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As activities that relate to innovation become increasingly global and open and so draw the private and public sectors into complex networks of partnerships, these activities also tend to concentrate where the ecosystem is most supportive. European public policy, which in recent years has emphasized the importance of research and development (R&D) in achieving competitive knowledge-based societies, is shifting toward approaches that address the broader qualities required of favorable ecosystems for innovation in a global economy, thereby incorporating the roles of market demand, public procurement, and regulation, as well as science, education, and industrial R&D, as part of determining effective innovation policies.

Successful innovation once depended mainly on the controlled qualities of the corporate research and development (R&D) laboratory, but noticeable changes became evident in the 1990s. These changes, at first stimulated by companies' desire to reduce cycle time and to bring technology development more closely under business unit control, have been turned to advantage by those companies that recognized that they could no longer develop all required technology in-house and that "gold plating" of proprietary technologies was counterproductive. Within this environment, small innovative companies have thrived through their ability to test, develop, and supply new methods and approaches more effectively than larger companies.

Coombs and Georghiou (*1*) referred to these changes as a "new industrial ecology" and Chesbrough (*2*) introduced the term "open innovation" to describe approaches that combine in-house and external resources. Organizations succeed by virtue of their ability to gain comparative advantage from the combined activities of competitors, suppliers, and customers; to obtain economic value also from intellectual property (IP) that is not needed for internal business purposes; to treat public research as a strategic resource; to spot and rapidly internalize discoveries from sources outside the company; and thereby to concentrate their own efforts on activities (such as improved service content) that best contribute to value creation and innovation for the company itself.

These trends are playing a major part in shaping corporate approaches to innovation. The March 2006 issue of the *Harvard Business Review* (*3*) describes the "connect-and-develop" approach taken by the global consumer goods company, Procter and Gamble (P&G). P&G reported that this approach now yields more than 35% of the company's innovations and billions of dollars in revenues. The approach was illustrated using an example of a small bakery in Bologna, Italy, run by a university professor who had extended ink-jet technology to print edible images on foodstuffs. By transferring this technology and modifying it to deal with different process conditions, P&G was able to take a new product (Pringle Prints) (Fig. 1) from concept to launch in less than a year, at a fraction of the cost of in-house development.

Open innovation has also been stimulated by the decreasing time frames during which companies can command premium prices from proprietary technologies. Whereas the price of videocassette recorders fell by 50% over a 10-year period, the price of DVD recorders, which came to market 25 years later, fell by this amount in 2 years. Remaining competitive in this situation requires considerable agility from companies, forcing them to concentrate on core skills.

As technological content of products and services grows, this must be packaged in ways that consumers find reliable and easy to use. Philosophies such as ambient intelligence (*4*) emphasize within the corporation that technology has to become a more natural, yet pervasive, part of the environment in which we live. The introduction of advanced consumer products such as luxury coffee machines, which bring the qualities of the professional espresso bar into the home and office, and music and video players like Apple's iPod shows how this goal is starting to be being addressed.

As a result of these combined pressures on innovation, emphasis within companies has shifted toward linking research and development more closely with activities such as design, production, and distribution. Growing technological complexity requires that the company anticipates developments in standards and stimulates the development of shared component platforms and technology roadmaps. Research collaboration among companies and with universities and other public research organizations takes on a more strategic importance. New businesses (*5*) mediated by the Internet facilitate technology exchange among companies and help match scientific skills globally with the problems that companies wish to resolve.

European Public Policy: Understanding the R&D Numbers

A key task for policy-makers is to address these developments in ways that benefit the home economy. Soon after the summit meeting of European heads of state in Lisbon in March 2000 placed innovation at the heart of the policy agenda, a substantial gap became evident between overall R&D intensities within the European Union (EU) and its main economic competitors, particularly with regard to private-sector investment. Treating this gap initially as both symptom and cause of lack of competitiveness, a subsequent summit projected that levels of R&D investment should rise from 1.9 to 3% of gross domestic product, in effect addressing a gap in competitiveness and innovation performance by means of a "research push." This has become known as "the Barcelona target," for which two-thirds of R&D investment would come from the private sector.

To a large extent, the gap between current levels of R&D investment in Europe and the 3% goal reflects a concentration of large R&D investors in certain industrial sectors. Most in-

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dustrial R&D worldwide is financed by a few hundred large companies (*6*). A main factor differentiating the levels of R&D in different regions (Table 1) is the sector concentration that resulted from previous patterns of company growth.

