Cole 1973; Merton 1973; Price 1963) of the mechanisms of cumulative reinforcement and social reward within science. From an economic perspective, the incentive structure governing science is the result of the interactions between the requirement of public disclosure and the quest for recognition of scientific 'priority,' the first discovery of a scientific result. Priority assures the alignment of individual incentives with the social goal of maximising the scientific knowledge base (Dasgupta and David 1987). Without the link between public disclosure and the reward of priority, it seems likely that scientists would have an incentive to withhold key information necessary for the further application of their discoveries (David, Foray and Steinmueller 1999).

As Stephan (1996) observes, the specific contribution of the new economics of science is in linking this incentive and reward system to resource allocation issues. Priority not only brings a specific reward of scientific prestige and status but also increases the likelihood of greater research support. Cumulative advantage therefore not only carries the consequence of attracting attention, it also enables the recruitment of able associates and students and provides the means to support their research. These effects are described by both sociologists of science and economists as the Matthew effect after Matthew 25:29, 'For to every one who has will more be given, and he will have abundance; but from him who has not, even what he has will be taken away.' As in the original parable, it may be argued that this allocation is appropriate since it concentrates resources in the hands of those who have demonstrated the capacity to produce results.

The race to achieve priority and hence to collect the rewards offered by priority may, however, lead to inappropriate social outcomes because priority is a 'winner takes all' contest. Too many resources may be applied to specific races to achieve priority and too few resources may be devoted to disseminating and adapting scientific research results (Dasgupta and David 1987; David and Foray 1995), a result that mirrors earlier literature on patent and technology discovery races (Kamien and Schwartz 1975).

Moreover, the mechanisms of cumulative advantage resulting from achieving priority may reduce diversity in the conduct of scientific research. This system has the peculiarity that the researchers who have the greatest resources and freedom to depart from existing research approaches are the same ones who are responsible for creating the status quo.

The principal challenges to the view that science is a distinct social system are the growing number of scientific publications by scientists employed in private industry (Katz and Hicks 1996) and the argument that scientific knowledge is tightly bound to social networks (Callon 1994). Private investments in scientific research would appear to question the continuing validity of the 'public good' argument. For example, Callon (1994) contends that scientific results are, and have always been, strongly 'embedded' within networks of researchers and that 'public disclosure' is therefore relatively useless as a means of transfer for scientific knowledge. Gibbons et al. (1994) argue that research techniques of modern science have become so well distributed that public scientific institutions are no longer central to scientific activity. While the arguments of both Callon and Gibbons et al. suggest that private scientific research is a direct substitute for publicly funded research, other motives for funding and publication such as gaining access to scientific networks suggest the public and private research are complementary (David, Foray, and Steinmueller 1999). The growing reliance of industry on science provides a justification for investing in science to improve the 'absorption' of scientific results (Cohen and Levinthal 1989; Rosenberg 1990). Employed scientists need to be connected with other scientific research colleagues who identify 'membership' in the scientific community with publication, and labour force mobility for employed scientists requires scientific publication. Thus, it is premature to conclude that the growing performance of scientific research in industry or publication of scientific results by industrial authors heralds the end of the need for public support of science.

The growing significance of private funding of scientific research does, however, indicate the need to improve the socio-economic analysis of the incentive and governance structures of science. Empirical work on the strategic and tactical behaviour of individual scientists, research groups and organisations is urgently needed to trace the implications of the changing environment in which the social institutions of science are evolving. Ultimately, these studies should be able to meet the goal of developing better rules for allocating and managing the resources devoted to science.

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4.10.59 Science Funding: Europe

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European governments invest considerable sums of money in science. This article examines the reasons why they do this, covering briefly the historical context of European science funding and highlighting current issues of concern. The focus is on *government* funding of science, rather than funding by industry or charities, since government has historically been the largest funder of ‘science’ as opposed to ‘technology’. As an approximate starting point, ‘science’ refers to research that is undertaken to extend and deepen knowledge rather than to produce specific technological results, although the usefulness of this distinction will be questioned below. By ‘science policy’ what is meant is the set of objectives, institutions and mechanisms for allocating funds to scientific research and for using the results of science for general social and political objectives (Salomon 1977). ‘Europe’ here only refers to Western Europe within the European Union, excluding the Eastern European countries.

