In terms of the sectoral focus of R&D funding in the Asian region, a contrasting picture emerged. Japan and NICs directed their science funding to high technologies, capital, exports of engineering goods, advanced materials, modern biology, and basic research in information and communication technologies. In the 1990s, Japan, South Korea, and Singapore registered greater proportions of private sector funding than even Germany and the USA. Japan's R&D expenditures have increased eightfold over the 20 year period from 1971 to 1993, which is the highest rate of increase among the industrially developed nations.

At the other extreme are the Southern Asian countries, including China, India, Pakistan, Bangladesh, Nepal, Myanmar, and Sri Lanka, where R&D funding related to agriculture and to the manufacturing sector assumed equal importance, as over 60 percent of their populations was dependent on agriculture. Another revealing feature about countries such as China, India, and Pakistan was the importance given to military and strategic R&D, which consumed 45 to 55 percent of the total R&D budget.

In most of the South East Asian countries, the contribution of agriculture to the GDP witnessed a considerable decline in contrast to Southern Asian countries. In terms of sectoral contribution to the GDP, none of the South East Asian countries accounted for more than 26 percent (the figure for Vietnam) for agriculture in 1998. The manufacturing and service sectors witnessed unprecedented growth rates between 1980 and 1998. Though these countries spend no more than 0.5 percent of GDP on R&D, the thrust of science funding is directed to manufacturing, industrial, and service-related activities. Agricultural research consumes only 5–10 percent of the total R&D funding, much less than in the Southern Asian countries.

See also: Infrastructure: Social/Behavioral Research (Japan and Korea); Research and Development in Organizations; Research Ethics: Research; Research Funding: Ethical Aspects; Science, Economics of; Science Funding: United States; Science, Social Organization of; Scientific Academies in Asia; Universities and Science and Technology: Europe; Universities and Science and Technology: United States

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World Development Report 1999/2000

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Science Funding: Europe

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 World War II, 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 postwar 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 counterproductive 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 that 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 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, multidisciplinary 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 programs do have an influence on the funding priorities of national governments. In theory, the EU does not fund research that 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 programs 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 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 that 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 that 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, p. 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 to the 1960s, but recent incidents in the 1980s and 1990s have led to a more radical diminution of public faith in scientific experts (with issues such as climate change, Chernobyl, and genetically modified foods).

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 epistemological 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.

See also: Infrastructure: Social/Behavioral Research (Western Europe); Kuhn, Thomas S (1922–96); Research and Development in Organizations; Research Funding: Ethical Aspects; Science, Economics of; Science Funding: Asia; Science Funding: United States; Science, Social Organization of; Universities and Science and Technology: Europe

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J. Calvert and B. R. Martin

Science Funding: United States

The pursuit of knowledge has historically been shaped by patronage relationships. The earliest scientists were astronomers and mathematicians supported at ancient courts in the Middle East and China. In Renaissance Europe, observers of and experimenters with nature had patrons in the aristocracy or royal families. In nineteenth century America, industrial philanthropists took up their cause.

Since World War II, research in the United States has received its support largely from government, with help from industry and private foundations. This article focuses on the postwar history of government funding for research in the United States. That history has been characterized by a creative tension between autonomy and accountability, embodied in successive waves of invention of new institutional arrangements. Should science set its own agenda, or should it answer to the public? Could the two goals be reconciled? These issues have echoed through five decades of research policy.

1. Autonomy for Prosperity

In the eighteenth and nineteenth centuries, the US federal government funded research only if it was applied directly to practical goals. The earliest federal efforts were in surveying and geological exploration, activities that contributed both to nation-building and to the search for mineral wealth. A second major wave of federal effort in the latter half of the nineteenth century took up agricultural research in partnership with the States, through land grant colleges and agricultural experiment stations. Scientists were also brought in to solve the immediate problems of wartime. World War I was known as 'the chemists' war,' because of the use of chemical warfare agents. World War II became 'the physicists' war,' with the invention of the atomic bomb. And in the 1930s, a small federal laboratory for health research was established, which later became the National Institutes of Health, the nation's research arm for biomedical sciences (Dupree 1964, Kevles 1978, Strickland 1989).

By the time of World War II, these efforts had grown into a set of research programs in mission agencies, focused on food, health, and defense. These activities were carried out largely in government laboratories, and were focused on immediate, practical goals. In later decades, two other agencies joined this group. The National Aeronautics and Space Administration (NASA) was formed in response to the launching of a Russian satellite, the Sputnik, in 1957 (Logsdon 2000). And the Department of Energy, when it was established in the 1970s, incorporated major research elements, including the high-energy physics laboratories. This array of government research efforts continues to anchor the mission-oriented portion of a pluralistic system of funding for US research.

The other dimension of that system is fundamental research. It is anchored in universities, and interwoven with graduate education and the preparation of new generations of researchers. This second dimension has its origins in moments of national crisis, when government research efforts were expanded temporarily through the cooptation of university researchers. After such an interlude in World War I, influential US scientists tried to convince the federal government to keep the research relationship with universities going, but to no avail. It was only after the success of the crucial atomic bomb project that the achievements of science carried enough weight to make credible proposals for permanent, across-the-board government support for research (Kevles 1978).

The spokesperson for this plan was Vannevar Bush, a university scientist who had been active in the government projects around the war. He called for the formation of a National Research Foundation, to provide basic support for research, without the specific targets that had been imposed during the war. He argued that unfettered research, carried out largely in

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