Competing companies tend to invest in a similar fashion in R&D regardless of where they are headquartered. In sectors such as information technology (IT) hardware, computer software, and biotechnology, large amounts of money are committed to R&D per unit of sales. Many larger companies in these sectors are headquartered in the United States, and most grew large in the last 50 years. Many of the larger European players are in sectors such as automotives and chemicals, where absolute R&D investments are high, but R&D intensity per dollar of sales is lower. There are also more specific European strengths in key growth sectors, for example, in the IT systems embedded into products such as cars and telephones.

Because of the dominant part played by the larger companies, aggregate R&D figures fail to reveal the part played by smaller companies. Deeper examination shows that the larger companies now depend on and, in turn, support extensive networks of smaller companies, some of which will become the large companies of the future. It is important to emphasize this interdependency and to understand its consequences.

Here, There, or Somewhere Else?

A second part of the policy equation is to understand and to anticipate where companies will place their new R&D investments. In the pharmaceuticals sector (*7*), for example, from 1990 to 1994, 88 "new molecular entity" pharmaceuticals came to market in Europe and 74 in the USA, and companies' R&D efforts were concentrated accordingly [1990: EU, €8 billion ($10.5 billion U.S. dollars); USA, €6 billion ($7.8 billion)]. These patterns have since reversed (2000–04: 57 new molecular entities in EU, 70 in the USA; estimated in 2004: EU, €21 billion ($27.5 billion) spent on R&D; USA, €27 billion ($35.4 billion). The shifts continue as new markets, trained people, and adequate support structures become available in Asia. In May 2006, the Anglo-Swedish pharmaceutical major, AstraZeneca, followed its Swiss and Danish counterparts, Novartis International, Novo Nordisk, and Roche, in announcing plans for R&D facilities in China.

Two recent studies examining factors driving decisions about the global R&D investments of U.S.- and EU-based companies (*8*, *9*) concluded that the most important features are potential for market growth, availability of environments that foster the development of a high-quality work force, and opportunities for productive collaboration between corporations and universities. There is still a tendency to place work addressing newer technologies and newer markets close to home, but this is by no means an absolute rule. Contrary to some assumptions, research costs have not proved to be the main factor stimulating companies to look toward Asia.

In its 2006 study (*8*) of more than 200 larger European companies, the European Commission found market access to be the most important factor in deciding where to locate R&D, followed by a predictable legal framework for R&D, access to specialized R&D knowledge and results, high availability of researchers, and macroeconomic and political stability. Respondents reported outsourcing an average of 18% of their R&D, around two-thirds going to other companies and one-third to public research organizations. Pharmaceutical and biotechnology companies outsource roughly twice the share of R&D as their counterparts in other sectors. These figures are consistent with other studies, including those by the author's organization, which suggest a U-shaped curve over the past 80 years. The minimum of around 3% outsourcing occurred in the mid-1970s, when the corporate laboratory was the dominant feature of the industrial landscape. Since then, the proportion of R&D performed outside the corporation has increased steadily, in line with the reported adoption of more open approaches.

Respondents distinguished between locations they considered most attractive for new R&D investment and where they expected their companies' R&D activities will grow. Although they often placed their home country first and saw the United States as most attractive outside the EU, they expected to direct most new investment toward China and the United States.

Thursby and Thursby (*9*) studied a similarly sized sample of medium and large U.S.- and European-based corporations and found that 38% reported that they plan to "change substantially" the worldwide distribution of their R&D over the next 3 years, with China and India attracting the greatest increase. For emerging country locations, the most important factors were found to be output growth potential, followed by quality of R&D personnel, supporting sales, IP protection, the ability to own IP, costs, collaborating with universities, and the expertise of university faculty. In developed countries, what matters most is the quality of R&D personnel and IP protection, university collaboration, output market factors, and IP ownership. The study revealed little difference between the views of U.S.- and European-based companies.

From Collaboration to Platforms to a Pact for Innovation

These and other (*10*) surveys confirm that companies prize locations that support business growth and offer high-quality work forces and collaborative partners. How can policy-makers improve the attractiveness of their own region?

In the European Union, a key objective remains to gain full benefit from a large single market. This still requires much work to reconcile the legal and other traditions of 25 member states and to overcome significant barriers, such as those concerning regulatory matters and mobility. There is a widely shared belief in having strong social structures supported by considerable public investment in areas like health care and transport. However, most public funding for these structures and for the dense network of public universities and national research organizations remains at the national level. As an illustration, the current European Research Framework Program (FP6) accounts for only a few percent of Europe's total research expenditure.

