Catching up in pharmaceuticals: government policies and the rise of genomics

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Abstract

Genomics — the sequencing of the human genome and the identification of the genetic mechanisms of development and disease — is driving a restructuring of the global pharmaceutical industry. Many policy initiatives in biomedicine are based on the assumption that strength in genomics research will be translated into economic success, that is, that investments in genomics will be a way to catch up in the development of the bio-industries. There is therefore intense competition between nations and regions to establish a strong position in genomics, as shown in the growth of public expenditure on biomedical research in the last decade. This article addresses questions regarding the possibility of smaller countries catching up in the bio-based economy, given its present concentration within a few research-intensive networks and the historical advantage of established knowledge clusters, which exist primarily in the United States.

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What is known about the topic?
Developments in the biosciences generally and genomics in particular are driving structural change in the global pharmaceutical industry. This process — and the social, economic and political implications of the rise of the biosciences more broadly — is the subject of intense international debate.

What does this paper add?
This article highlights the central role of governments in achieving an adaptation of institutional structures to the growth logic of knowledge-based industries such as pharmaceuticals. The experience and prospects of several large and small countries are summarised.

What are the implications for researchers and policymakers?
The transformation of the pharmaceutical industry is intertwined with public policy, notably with the magnitude and structuring of public investments in science and initiatives in support of private–public partnerships. A strong focus on research and democratic policy deliberations is essential if Australian and other societies are to benefit from the rise of the 'bio-economy'.

THE EMERGING SCIENTIFIC and technological field of genomics is associated with strong public research institutions. Biomedical research 'clusters' sustaining a new wave of process and product innovation are expected to result in a shake-up of the concentration of the pharmaceutical industry and play a major role in the repositioning of countries within this industry. This highlights the central role of governments in the transformation of a knowledge-based and increasingly globalised economy. Many countries with a weak position in the biomedical economy are now investing heavily in genomics, with the expectation that this will strengthen their position within the global pharmaceutical industry. The same applies to larger countries, especially the United States, which has evolved into the hegemon of the bio-based economy. Indeed, there is a race to capitalise on the commercial potential of genomics and its effects on the innovation strategies of the pharmaceutical industry.

This article explores the hypothesis that the rise of genomics will have a major impact on the structure of the pharmaceutical industry. Big firms are increasingly dependent on linkages with knowledge-producing institutions for their inno-

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vative capacity, and these connections tend to be concentrated within particular geographic areas. Old knowledge centres risk becoming obsolete in this process, while new ones are still in their infancy. Governments play a central role in the dynamics of the new bio-industries; government strategies can influence, for example, patterns of location and collaboration. This article focuses in particular on the issue of possible differences between large and small countries in their response to genomics. The pharmaceutical industry has traditionally been concentrated within a small number of countries, in particular the US but also Britain and several smaller European countries including Switzerland and the Netherlands. Most countries have only played a peripheral role in the global pharmaceutical industry.

Research policy across the industrially developed nations is grappling with developments in the biosciences. Many countries have implemented policies to capitalise on the new biology and reap benefits from its potentially large economic impact. For example, Singapore has initiated large-scale programs to attract scientists and investments from biotechnology and pharmaceutical companies. The Netherlands, Canada, Australia and other nations have also made committed efforts to develop post-genomic centres of excellence to support technological and industrial development. The logic behind these investments is based on the cluster argument: the expected link between a vibrant basic biomedical academic sector and the establishment of a biotechnology research sector that generates growth in the knowledge-based economy. Thus, the role of the state in the knowledge-based economy is growing rather than declining, which would seem to invalidate dominant discourses on the virtues of a free market (Jessop 2000). This article surveys and compares policies in support of genomics and genomics-based economic growth in larger economies — the US, the UK and Germany — and in smaller nations such as Canada, the Scandinavian countries, and Australia. How are smaller countries preparing for the transformation of the changing knowledge base of the pharmaceutical industry? And how are larger countries — the hegemons of the bio-economy — responding to changes in the science and technology that sustains the pharmaceutical industry?