1. Background

Government funding of science in Europe started in a form that would be recognizable today only after the Second World War, although relations between science and the state can be traced back at least as far as the Scientific Revolution in the seventeenth century (Elzinga and Jamison 1995). The history of science funding in Europe can be summarized broadly as a movement from a period of relative autonomy for scientists in the post-war period, through stages of increasing pressures for accountability and relevance, resulting in the situation today, where the majority of scientists are encouraged to direct their research towards areas that will have some socially or industrially relevant outcome.

However, this account is too simplistic. Many current concerns about science funding are based on the idea that ‘pure’ or ‘basic’ science (autonomous research concerned with questions internal to the discipline) is being sacrificed in place of ‘applied’ research (directed research concerned with a practical outcome), incorrectly assuming that there is an unproblematic distinction between the two (see Stokes 1997). Looking back, it can be seen that even in the late 1950s there were expectations that science should provide practical outcomes in terms of economic and social benefits, and the work that scientists were doing at this time was not completely ‘pure’, because much of it was driven by Cold War objectives. This is a demonstration of the broader point that in science policy the categories used to describe different types of research are problematic, and one must be careful when using the traditional terminology. With these caveats in place, it is possible to trace the major influences on European science funding.

In the 1950s and 1960s much of the technologically-oriented funding of research was driven by military objectives and attempts to develop nuclear energy. In terms of science funding, this was a period of institutional development and expansion in science policy (Salomon 1977). The autonomy that scientists enjoyed at this time was based on the assumption that good science would spontaneously generate benefits. Polanyi (1962) laid out the classic argument to support this position, describing a self-governing ‘Republic of Science’. He argued that because of the essential unpredictability of scientific research, government attempts to direct science would be counter-productive because they would suppress the benefits that might otherwise arise from undirected research. This influential piece can be seen as a response to Bernal’s work (1939), which was partly influenced by the Soviet system and which argued that science should be centrally planned for the social good.

Another important concept of the time was the ‘linear model’ propounded by US science adviser Vannevar Bush (1945). In this model for justifying the funding of science, a one way conceptual line was drawn leading from basic research to applied research to technological innovation, implying that the funding of basic research would ultimately result in benefits which would be useful to society.
But pressures on science from the rest of society were increasing. In the 1970s there was a growing awareness of environmental problems (often themselves the results of

scientific and technological developments), and European countries also experienced the oil crises, with accompanying fiscal restrictions. There were increasing pressures on scientists to be accountable for the money they were spending on research. Also at this time the social sciences, especially economics, provided new methods for understanding the role of scientific research in industrial innovation and economic growth (see Freeman 1974).

In the 1980s Europe realized it had to respond to the technological and economic challenges of Japan and the US, and because of the ending of the Cold War, military incentives for funding science were no longer so pressing. Technology, industrial innovation and competitiveness were now the main reasons for governments to fund science. Academic studies of innovation also began to question the linear model of the relationship between science and technology, described above, arguing that the process was actually more complicated (e.g. Mowery and Rosenberg 1989). This led to pressures on the previous ‘contract’ between government and scientists (Guston and Keniston 1994), which had been based on the assumptions of the linear model. Rather than presuming that science would provide unspecified benefits at some unspecified future time, there were greater and more specific expectations of scientists in return for public funding. This was accompanied by reductions in the growth of science budgets, producing a ‘steady state’ climate for scientific research, where funding was not keeping up with the rapid pace at which research was growing (see Ziman 1994).

Science policy work at this time produced tools and data for measuring and assessing science. Various techniques were developed, such as technology assessment, research evaluation, technology management, indicator-based analysis, and foresight (Irvine and Martin 1984).

