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Life Sciences Clusters and Regional Science Policy

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Summary. This paper focuses upon Life Sciences and the manner in which R&D-led clustering concentrates key resources such as basic research funding, research infrastructure and innovative businesses in a few clusters where even large pharmaceuticals firms are nowadays often learners (from academia) rather than research leaders, as in the past. Because Life Sciences and healthcare are strongly intertwined, and huge increases in healthcare R&D and general expenditure mean that some 20 per cent of GDP is accounted for by the broad sector, regions that have missed out on this future 'knowledge economy' bonanza are desperately seeking to remedy things. Examples are provided of new regional science policy instruments for redistribution of such knowledge economy advantages that moves beyond mere innovation support.

1. Introduction

In this paper, the aim is to explore the likely effects upon science policy of changes in R&D-based clusters due to the rise of 'knowledge economies' (Dunning, 2000; Cooke, 2002). To advertise the argument beforehand, it is that the decline in R&D power of large corporations is accompanied by the rise of specialist research firms. The latter include, for example, those referred to as 'discovery companies' in Life Sciences, along with university and other research labs in proximity to which knowledge-intensive firms increasingly cluster. This is particularly pronounced in biotechnology, but also occurs in other knowledge-intensive sectors like information and communication technologies (ICT), new media and advanced business services. Broadcasters and *bourses* are stronger cluster magnets than universities in the last two cases. That Life Sciences activities cluster geographically along the knowledge value chain from exploration (basic research) through examination (clinical trials) to exploitation (dedicated biotechnology firms—DBFs) is widely known and shown.[1]

Continuing the argument, it will be shown that over the 1990s many regional governance agencies developed interest and capability in formulating policies to network regional innovation systems. To some extent, multilevel governance hierarchies have evolved, as suggested in Lundvall and Borrás (1997) and Cooke *et al.* (2000) where national governments are mainly responsible for delivering science policy and basic research funding, while regional governance systems (involving public and private actors) deliver innovation programmes. These are usually near-market incentives to firms to build innovation networks, access co-funding and engage in joint marketing to enhance innovative potential and competitiveness. In

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Europe, the European Union was less directly involved than member-states in basic research funding, more in research and technology development (RTD) and, while co-funding *innovation* initiatives, leaving these to regions to deliver along with their own and any national programmes on the ground.

In what follows, the first main section will show how and why knowledge economies create regionalised innovation networks and clusters in Life Sciences and biotechnology. In section 2, the implications of this are explored for the national innovation system model of 'big science' and—for example, 'big pharma' following an expensive 'chance discovery' methodology, also involving big departmental research laboratories in universities. Then, finally, evidence is mobilised to show the emergence of regional science policy and regional science policy *funding* mechanisms. A model that responds to regional *science* funding requirements within the national basic science funding remit is also discussed.

2. Knowledge Economies and Their Regionalisation

A common misconception among non-regional scientists is that when regional analysis is done it inevitably means somehow ignoring other spatial, economic or political scales. As will be shown, the contrary is the actual position, particularly where science, technology and innovation are in focus. Indeed, what has been shown elsewhere (Lagendijk, 2001; Cooke, 2001b) is that, by excluding the *regional* level from analysis, major innovation interactions between key knowledge generation and exploitation actors are likely to be overlooked. As Dicken (2001) sees it, from the TNC perspective, regionalisation enables faster delivery, more customisation and smaller inventories than globalisation. But this does not mean TNCs become less global; rather, they use whatever advantages may be available to them in seeking value chain efficiencies. So it is with regard to what might be termed the 'knowledge value chain' that this exploration is directed.[2] What is this and how might it be changing? We know of the changed emphases in knowledge production proposed by Gibbons *et al.* (1994). Key differences involved are the move from Mode 1 to Mode 2 conventions like disciplinary purity to *transdisciplinarity*, organisational hierarchy to *flexibility and diversity* and value freedom to *reflexivity*. Related to reflexivity, the authors argue, are *quality*-related questions of a new kind concerning the competitiveness of knowledge outcomes in the market, or cost effectiveness and social acceptability.