In recent years, smaller countries like Finland, Sweden, and Ireland have performed better than their larger, southern neighbors in terms of encouraging innovation-led growth through policies of market reform and effective public-private collaboration (and Finland and Sweden are well ahead of the Barcelona target for R&D), but these economies are now running close to their full capacity. The challenge is to find approaches that benefit the whole EU, improving and gaining more leverage from all the capabilities available within and beyond Europe.

Responding to discussions about innovation-led growth among heads of state in late 2005, a group led by former Finnish Prime Minister Esko Aho has recently reported (*11*) on how this

Table 1. Distribution of the headquarters of the 700 multinational companies that account for some 80% of private sector R&D investment and over 50% of all R&D within Organization for Economic Cooperation and Development member states (*6*).

Type of industry	Headquarters' location			R&D/Sales
	Europe	North America	Rest of the world	
Global 700	192	334	174	4.3%
"High R&D"	72	220	87	
IT hardware	15	93	22	10.1%
Automotive/parts	16	14	17	4.2%
Pharmaceuticals/biotechnology	22	42	18	13.7%
Electronics/electrical	10	14	28	6.0%
Software/services	9	57	2	9.0%
Other sectors	120	144	131	2.0%

might be achieved. The report recommended a combination of approaches, which reflect the trends described in the first part of this review. The group called for simultaneous, synchronous efforts in three areas:

1) To provide an innovation-friendly market for businesses, requiring actions on regulation, standards, public procurement, and IP; fostering a more pro-innovation culture; and creating demand focused on large-scale strategic actions.

2) To increase resources for excellent science, industrial R&D, and the science-industry nexus; to improve R&D productivity; and to shift the use of the so-called "structural funds" (used to underpin economic development in poorer regions) toward R&D.

3) To achieve far greater mobility of people across sectors, of financial resources and knowledge, and in the structures and clusters that frame innovation.

The report calls for a pact for research and innovation from political, business, and social leaders to drive the agenda forward. Its recommendations are strongly market-oriented in philosophy. Areas mentioned as possibilities for large-scale strategic actions include health, pharmaceuticals, energy, environment, transport and logistics, security, and digital content, where opportunities go beyond the capacity of individual economic actors. Although more resources for R&D and innovation are seen as a necessity, the 3% target for R&D becomes an indicator of success rather than an objective in its own right.

The response to these recommendations is currently being worked out and will become evident in the months ahead. Some conclusions can already be drawn from the wide range of programs that are already under way at European and national levels to establish conditions for greater competitiveness through research and innovation. There is growing understanding of the use of direct tax and fiscal measures, and the Dutch approach of relating tax credits to R&D employment through social charges is proving attractive. The revision of rules for State Aid (*12*) is intended to bring these rather arcane rules more in line with the requirements for innovation-led growth and effective use of public R&D grants. One more push may be sufficient to achieve a uniform single patent regime in Europe, even though this has defied all attempts at a solution for 40 years.

Ambitions for the European Framework Program are perhaps the easiest to state. A substantially larger budget, €50.5 billion ($66.3 billion) from 2007 to 2013 (*13*), has been agreed for the new program (FP7), whereas clearer emphasis is placed on excellence and utility. Its success depends on obtaining the best proposals and improving participation by both industrial and public research. An important innovation in FP7 is support for the new European Research Council, charged with fostering the best "frontier research" (a term intended to highlight that the traditional distinction between basic and applied research is no longer appropriate). A first priority for ERC's Scientific Council is the development of independent careers for excellent researchers establishing their first research team.

Improving Links Between Science and Industry

The quality of connections among companies and with universities and other public research organizations is an increasingly important factor that supports open models of innovation and is as important (or perhaps more important) in the long term as the number of university spin-offs and simple technology licensing agreements. Although there is a long tradition of informal joint supervision of Ph.D. projects in some European countries, the well-known difficulties presented by industry-academic collaboration are becoming more apparent as these activities take on more strategic importance. It is necessary to improve management of IP by public research organizations; to take steps to align interests, motivation, and culture; to address ownership of results and exclusivity; to improve project management; to compensate indirect costs; to deal with volatility of relationships; and to ensure equitable share of returns in case of success. These improvements require new professional skills and mind-sets, so that collaborative activities can enhance, not dilute, the distinct missions of public and private-sector research.

One way forward is through the development of standard model agreements and codes of practice for collaborative R&D, steps recently taken, for example, by the U.K. (*14*) and Irish governments (*15*). The 2005 launch of the Responsible Partnering initiative in Europe (*16*) marked renewed efforts to support changes in attitude and approaches to collaboration at the grass-roots level. Its recommendations are very similar to those reached by a similar initiative launched by the U.S. Government-University-Industry Round Table (GUIRR) (*17*). Both initiatives emphasize the need to establish conditions that foster stable, long-term collaboration and trust. This requires developing a better understanding at senior levels within public and private-sector organizations of managing open innovation, then recruiting and developing the new skills needed to handle collaborations effectively, establishing quality of collaboration as a key performance metric.