The bio-society: a new wave of social and economic development?

The 1990s was a decade marked by the search for a post-industrial growth engine. The dramatic increase in the number of Internet start-ups signalled the rise of a new mode of economic growth and corporate organisation — the 'new economy'. Its institutional foundations were high-technology based entrepreneurship, a rich supply of risk capital, and a thriving stock market. The information and communications technology (ICT) sector was seen as an arena for the integration of new ideas, innovative organisational practices, and the rise of a new, culturally oriented type of entrepreneurship (Kelly 1998). The role of the state in this emerging mode of economic growth was relatively limited, at least on the surface, and the rapid growth of ICT entrepreneurship seemed to confirm the free-market political dogma of the 1990s.

Since the sudden decline of the Internet industry around the millennium shift, other sectors have become more attractive as role models for a knowledge-based economy. The bio-sector is the prime example, especially the broad field of biotechnology. The bio-economy is not a 'new economy' in the sense that the ICT industry was; its institutional foundations are quite different. The biosciences are science-driven rather than driven by changes in design, as in the case of ICT (Stankiewicz 2001). Hence, the development of social and industrial applications, creating novel and profitable ways of intervening in nature, are more dependent on an active role of the state, and in particular the structure of the public science base, than is the case in the domain of ICT. The state is the dominant funder of basic research, and the university system is publicly operated in most countries. The lead times to new products are different: instead of a few months in information technology, development of new biotech products may take up to a decade, requiring investments of hundreds of millions of dollars. Public basic research is typically necessary in the initial phase of the development process. In effect, the state acts as a risk-sharer in the pharmaceutical industry as well as in other sectors based on the biosciences. There is a large need for highly trained personnel, generally graduating from publicly funded institutions, to master complex scientific and technological issues. To exploit the new opportunities, there is also a need for bridges between different public and private institutions in the development, dissemination and utilisation of new knowledge, especially between academic institutions, research-based small firms and large companies.

Location patterns in the bio-industries are to a large extent related to variations in the strength of the public research systems (Cooke 2004). Furthermore, the regulation of life forms and social relations are central to the growth of the bio-industries, a regulatory capacity mainly provided by the state (Rose 2001). The state is a powerful agent in shaping knowledge production and organising the health care system, but also in influencing public attitudes to new technologies, hence sharing the risks of pharmaceutical companies in the development and diffusion of new products and technologies. The search for a stable growth paradigm based on the bio-sciences thus requires a different type of institutional framework than the one associated with the 'new economy', which was primarily market-driven. The role of government agencies is much more central; the state acts as a powerful shaper of the knowledge foundation of bio-industries as well as of public attitudes towards the new technologies.

The root of genomics lies in molecular biology, which in turn emerged with the rise of biochemistry and the development of knowledge of the transformation of molecules within organisms (Furukawa 2002). Genomics is technology-driven in the sense that research instruments have played an essential role in the understanding of complex biological phenomena (Keating & Cambrosio 2003). Genomics as a scientific and technological field is thus highly dependent on public research institutions, given the uncertain commercial potential of large-scale technology investments. The development of genomic knowledge is therefore emerging from interactions between public research organisations and dedicated biotechnology firms, while the large pharmaceutical firms are awaiting signs of technological breakthroughs that will impact the drug development process.

Indeed, the whole area of genomics has arisen on the basis of public research. It is only at a later stage that a few private firms like Celera and deCode have emerged to perform genomic and post-genomic (studying the functions of genes in the organism) research (Davies 2001). Advances in biomedical sciences occurred and continue to occur in or around medical schools and hospitals. This leads to a clustering phenomenon where academic centres with a critical mass of expertise are intertwined with various support functions such as technology parks, venture capital providers, ICT companies, patenting, insurance and legal firms, etc. Large pharmaceutical and biotechnology firms tend to locate their facilities according to this logic of clustering (Cooke 2001). For the large firms, the attraction of locating in an already existing cluster of expertise is the potential of becoming part of an 'innovation community' characterised by dense market exchange as well as strong flows of non-codified information (Howells, Andrew & Khaleel 2003).