Critique of this view focused on its technocratic introspection and failure to show science having to engage with social forces. In a subsequent book (Nowotny *et al.*, 2001), some of these authors respond with an acceptance of Latour's (1998) identification of a struggle between 'science' and 'research'. The former is stable, the latter unstable and the rise of research expresses a 'contextualisation' of science by society, politics and economy despite its claims to objectivity. Thus more multidisciplinary concerns and network interactions typify modern Life Sciences, as Powell *et al.* (1996) and Orsenigo *et al.* (2001) among many others show. Indeed, the former go as far as to assert that 'knowledge is in the networks', a revision of the traditional primacy of codified over tacit knowledge. Orsenigo and colleagues explain this in terms of the heterogeneous nature of the cognitive skills demanded in bioscientific research. The economic and ethical demands of 'research' give rise to collaborative learning through transdisciplinary network relationships. Science's engagement with society initially occurred on *its* terms, as 'public understanding of science', now rightly criticised for its patronising disposition. It is, accordingly, difficult to see voluntary *reflexivity* in knowledge production in Life Sciences and others. Rather, ethical regulatory powers and company protocols to constrain 'value-free' excesses in the field have had to be imposed externally. Contrariwise, as we shall see, the inclination for stock market imperatives to interfere with peer review norms of scientific reporting is increas-

ingly driving announcements of scientific discovery and raising further ethical issues.

Thus, in 2001, Millennium Pharmaceuticals and Human Genome Sciences both made press announcements when experiments reached Phase 1 of clinical trials, at least three years away from possible approval.[3] In the past, such announcements would be made on applying for approval. Also, dedicated biotechnology firms (DBFs) have recently made announcements on experiments still at basic research stage, such as Advanced Cell Technology's claim to have cloned a human embryo and PPL's to have cloned pigs, both in advance of peer review and publication of results. This is doubly problematic when, at approval stage, large numbers of candidate treatments are rejected, as 30 were by the US Food and Drug Administration during 2001. These included Chiron's anti-sepsis drug, Immunex's cardiac infarction treatment and Maxim's melanoma product. A US head of bioethics was quoted as saying that "these companies must raise enormous amounts of money and the only way to do that is to put a hard spin on any good news" (Griffith, 2002).

An effect of the rise of research is that the mode of knowledge production has shifted, as revealed in Life Sciences R&D databases such as that of Pammolli *et al.* (2000) at the University of Siena. For example, of the 50 dedicated biotechnology firms (DBFs) in the database pursuing 'designer molecule' rather 'discovery' methodologies, 74 per cent operated in global, hierarchical networks with big pharma developers. From 1992 onwards, the incidence of R&D projects involving combinatorial chemistry, target-based screening, genomics and genomic libraries doubled. All but one of the 26 per cent of specialists followed the leaders after 1992, mostly in bioinformatics. Strikingly, 54 per cent of the DBFs responsible for originating all these R&D projects were in 4 key US clusters: Cambridge, MA (18 per cent), San Francisco-San Jose, CA (16 per cent), San Diego, CA (12 per cent), and Maryland (8 per cent). Hence we see a highly globalised, hierarchical knowledge generation model in which leading-edge research is initiated by multidisciplinary DBFs in clusters linking with (often many) large pharmaceutical firms, research institutes and other DBFs as developers. It is plain that the clusters are increasingly the locus of knowledge generation.

The rise of research over science explains the rise of DBFs over big pharma in new knowledge generation. But DBFs still need large drugs firms to fund their discovery programmes. Thus despite most of the major companies experiencing drought in the product pipeline, they accommodate to new realities. For example, Swiss company Novartis announced in early 2002 that Glivec, its already successful chronic myeloid leukaemia (CML) drug also works for stomach tumours. The US Food and Drug Administration (FDA) hastened approval for Glivec to save the lives of leukaemia sufferers and the product was granted orphan drug status in the US and the UK for gastrointestinal stromal tumours.[4] Novartis' methodology for developing Glivec was a prototype for the rational drug design or 'silver bullet' rather than 'chance' mode of drug discovery. This entailed genomic research to target the precise molecule giving rise to the mutation causing CML.

Actually, Glivec is rather unusual in that DBFs were not directly involved in the progress towards production of the therapeutic treatment. Rather, as may be seen in Table 1, the elapsed time from initial discovery to final approval was 40 years. This is too long for DBF and venture capitalist survival of the normal 10 years or so from proof of concept to hoped-for initial public offering of the DBF to the stock market. Nowadays, combinatorial chemistry that allows vast numbers of compounds to be screened rapidly and systematically through high-throughput screening (HTS), applied also to methods for sequencing genes, speeds up the process (although for big 'pharma's' failures also in this field, see Cooke, 2004). Research DBFs have advantages in swiftly bringing together networks of distinctively skilled researchers and technologists to target specific molecules.

