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from the Society's archives some 300 years ago and discovered in 2005 in a private house—was about to be auctioned when the Society and the vendors reached an agreement for a UK£1 million transaction. "We are keen that as wide an audience as possible, including scholars and the general public, should now be able to appreciate these documents," commented the Royal Society's President, Lord Rees of Ludlow, in a press release (Royal Society, 2006).

The moral of the story is that a general lack of awareness and sense of history has put at risk irreplaceable artefacts from a key scientific era. Scientific institutions, with a few remarkable exceptions, had little perception of science history, thus leaving the past of molecular biology unattended. At the same time, private collectors, book dealers and—worse—scientists ignored the public significance of the documents they were trading. "It is hoped that better awareness, stricter rules and more incentives [to institutions] will help achieve [a situation in which] scientific papers do not end up in the hands of private collectors but are deposited in established archives where they are accessible for historical research," de Chadarevian said. "The advice of the NCUACS would be that archives should find a permanent home at the institution with which the scientist was principally associated, subject of course to that institution's ability to provide professional curation and public access," confirmed Harper, adding that it must be genuine public access, not just for a handful of privileged researchers. He also expressed reservations about digitalization as a solution to problems associated with private ownership. "What guarantees are there of the authenticity of the digital record? Does a digital record in all cases replace the need to consult an original paper record?" Harper asked. At a minimum, scientists and historians can find some comfort in the recent sale of molecular biology papers, as it might prove to be an instructive lesson that inspires future efforts in the protection of our scientific heritage.

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Science cannot be left to the market alone

Meshing basic research with fiscal competitiveness is the key to economic success

Most leading industrialized nations, and an increasing number of developing countries, are realigning their publicly funded research more closely with the perceived demands of economic competitiveness and sustainable growth. The USA recently announced a substantial increase in its funding for physical sciences, and last year the European Union (EU) created the European Research Council (ERC) with a commitment to support only high-quality research across all sciences. India and China are increasing their investments in basic research, to catch up with Europe and North America scientifically as well as economically. Meanwhile, smaller nations are homing in on specific sectors in both basic and applied research, such as pharmaceuticals and nanotechnology, rather than spreading their limited resources thinly across the whole scientific spectrum.

The fact that research, technological progress and economic growth are closely linked is beyond dispute; however, there is still debate over which strategy is best suited to deploy finite resources and to stimulate technology transfer. A useful starting point

is the observation that major 'disruptive' inventions, which change the course of an industry or the world as a whole, are almost always based on results from basic or fundamental research, according to Jörn Erselius, Managing Director of Garching Innovation (Munich, Germany), which organizes technology transfer from the Max Planck Institutes to businesses in Germany. "Examples [of major inventions] include monoclonal antibodies, PCR [polymerase chain reaction] and RNA interference," he said. These emerged from fundamental research and became important platform technologies for the life sciences. Surveys during the past two decades support Erselius' argument—for example, one study showed that 44% of innovative pharmaceutical products were derived from basic research (Mansfield, 1995).

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Another, more recent, example is research on the errors that occur when bacteria multiply, from Jeff Errington, Professor of Microbiology at Oxford University, UK. The work was funded by the Biotechnology and Biological Sciences Research Council (BBSRC), based in Swindon, which is the primary funding body for fundamental life-sciences research in the UK. "This later led to a spin-out company, Prolysis Ltd, which applies this knowledge in the development of antibiotics to defeat bacterial infections, such as MRSA [methicillin-resistant *Staphylococcus aureus*]," said Doug Yarrow, Director of the BBSRC Corporate Science Group.

Such examples imply that scientific programmes aiming to spur economic development must include a mixture of directed goal-orientated projects and 'blue-sky' research. However, studies that affirm the general value of fundamental research address the question of scientific priorities only from a global perspective. They say relatively little about where the priorities of individual countries should lie. Accordingly, there is a longstanding argument that science should be left to larger countries, notably the USA, which already excel and are able to devote the most resources. Smaller countries would benefit by exploiting the results from the research investments made by larger nations. Indeed, several smaller nations, such as new EU member states from Eastern Europe, have produced their own research centres and industries on the basis of intellectual property (IP) developed elsewhere. Major technologies, such as PCR, are now used around the world irrespective of where they originated.

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However, Erselius believes that such strategies can only achieve short-term gains. "The example of Japan shows that sustainable economic competitiveness can only be achieved by investing more in research than average [currently 3.1% of gross domestic product], with a strong emphasis on basic research," he insisted. China is taking a similar

line, having progressed from copying technology to becoming a world leader in sectors such as nuclear research; the country expanded its nuclear programme during the 1990s, precisely when such research was being cut back elsewhere after the end of the Cold War.