Universities tend to be central within such knowledge agglomerations or clusters. If academic centres in biomedicine are of high quality, they attract qualified scientists and engineers, who attract other skilled professionals. Hence, well-established academic milieus become 'collectors of talent' (Florida 2002). Also to be expected is a race to accumulate 'strategic intellectual capital' as a building block in the development of strong biomedical clusters (Cooke 2004).

Molecular biology and genetics research have opened a whole new path for the pharmaceutical industry by mapping genes and beginning to identify their function and interdependence in the organism (Drews 1999, p. 162). The vision outlined by its proponents is that genomics will make it possible to integrate hypothesis-driven and clinical studies, potentially integrating genomics research with clinical innovations and new therapies into the emerging field of 'molecular medicine' (Bell 2003). If this vision turns out to be soundly based, the evolution of genomics will change the organisational structure of the pharmaceutical industry, with universities and biotechnology firms becoming increasingly important as central drivers of the drug development process. The core of drug development will be undertaken by cross-organisational teams, encompassing a broad set of competencies — including molecular biology, biotechnology, biochemistry, physiology, computer science, physics, etc. — and with a broader orientation than the traditional academic role of pursuing independent science or the traditional industrial role of developing new products. Research constellations of this type will be technology-driven, vertically integrated (research, development and parts of the entrepreneurial function) and horizontally integrated (integrating the academic system, small firms, and big companies).

Genomics research is therefore often identified as a new innovation avenue for a business increasingly plagued by declining innovative capacity. Despite the sharp increase in research and development (R&D) expenditure in the pharmaceutical industry, genuinely new products are increasingly scarce (Triggle 2003). Arguably, this slowing pace of pharmaceutical innovation has been matched by the rise of new organisational structures, reinforcing the industry's capacity to maintain profit levels through aggressive advertising campaigns and legal actions to support existing products (Angell 2004). Although this strategy may be effective in the short term, the current structure of the pharmaceutical industry seems to be detrimental to an innovative turn in pharmaceuticals. The large pharmaceutical firms claim that high profit margins are necessary as a foundation for product renewal and risk-taking, but studies indicate that the share of profits spent on R&D is much smaller than expenditure on marketing, legal consultancy, and other activities not related to industry renewal and innovation. R&D activities also focus increasingly on imitations or incremental improvements of existing drugs rather than radical innovations.

Genomics could be a driver of technological renewal and the restructuring of the pharmaceutical sector, dominated as it is today by a limited number of large firms concentrated in a few areas of the world, especially in the United States (Cooke 2004, p. 187). The role of research-focused organisations such as academic institutions and small biotechnology firms can be expected to increase, while larger firms would concentrate on activities further downstream in the development process. Such disintegrating tendencies are not new to the pharmaceutical industry, but would be sharpened by the rise of genomics. This, in turn, is part of what has been described as an emerging growth logic of knowledge-based industries, based on the role of basic research for industrial development (Florida 2002). For governments, such disintegration offers threats as well as opportunities, as will be further explored below.

Cockburn (2004) has argued recently that reconfiguration of the pharmaceutical industry along these lines does not necessarily solve the R&D productivity crisis. It could introduce new problems, such as increasing transaction costs and escalating litigation between interacting organisations. Nonetheless, there are indications that the science base has become a productive source in the search for a position in the global, knowledge-based economy with an ensuing trend towards organisational disintegration of knowledge-based sectors (Cooke 2002). In essence, the emergence of science-based technologies — such as genomics and its applications in drug development — drives a global reorganisation of business sectors and their technological foundations, and governments are challenged to respond through the use of public research funding to strengthen the national competitive position in these sectors. In the following sections I explore policies devised to capitalise on the emerging clustering logic of R&D activities in pharmaceuticals, that is, attempts to stimulate — through investments in public sector research — the emergence of knowledge clusters seen as entry-points into the bio-economy. Larger countries will try to maintain or strengthen their leading position in the biosciences and the pharmaceutical industry, while the objective of governments in smaller countries is to reap at least some of the benefits of a scientific and technological transformation seen as signalling the breakthrough of new bio-economy.