Table 1. Institutional and corporate history of Novartis CLM treatment 'Glivec'

Date	Institution	Name	Indication
1960	University of Pennsylvania	Nowell/Hungerford	Blood chromosome 22 'Philadelphia chromosome'
1973	University of Chicago	Rowley	C22 translocated to C9 discovery
1986–87	Whitehead Institute, Cambridge MA	Baltimore	Bcr-Abl protein: Tyrosine Kinase (cell regulator)
1992	Dana–Farber Cancer Institute, Boston	Druker	Bcr-Abl > CM leukaemia; mutant enzyme jams cell-signals discovery
1993	Oregon Health Sciences University	Druker/Ciba–Geigy	Reagent and inhibitor for Tyrosine Kinase activities
1993	Ciba–Geigy	Leyden/Matter	ST1571 inhibitor compound (Glivec) selected
1998–2000	Novartis	Druker	Clinical trials and FDA approval
1998		Nowell/Rowley	Lasker Medical Research Award

Source: Journal of the National Cancer Institute, 5 January 2000 (http://www.nci.nih.gov/clinical_trials).

case study of Glivec

Thus it was university and private research institute scientists that conducted the fundamental research that resulted in Novartis releasing the world's first approved drug directly to turn off the signal of a protein known to cause cancer. In other words, the 'rational drug design' approach pioneered in cancer treatment by Novartis was really the culmination of university and research institute processes of origination, and final development through the company. Although it started as 'chance' discovery of the Philadelphia chromosome, it evolved into a process in which precise molecular targeting became possible. This is expected to become an important, possibly the paradigmatic, methodology in the post-genomic era.

In the Glivec case, the importance of particular centres of research excellence in a strong biotechnology region like Greater Boston is evident. Random discoveries were made elsewhere early on but key milestones were reached in the 1980s and early 1990s, first at the Whitehead Institute (Cambridge, MA), subsequently co-leader of the human genome project, and the Dana–Farber Cancer Institute (Harvard), in identifying and then understanding the mechanism causing a mutant enzyme to jam the signal that normally prevents massive overproduction of white blood cells, hence CML. This built on the prize-winning research elsewhere that first identified and, secondly, found where the key piece of missing DNA had translocated, which was a valuable research by-product. Thereafter, the main development technology moved with Brian Druker, the holder of the reagent that matched Ciba–Geigy's inhibitor compounds for Tyrosine Kinase activities, from Harvard to Oregon and Basel, Switzerland. This meant Ciba only had to check its bioinformatics library. Such is the esteem in which Greater Boston is held by Novartis that in 2002 the company announced the location of its new $250 million Genomics Research Institute there. In 2003, Aventis announced a larger ($350 million) genomics research investment in Canada's leading cluster at Toronto. Comparable research clustering occurred in San Diego around the Scripps, Salk and Burnham Institutes and San Francisco in relation to the University of California Medical School and continues in—for example, Seattle in relation to the Fred Hutchinson Cancer Institute and Cambridge, UK, in relation to many but particularly the MRC Molecular Biology Research laboratory which has hosted 11 Nobel prize-winners in its time.

A key interim conclusion here is *not* that only a few places in the world (mostly in the US) can ever pretend to global excellence in

Life Sciences and their biotechnology exploitation capabilities. Healthcare, let alone agro-food and environmental applications, is enormous, constituting some 20 per cent of GDP (DTI, 1999) in advanced economies. That biotechnology is far more thorough-going than an esoteric toolkit is testified to by the political scramble to find ways at regional level to facilitate development of relevant capabilities world-wide (see Cooke, forthcoming). In the UK—for example, research performance assessments have resulted in the majority of Life Sciences research funding being allocated within the so-called Golden Triangle among London, Oxford and Cambridge.