In the 1990s there was greater recognition of the importance of scientific research for innovation, with the development of new hi-tech industries that relied on fundamental scientific developments (such as biotechnology), in conjunction with other advanced technologies. There were also growing pressures for research to be relevant to social needs. Gibbons et al. (1994) argued that the 1990s have witnessed an increasing emphasis on problem-oriented, multi-disciplinary research, with knowledge production having spread out to many diverse locations, and that distinctions between basic and applied science, and between science and technology, are becoming much more difficult to make.

2. The Influence of the European Union

Moving from a general historical context to look more specifically at the European level shows that research funding from the European Union (EU), in the form that it currently takes, did not start until 1984 with the first ‘Framework Programme’. This funded pre-competitive research (i.e. research that is still some way from market commercialization) following an agenda influenced by industrial needs (Sharp 1997). From the 1960s onward, the Organization for Economic Cooperation and Development (OECD) had been a more influential multinational organization than the EU in terms of national science policies (Salomon 1977). In particular, the OECD enabled countries to compare their research activities with those of other countries, and encouraged greater uniformity across nations.

Currently EU research funding only comprises a few percent of the total research funding of all the member states (European Commission 1994), although it has been more important in the ‘less favored’ regions of Europe (Peterson and Sharp 1998). Consequently, in terms of science funding, the national sources are more important than the EU. However, EU programmes do have an influence on the funding priorities of national governments. In theory, the EU does not fund research which is better funded by nation states (according to the ‘principle of subsidiarity’ - see Sharp 1997), so it does not fund much basic research, but is primarily involved in funding research that is directed towards social or industrial needs.

The most important impact of the EU has been in stimulating international collaboration and helping to form new networks, encouraging the spread of skills. One of the requirements of EU funded projects is that they must involve researchers from at least two countries (Sharp 1997). This could be seen as part of a wider political project that is helping to bind Europe together. It is possible that many of these collaborations might have happened without European encouragement because of a steady rise in all international collaborations (Narin et al. 1991). However, it is likely that through its collaborative programmes and their influence, the EU will play an increasingly important role in the future of research funding in the member countries (Senker 1999).

3. Individual Countries in Europe

Since it is the individual countries in Europe that are responsible for the majority of science funding, the organization of their research systems deserves attention.

All the countries have shown the general trends outlined above, but the historical and cultural differences among the European nations lead to considerable diversity in science funding arrangements. It is possible to compare the different countries by looking at the reasons why they fund science and the ways in which research is organized.

European nations, like those elsewhere, have traditionally funded science to encourage economic development, although most countries also attach importance to advancing knowledge for its own sake. Some countries such as Sweden and Germany have emphasized the advancement of knowledge, and other countries, such as Ireland, have put more emphasis on economic development (Senker 1999). Since the 1980s, the economically important role of science has been emphasized in every country. This has often been reflected at an organizational level with the integration of ministerial responsibilities for science funding with those for technology and higher education.

We can compare individual countries in terms of differences in the motivations behind funding research. Governments in France and Italy have traditionally promoted ‘prestige’ research, and have funded large technology projects, such as nuclear energy. These reasons for funding research, even though they are less significant in the present climate, have had long-lasting effects on the organization of the national research systems. The UK is notable in that the importance of science for economic competitiveness is emphasized more than in other European countries, and industrial concerns have played a larger role (Rip 1996).

Organizational differences between countries can tell us something about the way research funding is conceptualized and can also reflect national attitudes toward the autonomy and accountability of researchers. In the different European countries the locus of scientific research varies. In some countries the universities are most important (e.g. Scandinavia, Netherlands, UK), and funds are competed for from research councils (institutions that mediate between scientists and the state - see Rip 1996). In this type of system there will usually be some additional university funding which provides the infrastructure, and some of the salaries. The level of this funding varies between countries, which results in differences in scientists' dependence on securing research council funds and has implications for researcher autonomy. In other countries a great deal of scientific research is carried out in institutions which are separate from the universities (e.g. France and Italy).