It is also important to raise standards within public research itself. This will almost certainly entail giving these institutions greater autonomy to set direction and to concentrate on strengths and, thereby, to attract the best talent to come to, and remain in, Europe. In several countries, universities remain subject to extensive national regulatory frameworks and have little control over their resources and priorities. There are close to 2000 universities in the EU, and most conduct research and offer postgraduate degrees across a broad curriculum. By contrast, fewer than 250 U.S. universities award postgraduate degrees and fewer than 100 are recognized as research-intensive.

Educational curriculum reform is under way in more than 40 European countries through what is known as the Bologna process. This aims to establish easily recognizable and comparable degrees based around a two-cycle system of studies, starting with a bachelor's degree and moving on to the master's level. A third cycle aims to ensure that doctoral studies remain relevant to changing career patterns.

Technology Platforms and Shared Strategic Research Agendas

Technology roadmaps have been used for more than a decade as a tool for providing frameworks for discussion between different business functions and for a more conscious integration of all aspects of technology into business strategy. The roadmaps enable decisions to be taken more quickly and to be implemented with greater confidence. They can also be shared within an industry sector and so lead to the adoption of common development platforms and strategic research agendas.

These approaches are being extended, thereby involving more stakeholders in the early stages and subsequent implementation of major research programs. As one example, the Netherlands Genomics Initiative (NGI) (*18*), involving many Dutch companies and university departments, is coming toward the end of its first, €300 million ($393.7 million), phase of a program to build an internationally leading genomics infrastructure that will stimulate excellent research and generate a continuous flow of new economic activity, while remaining firmly linked to the concerns and interests of Dutch society. NGI is set to enter its next phase, when it will seek to couple national resources more closely with international strengths while also concentrating on delivering economic benefits to the Netherlands.

European Technology Platforms (*19*) take the approach a step further. Some 29 of these industry-led initiatives provide frameworks for all stakeholders to define research and development priorities, time frames, and action plans on issues where growth, competitiveness, and sustainability objectives require major medium- to long-term research and technological advances. A number of platforms are now ready to begin implementation. Some funds for work that has a high degree of industrial relevance may come from the Framework Program, although this is not guaranteed. The challenge for the platforms is to fully mobilize resources and public authorities at national and regional levels, as well as from the private sector. In some cases, the scope of an objective and the scale of resources may lead to the setting up of long-term European public-private partnerships, in what are being

termed Joint Technology Initiatives (JTIs). The intention is that JTIs will combine private-sector investment and national and European public funding, including grants from the Framework Program and loan finance from the European Investment Bank.

An example comes in the field of health care. Among ways to respond to the trends in the health-care industry described earlier in this review are to obtain more effective methods for early safety evaluation, to provide better tools for integrated and predictive management of enormous volumes of data, to improve education and training in the use of these techniques, and to reduce barriers to carrying out clinical trials in Europe. These require efforts that go beyond the capabilities and remit of an individual company or public body. The Innovative Medicines Initiative (*20*) began by developing a strategic research agenda by consultation among all stakeholders. The agenda proposes the establishment of a public-private partnership to be operational in 2007, with investments around €440 million ($577.4 million) per year.

Conclusions

The challenge for European governments, companies, and public research institutes is to use the opportunities offered by open innovation to develop strengths and to build greater critical mass within Europe to support sustainable markets from new science. A main lesson from the past is that primarily top-down, centrally planned approaches are rarely effective. There is still much to gain from removing existing barriers to innovation, but policy-makers must now learn how to channel the significant resources and skills available within both public and private sectors to better address market opportunities. The goal will be to encourage innovation in ways that address the desire for strong social systems in Europe without either compromising the global competitiveness of European companies or reverting to old styles of "picking technological winners." A twofold approach is likely to emerge, aimed at encouraging a more market-oriented view of innovation while using direct measures to support more effective industrial and public-sector R&D. The appropriate balance between these elements remains an open question, the answer to which is likely to be determined by how responsibilities are shared between nation states and the European Commission as the Union continues to develop.

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6. Company data can be found at www.innovation.gov.uk/rd_scoreboard.
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20. Innovative Medicines Initiative, FP6; http://ec.europa.eu/research/fp6/index_en.cfm?p=1_innomed.

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