Furthermore, there are clear long-term dangers in relying only on other nations for scientific discoveries and IP, according to Andy Cosh, Assistant Director of the Centre for Business Research at Cambridge University, UK. When someone else owns the IP, anyone exploiting it can be held to ransom. There are already signs that the USA is making use of its dominant position in research and development. "In terms of IP rights there is some argument that US universities are pricing themselves too highly, and that challenges the idea that other countries can rely on them for their research," said Cosh. Indeed, the USA might have priced itself out of the international market; emerging scientific powers, most notably China and India, now provide an alternative source of research and IP for European companies, which are happy to exploit their lower labour costs.

Yet outsourcing basic research and technology development brings risks for both parties. For the country on the receiving end, the benefits of outside investment can be offset by the fact that the IP is owned by the companies in the outsourcing country, thus depriving the host of opportunities for technology transfer. This is increasingly being recognized, according to Anitha Kurup, a fellow of the Indian Institute of Science in Bangalore, who organized the National Conference on India's Competitiveness and Preparedness in Science and Technology for the Coming Decades in October 2005. "We do observe that several multi-national companies are setting their R&D [research and development] here and planning to tap the research potential of India," she said. "However, the partnership we must look for is one that is fair, where collaborations must not exclude the IP rights. The industry-institute linkages must be carefully drawn in such a way that there is a mutual benefit to both."

There is also the risk for the host country that the best scientists—often the ones performing the research—will eventually emigrate, lured away by higher salaries abroad. In this way, the host country might be confined to the margins of major research projects,

performing more routine tasks, while the outsourcer enjoys the more challenging and intellectually stimulating work, and as a result is best placed to exploit the IP.

For the outsourcing country, the main hazard is the erosion of its scientific base, thus depriving local businesses of access to the expertise they need for new and ongoing projects. It is significant that in the USA—the world's most successful exploiter of its science base—40% of businesses collaborate with their local university, compared with 25% in the UK, according to Cosh. When more research is outsourced, such opportunities for local technology transfer are further diminished.

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At the same time, however, outsourcing represents a competitive weapon by reducing the costs of research. The key is to achieve the right balance, according to David Connell, Director of TTP Capital Partners (Cambridge, UK), a venture-capital firm that finances high-technology start-ups. "One of the challenges for UK and European companies must be to use that outsourcing resource in a way that maintains your competitiveness," he said. Connell related this to the wider challenge of deciding in which scientific and technology fields a country should stay competitive, because only the largest, such as the USA and China, can cover a wide spectrum. But it is important for Europe's knowledge-based economies to maintain expertise and leadership in at least some key fields, Connell insisted. "In the UK for example, we are no longer involved in most areas of manufacturing, and are losing it in areas of service, so if we also lose out to emerging nations in research, development and engineering, what else is left?"

In answer to this question, medium-sized countries should direct their research budgets disproportionately towards core areas of competence, as the UK has done to some extent in pharmaceuticals, and Nordic countries have done in renewable energy. By focusing too tightly, however, countries could miss out on other fundamental research that produces unexpected

dividends. It is here that the EU, with its various funding schemes from the framework programmes to the ERC, could fill the void and support the types of science that its individual member countries find too expensive.

Such decisions on research strategies inevitably involve a long-term view and, for smaller countries, there is the risk of betting on the wrong horse. Even the USA has to juggle its priorities to some extent, and has recently made what can be seen as a bold decision to rebalance its federal budget substantially in favour of the physical sciences. This was not a direct response to China's huge programme in physical sciences, including nuclear energy, insisted John Marburger, Director of the US Office of Science and Technology Policy, and Chief Science Advisor to President George W. Bush. Instead, the US Government identified the physical sciences as providing the future framework for the whole spectrum of R&D—including bio-sciences—given the increasing importance of atomic-scale imaging and manipulation, according to Marburger.

As a result, President Bush announced in February 2006 that agencies directly funding the physical sciences—such as the National Science Foundation, the Department of Energy Office of Science, and the National Institute of Standards and Technology—would have their budgets doubled within 10 years as part of the new American Competitiveness Initiative (Domestic Policy Council, 2006). This would amount to US\$50 billion for direct R&D funding, augmented by a separate programme to extend the range of R&D tax credits. Recipients include the National Science Foundation (Arlington, VA, USA), which funds two programmes deemed critically important by Marburger: the National Nanotechnology Initiative, and the Networking and Information Technology R&D Initiative.