The situation is not static, and scientific research in the university sector has been growing in importance across the whole of Europe (Senker 1999). For example, in France, the science funding system has traditionally been centralized with most research carried out in the laboratories of the Centre National de la Recherche Scientifique (CNRS). Now the situation is changing and universities are becoming more involved in the running of CNRS labs, because universities are perceived to be more flexible and responsive to user needs (Senker 1999). Germany is an interesting case because there is a diversity of institutions involved in the funding of science. There is a division of responsibility between the federal state and the Länder, which are responsible for the universities. There are also several other types of research institute, including the Max Planck institutes, which do basic research, and the more technologically-oriented Fraunhofer institutes. Resulting institutional distinctions between different types of research may lead to rigidities in the system (Rip 1996). In all countries in Europe there is an attempt to increase coordination between different parts of the national research system (Senker 1999).

4. Current trends

As has been emphasized throughout, European governments have demanded increasing relevance of scientific results and accountability from scientists in return for funding research. Although the situation is complex, it is clear that these pressures, and especially the rhetoric surrounding them, increased significantly during the 1990s.

This has led to worries about the place for serendipitous research in a "utilitarian-instrumental" climate (Nowotny 1997:87).

These pressures on science to be useful are not the only notable feature of the current funding situation. The views of the public are also becoming more important in decisions concerning the funding of science.

The risks and detrimental effects of science are of particular concern to the public, possibly because the legitimacy of the authority of politicians and scientists is being gradually eroded (Irwin and Wynne 1996). Throughout Europe there has been a growth in public distrust in technological developments, which has led to pressures for wider participation in the scientific process. This is related to the current (and somewhat desperate) emphasis on the ‘public understanding of science’, which is no longer simply about educating the public in scientific matters, but has moved towards increasing participation in the scientific process (see Gregory and Miller 1998). Concerns about the environmental effects of scientific developments can be traced back many decades, but recent incidents have led to a more radical diminution of public faith in scientific experts (with issues such as climate change, Chernobyl, BSE and GMOs).

The public distrust of science may also be due to the fact that scientists, by linking their work more closely either to industrial needs or to priorities set by government, are losing their previously autonomous and potentially critical vantage-point in relation to both industry and government.

Certain European countries, especially the Netherlands and Scandinavia, which have a tradition of public participation, are involving the public more in debates and priority setting on scientific and technological issues. This has been described as a "post modern" research system (Rip 1996). As the distinction between science and technology becomes less clear, in this type of research system there is also a blurring of boundaries between science and society.

5. Implications

An implication of these changes in science funding is that the growing importance of accountability and of the role of the public in scientific decisions may have epistemiological effects on the science itself, since scientific standards will be determined not only by the scientific community but by a wider body of actors often with divergent interests (Funtowicz and Ravetz 1993).

If norms are linked to institutions, and if institutions are changing because of the greater involvement of external actors in science, and of science in other arenas, then the norms may be changing too (Elzinga 1997). This is an issue that was touched on in the 1970s and 1980s by the proponents of the ‘finalization thesis’ who argued that, as scientific disciplines become more mature, they become more amenable to external steering (Böhme et al. 1983). The importance of external influences leads to worries about threats to traditional values of what constitutes ‘good’ science (Elzinga 1997, see also Guston and Keniston 1994 for US parallels). There may be an emergence of new standards of evaluation of scientific research.

European science funding has changed considerably since it was institutionalized, partly because of its success in generating new technologies and partly because of its failures and their social consequences. It is becoming more difficult to categorize science, technology and society as separate entities (Jasanoff et al. 1995), or to think of pure scientists as different from those doing applied research. Wider society has become inextricably linked with the progress of science and the demands placed on scientists and science funding mechanisms are starting to reflect this restructuring. This tendency is likely to continue into the future.

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