Large countries' response to genomics

The big pharmaceutical companies that dominate the global prescription drug industry are headquartered mainly in the larger nations. The US in particular has attracted a major share of bio-industry investments due to its strength in biomedical research, policies for stimulating commercial exploitation of public R&D, and the size of its market. The US share of the global pharmaceutical market is currently around 50%, compared with 25% for the European Union. Public bioscience R&D expenditure in the US is also about double the size of investments in the European Union (Cooke 2004, p. 188). This process of concentration in the US began in the early 1990s. At this time, the US and European markets were of the same magnitude, and investments in bioscience R&D were also roughly equal in Europe and the US. The rapid US expansion in the past fifteen years is due largely to higher prices than in other industrially developed countries, as a consequence of the absence of government price controls, and to a generally more favourable institutional environment for the biosciences.

The National Institutes of Health (NIH) form a key part of the US biomedical research system. In the 1990s, funding of the NIH was almost doubled (in current prices) and the investments are still increasing, although at a lower rate (Greenberg 2001, p. 485). In some years of the late 1990s the NIH budget rose annually up to 20%. In dollar terms, the NIH budget increased from US$18 billion in 2000 to more than US$23 billion in 2003. The real change in NIH funding took place from the mid 1990s under President Clinton, and the support has been channelled into both an expansion of intramural NIH research and a growing external project portfolio. In the genomics field, the NIH runs the National Human Genome Research Institute and it also funds research grants and a variety of Centres of Excellence in Genomics Science. The budget of the National Human Genome Research Institute has been increased from US$60 million in 1990 to over US$420 million in 2002. Several other institutes, such as the National Heart, Lung, and Blood Institute, also operate genomics programs. In addition, the US has a large number of philanthropic institutions supporting biomedical research, the largest of which is the Howard Hughes Medical Institute which in 2002 provided around US$500 million to biomedical research. The massive injections of new funding have been accompanied by a multitude of programs for academy-industry collaboration, especially among research-intensive universities (Mowery et al. 2004).

The US biomedical system has thus expanded rapidly in the last decade through large injections of both public and private funding. The competitive advantage of the American research system in the biomedical area in general, and genomics in particular, in terms of both basic science and commercial developments, will most likely be reinforced in the future. This poses a major challenge to smaller nations, especially when it comes to recruiting and retaining cutting edge researchers.

The UK is the leading European investor in biomedical research. The UK biomedical research sector comprises several of the world's leading biomedical research institutions (including Oxford, Cambridge and Edinburgh Universities) and several major pharmaceutical companies such as AstraZeneca and GlaxoSmithKline, as well as significant biotechnology clusters, notably that of the Cambridge area (Cooke 2002). Currently, funding for genomics research in the UK is channelled through the dual system of the public Medical Research Council (MRC) and the private fund, The Wellcome Trust. The MRC budget has increased over 30% in the last three years, and is expected to increase further. The MRC has increased its support for genomics dramatically. New initiatives were announced in 2000 as part of the increased appropriations to the MRC: UK£65 million earmarked for genomics research, and 1 billion (jointly with the Wellcome Trust) to the Science Research Infrastructure Fund, expected to focus parts of its efforts on biomedical research in the genomics area. At least £500 million will be spent on medical research. Support is also provided to more than ten MRC units with an orientation towards genomics. The MRC Mouse Genome Centre and Mammalian Research Centre at Harwell, founded in the mid 1990s and employing around 200 research staff, are examples of recent major investments in genomics facilities.

The Wellcome Trust is now the largest funder of biomedical research in the UK, allocating about £3 billion to research in this field in the 2000–2005 period. The Trust established the Functional Genomics Development Initiative in 1999 and will invest more than £300 million between 2001 and 2006 in the Wellcome Trust Sanger Institute, part of the Wellcome Trust Genome Campus (which also includes the Human Genome Mapping Project Resource Centre, founded in 1993 as a collaboration between the Trust and the MRC). The Trust is also involved in the setting-up of a UK Biobank, supports a number of multidisciplinary research consortia and is engaged in support for stem cell research.