The situation in the EU is different, as government spending on R&D amounts to about 95% of the total money invested in research, with only 5% coming from the EU. Nevertheless, through its framework programmes, the EU has a vital role in stimulating and creating the same kind of long-term investments that the USA are making right now. A key element is the idea of technology platforms, which are being set up within several sectors to identify the infrastructures

and other resources that are needed, according to Janez Potočnik, European Commissioner for Science and Research. "We see technology platforms as a smart, European way of working together to support industrial competitiveness," he said. "It will mean that research is targeted to the identified needs of that sector, and it provides a potential forum for a range of other issues that can usefully be discussed, such as standardization or regulation." Unlike the USA, the EU has not singled out the physical sciences for special attention, or identified specific fields as being vital for its economic competitiveness. However, as Potočnik pointed out, with only 5% of total science funds at its disposal, the EU is not in a position to make such fundamental decisions on behalf of its member states.

However, the EU as a whole, and some individual member countries, are already adopting certain aspects of the US technology transfer policies, particularly to stimulate the creation of spin-off companies at universities and research institutes. The USA has encouraged small businesses via its Small Business Innovation Research (SBIR) programme since 1982, followed by the Small Business Technology Transfer (STTR) programme a decade later. The SBIR provides financial help to small businesses bidding for federal research contracts, whereas the STTR is pitched at collaboration between small businesses and non-profit research institutions.

The SBIR was launched in response to a US study, which found that small businesses had 2.5 times as many innovations per employee as large businesses, and yet were only one-third as likely to receive government assistance (Bomberger, 1982). Sadly this is still true in much of Europe, although it has changed radically in the USA as a result of the SBIR and STTR programmes. Indeed, Europe is only just getting its act together on this front. "It is a competitive disaster for UK companies, especially early-stage start-ups and university spin-offs, that we do not have such programmes," said Connell.

The importance of a strong, publicly funded university-based research sector seems to be clear, given its proven role in spawning and stimulating innovation

Potočnik agreed that similar support for small and medium-sized enterprises (SMEs) is necessary in Europe, and insists that the issues are being addressed within the Seventh Framework Programme. "For the first time, a European programme will explicitly tackle these issues for SMEs through improving access to finance and supporting investment in innovation activities. It will provide SMEs with information and advice on single market opportunities and community matters," he said.

However, Cosh pointed out that innovation can occur in a variety of ways, and warned that universities and governments should be wary of focusing all their resources on the conventional spin-off model. "It is this role that is become very popular, of laboratory research leading to discovery to patenting and onto licensing or, better still, spin-offs," said Cosh. "What we are trying to show is that, important though this model may well be, it is only a relatively small part of the overall picture. When we ask businesses what is the most important part of the universities' role, even those scientists who have been involved in spin-offs play down the importance of patenting and licensing." Instead, they cite informal contact, publications, conferences and joint R&D as being more significant.

The importance of a strong, publicly funded university-based research sector seems to be clear, given its proven role in spawning and stimulating innovation. Yet there is another dimension to consider, as important research projects—especially in medicine and biotechnology—are becoming more expensive and difficult for even the largest universities to run on their own.

Thus, partnerships between the public and private sector are important, as universities and governments need to attract investment from businesses to maintain their long-term research programmes.

"Commercialization has become fundamental to research," noted Nelson Phillips, Chair in Strategy and Organisational Behaviour in the Tanaka Business School at Imperial College London, UK. "The trick then for universities and for individual researchers is 'how do I do what I'm really interested in and somehow connect it with something companies can use?'" This does not necessarily mean that research has to have immediate commercial value, but scientists themselves have to be more marketable and willing to work more closely with companies. At the same time, universities need to forge partnerships with each other and with companies, to reach the critical mass of expertise and resources required to tackle major research themes.

However, for Europe especially, there are still big challenges in making science and development more competitive, notably whether to concentrate resources more heavily in elite institutions and specific areas of competence. This also raises the valid ques-

tion of whether the continent as a whole needs an overall long-term strategy for science (Gannon, 2006). These are questions that the new ERC will have to grapple with, alongside its sister organization, the European Science Foundation, which is able to draw on the research budgets of individual countries in projects involving three or more EU member states. Whether or not Europe has a coordinated science strategy, the only way forward is for nations to cooperate more, to create the infrastructure and knowledge base required for future research.

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