UK public debate and policy rationale is similar to that in the US, namely to reap the economic and social benefits of British industrial specialisation in the biomedical area. With this objective, increases in research funding have been matched by various programs to bolster science-based entrepreneurship (Cooke 2004). The pharmaceutical industry plays an important role in the British economy in terms of employment, value-added, and exports. The largest pharmaceutical firms account for about a quarter of total R&D expenditure in British industry (Georghiou 2001, p. 255). Investments in genomics are premised on the belief that Britain's scientific, technological and industrial position in the bio-area is critically dependent on decisive interventions to strengthen linkages between the science base and this industrial stronghold.

Germany is an example of a large country historically not specialised in the knowledge-based sectors. The German research and innovation system has traditionally had its strongholds in mechanical engineering, transportation and similar fields with strong linkages to areas of German industrial specialisation. The development of the bio-sector has been much slower. To alleviate these problems, the German government has emphasised the regional dimension of biomedical research policy. A 'Bio-region' initiative was introduced in 1995 to prop up the biotechnology capacity in Germany, integrating universities, research institutes, industry and regional authorities (Cooke 2002). With a focus on genomics research, a National Genome Research Network (NGFN) was established by the federal government to strengthen the academic infrastructure and to develop technology and research platforms and disease-focused research.

The main German channels for support of biomedical research are the university system, the German Science Council (DFG) and the Max Planck institutes. The university system — comprising over 80 universities — is generally considered inflexible, segmented, and too overloaded to be able to provide a strong infrastructure for top-class research (Meyer-Kramer 2001, p. 214). Nonetheless, investments in university-based genomics research are of significant magnitude. The German Research Society (Deutsche Forschungsgemeinschaft) is responsible for a range of initiatives in genomics, such as The Rudolf-Virchow Centre for Experimental Biomedicine which is one of three DFG-Research Centres, a dozen basic and clinical research centres, a number of collaborative research centres, etc. These add up to more than €200 million annually for biomedical research.

The private foundation the Max Planck Society operates the Max Planck Institutes which have proven to be effective vehicles for basic research, especially in the natural sciences and biomedicine. The significance of the Max Planck institutes is their orientation towards interdisciplinary co-operation, their emphasis on scientific leadership, and their flexibility (providing post-doctoral fellowships and interaction with the universities). They are usually comprised of up to several hundred mostly contract-employed researchers, organised into laboratories and groups headed by senior researchers. The most recent and most adventurous of these initiatives was the setting-up of a new Max Planck institute for molecular cell biology and post-genomics in Dresden. The institute, with an international recruitment basis, is complemented by large investments in two centres for bio-innovations and bio-informatics. Among other institutes operated by The Max Planck Society are the Institute for Biochemistry in Martinsried, which concentrates on studies of gene functions, and the Max Planck Institute for Molecular Genetics in Berlin, specialising in studies in DNA replication and gene regulation.

Germany's traditional competitive advantage is in mature industrial sectors, not in science-based industries. The capacity for rapid deployment of resources in the national innovation system is underdeveloped and the emphasis historically has been on incremental, rather than structural, technological and economic change (Meyer-Kramer 2001) — hence the need to develop integrated science-technology and industry clusters based on scientific expertise in well-funded institutions and to provide support for an innovative environment for commercial exploitation and integration of biological and technical research.

In summary, larger countries, in particular the US and the UK, are seeking to consolidate their leadership in the bio-industry through continued large-scale investments in public research and a variety of programs to commercialise biomedical research and reinforce linkages between public and private institutions. Germany, by contrast, is a large country that has historically emphasised research and development in fields other than the biosciences. However, Germany is now developing state-orchestrated growth alliances in the bio-sciences, with the state compensating for traditionally weak academy–industry relations.

New opportunities for smaller countries?

While the larger countries seek to strengthen their already dominant position in pharmaceuticals by devising large-scale programs for genomics knowledge clusters, smaller countries are also promoting the biosciences in general and genomics in particular. For instance, in the Netherlands, government spending on genomics research has increased substantially. As a result of the recommendations of the so-called Wijffels Committee, it was accepted in 2002 that €200 million were to be spent in the genomics area. A national organising body, called the Netherlands Genomics Initiative (Nationaal Regie-Orgaan Genomics) has drawn up an ambitious strategic plan for research on genetic material. This agency currently funds four centres of excellence and two technology infrastructure centres.

The Scandinavian countries have also responded to genomics and the opportunities of expanding bio-industries (Benner 2003). The Danish Medical Research Council has a program for large research groups in genome research. The Danish National Research Foundation, established in 1991, funds a number of research centres in the genomics area. The Norwegian government, through a Research and Innovation Fund, supports several large research centres in biomedicine. Finland, which has moved rapidly to the top of both academic and commercial rankings in the bio-area, has two large-scale programs with implications for biomedicine and genomics: a Centre of Excellence program (with several programs in genomics) and three large technology development programs in drug development, diagnostics and biotechnology. In Sweden, most genomics funding has come from the private Wallenberg foundation, in the form of two technology platform programs. The overall objective of the Wallenberg initiatives was to develop and use state-of-the-art technology for high-throughput functional genomics. In all the Nordic countries, public and private research funding has been combined with policies for regional development and industry clustering, most notably in Finland where an aggressive state-initiated policy for bio-region development was pursued throughout the 1990s (Cooke 2004).

Canada, the vulnerable neighbour of the US biomedical powerhouse, has also devised an ambitious policy to strengthen its position in biomedicine in general and genomics in particular. For the first of these purposes, Canada has massively increased the number of professorships in biomedicine: CA$900 million has recently been allocated to establish 2000 research chairs, of which 1000 are in biomedicine and biology. The Canadian government recently launched a large-scale program to enhance genomics research — GenomeCanada, funded with CA$4375 million from the federal government and another CA$300 million from other sources. The centres, technology platforms and projects supported receive about CA$10 million over their lifetime. A Structural Genomics Consortium, a collaboration with the Wellcome Trust and GlaxoSmithKline, with funding at around $95 million, was the largest research effort ever in Canada. In addition, there is a $3.65 billion Canada Innovation Fund which supports infrastructural investments, clinical research, career awards, and international collaborations.

Organisationally, these initiatives have been channelled through new structures, mainly regionally based research centres integrating several existing research organisations. The very idea behind the program is to develop research centres with resources of a scale previously unusual in Canada, and to develop ". . . large-scale genomics and proteomics projects that draw on existing Canadian strengths and expertise, and whose scale and scope are such that they cannot currently be funded at internationally competitive levels . . ." (GenomeCanada 2003). The objective is to foster new structures of economic growth and societal development in Canadian society. The strategy for developing genomics and post-genomics as a particularly strong field in science and industry is grounded in the target to "make Canada one of the leading research countries in this field". It is also part of Canada's 10-year innovation strategy, "moving Canada into the ranks of the most innovative countries in the world by the year 2010" (Allan Rock, Minister of Industry, quoted at www.innovationstrategy.gc.ca). This is combined with a stringent macroeconomic policy, which has generated a budget surplus and invested in programs such as GenomeCanada, Canada Research Chairs, and the Canada Foundation for Innovation. The design of the genomics initiative is partly related to the traditional structure of the Canadian economy, dominated by sectors such as agriculture and forestry, but is also seen as a way to stimulate industrial renewal through new industrial activities.

Along similar, if less spectacular, lines, Australian governments have allocated substantial investments to the bio-industries, despite an emphasis on free market policies for industrial development (Lofgren & Benner 2003). This includes a doubling of expenditure on biomedicine through the National Health and Medical Research Council (NHMRC) — from A$175 million in 1999 to A$350 million in 2005. An Australian Genome Research Facility (AGRF) has been established as a joint private–public facility to enhance the interaction between the public research system — which is of an internationally competitive standard — and the bio-industries, which constitute a weak component in Australia's industrial system.

Singapore, finally, represents perhaps the most dedicated state-led attempt to develop a research and innovation policy for the biomedical area (Brantley 2002). Based on the so called Industry 21 initiative launched in 1999, the Singapore government will spend more than US$3 billion on policies for cultivating biomedical research and related industrial activities. The life sciences cluster was selected as the "4th pillar of Singapore's manufacturing sector" (Brantley 2002). Tax concessions, the development of a 'bio-polis' for bio-based firms, a biomedical research council assigned the task of recruiting international star scientists, an advanced infrastructure for technology transfer, and other measures, form a comprehensive package of policy initiatives for the development of knowledge-based industries. The social dimensions of this program are also addressed, including attempts to create conditions for an 'innovation lifestyle' to facilitate the recruitment of leading biomedical researchers to Singapore.

In summary, many smaller countries and economies are trying to catch up with the large countries in the bio-industries. They do so by massive injections of public funding of the biosciences, with a special focus on genomics. These research policy initiatives are complemented by support schemes to enhance the interaction between academic research centres and commercial activities in research-oriented small firms and larger pharmaceutical companies. In some cases, most notably in Singapore, innovation policies include programs to change the social fabric within which the knowledge clusters are embedded, to create congenial environments for high-technology economic developments.

Concluding discussion

Across the OECD, there is a race on to adapt institutional structures to the growth logic of the knowledge-based industries. Public policy measures, typically tailored on the US model, include support for developing strong private–public partnerships and expanded funding for the science base to attract international investments and to create internationally visible and well-connected research centres. Small and large countries alike pursue aggressive policies to develop genomics research and its commercial applications. While policy initiatives concentrate mainly on increased expenditure on public research, some countries — notably Singapore but also to some extent Australia and Finland — have initiated a broader set of institutional changes, including the development of joint private–public research facilities, technology transfer organisations, and measures aimed at changing social organisation and public attitudes. It can not be predicted, of course, whether such policies will 'succeed' in terms of influencing the global structure of the pharmaceutical industry and achieving a stronger integration of particular national innovation systems into global technology networks. Results will depend on the degree to which genomics research and a disintegration of the large corporate conglomerates will actually reinvigorate drug development. It is clear, however, that governments worldwide are developing policies premised on the expectation that science and technology policies will influence the position of nations in knowledge-based sectors like pharmaceuticals.

A critical question remains; how will the rise of genomics affect the structure of the pharmaceutical industry, and to what extent will a changed industrial structure be open to new players? As yet, the trend if anything seems to be for the concentration process to be reinforced. The key drivers of genomics — public research centres and small biotechnology firms — are located in a small number of knowledge clusters mainly in the US and the UK (Cooke 2004). Even though genomics may drive a partial disintegration of the pharmaceutical industry, a whole new landscape for drug development will not emerge. Changes in the structure of the value chain — where public research organisations and dedicated biotechnology firms are becoming increasingly central — will not necessarily result in a new global division of labour in pharmaceuticals. Instead, the old pattern of concentration in the US and a few other large countries is likely to be consolidated, not least because of the massive investments by the governments of these large countries in biomedical research. The remarkable development of the pharmaceutical industry in Singapore and in Finland shows, however, that with sustainable investments in research and development together with industrial support schemes, smaller countries can catch up with the larger countries in a sector increasingly marked by concentration.

The major conclusion to be derived from this analysis relates to the role of the state in the global knowledge-based economy, within which the pharmaceutical industry is typical. The state plays a central role in the development of knowledge-based industries. Investments in the early phases of technology development are financed mainly by the state, and there is no sign that the emergence of new technologies will change this pattern. If anything, the role of the state has been reinforced as large firms shift their focus to near-market activities. This creates both opportunities and threats to government, especially in smaller nations. They may have no option but to invest heavily in the new research fields and technologies, but there can be no guarantees of future success in terms of economic advancement.

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