3. Strategic Science Policy and Science Funding: Do Regions Matter?

It has been argued thus far that knowledge production is becoming rather strongly regionalised in particular clusters. This is because of the growing importance of university and research institute laboratories to clusters of DBFs that exploit and commercialise basic scientific knowledge, with the support of venture capitalists and other business or legal services. Simultaneously, possibly more distant multinational pharmaceuticals companies are investors in milestone payments that fund the research in exchange for future expectations of licences or acquisitions. Thus the innovation system in this sector is both highly regionalised, for research and early exploitation, and highly globalised for development and, later, distribution and marketing. Is there evidence of a growth in *regional* science policy and consequent allocations? Moreover, if there is, does it take a different form from the state or pooled public (EU) one described above? And if globally networked regional clusters predominate in biotechnology, as there is abundant evidence they do (see Swann *et al.*, 1998; and papers in *Small Business Economics*, Special Issue, 2001), is this leading to new policy thinking? Is 'ground–up' strategic science policy and funding within specialist 'knowledge economy' regions occurring for other sectors too? In the space available, this can only be explored for biopharmaceuticals, but the resulting evidence makes the hypothesis worthwhile exploring further. The key point, tackled later, is that while regional technology and innovation policy are not new, regional *science* policy is, in the sense of regional administrations pressing for augmented basic research budgets or for central governments where policy supremacy for science allocations lies to find ways to assist less research-favoured regions à la EPSCoR (see below). Despite Ashcroft *et al.*'s (1995) critique of, for example, UK innovation policy, there is no evidence of any UK regional science strategies such as that promulgated by the Scottish Executive in 2001 because there were none at that time.

Strategic research (as defined by Irvine and Martin, 1984) has become less military and more civilian since the end of the Cold War (despite the rise of funding against bioterrorism). It is arguable it has been forced to become more 'relevant' in the sense of more market-facing and ethically sensitive, as we have seen (Nowotny *et al.*, 2001). Importantly, it has allowed a repositioning of major science policy priorities towards the health rather than the defence of civilian populations. Even in the 1980s, the US spent nearly 50 per cent of its national academic and related research budget on Life Sciences. In 1987, US public healthcare R&D (funded by the National Institutes of Health) was $7.4 billion; by 1999, it was $14.8 billion and for 2003 it was over $27.3 billion, causing the following comment from the director of science policy at the American Association for the Advancement of Science.

> As a result, NIH is now the 800-pound gorilla of the research community, accounting for 42 per cent of all non-defense R&D, more than half of all federally-funded basic research, and nearly two-thirds of all federal support for R&D in colleges and universities (Teich, 1999, p. 12).

The 2003 appropriation was 51 per cent of federal basic research, a $3.7 billion increase over 2002 (Burnell, 2002). To this must be added portions of National Science Foun-

dation, National Aeronautics and Space Administration and Department of Energy (human genome) research budgets. It is abundantly clear that health care is driving the US basic research-funding portfolio as never before. In the UK and Germany totals for biosciences research are of the order respectively of $2 billion and $1 billion annually. Senker and van Zwanenberg (2001) estimated annual public EU Life Sciences R&D expenditure at $10 billion, about half that in the US.

The very large sums of research funding now going to regional biosciences/biotechnology clusters in the US and their younger equivalents in European countries give these locations both the resources and expertise to develop as implicit if not explicit 'centres of excellence'. Because of the perceived relevance and political virtue of life sciences research, health research budgets have mushroomed. Correspondingly, financial pressure on hospitals to treat not conduct research on patients (see below) has undermined clinical scientific opportunity to take advantage of the molecular biology revolution. Hence, such centres of excellence attract further funding, from their regional governments, from bilateral industry research investments. Thus, although Novartis and University of California Berkeley announced a $25 million licensing agreement for Life Sciences patents, a year later in 2002 Novartis announced its $250 million Genomics Research Institute investment in Cambridge, Massachusetts, to tap into the knowledge and talent arising from human genome research. There are also great resources from endowed institutes and medical foundations which, in the shape of those such as the Howard Hughes Medical Institute ($13 billion endowment) and in the UK the Wellcome Trust with a $21 billion endowment and $1 billion annual expenditure, are of major signifi-cance. The latter explicitly operates a centres of excellence programme, which in the UK involves the Universities of Glasgow (parasitology), Edinburgh (cell biology), Manchester (cell matrix), Cambridge (cancer jointly with Cancer Research), Oxford (human genetics) and London (history of medicine). The Howard Hughes Medical Institute primarily funds researchers rather than centres, but has laboratories at the universities of Maryland, California–Los Angeles, Washington–St Louis, Rockefeller and internationally.

In the US, there are, of course, numerous other charitable and corporate medical foundations, the largest of which are shown in Table 2. Grants from these augment the large-scale NIH awards and add further to the resource base of centres of excellence. Indeed, the more a regional centre is designated as such the more likely it is to attract further funding. The UK is unique in having a single charitable health research trust that spends per year an amount equivalent to the sums the top 10 US charitable foundations spend together. This makes the Wellcome Trust a strategic science funder and policy-maker in its own right in the UK. It is as, if not more, important as the UK government in determining bioscientific and health research expenditure flows, as a glance at selected highlights of its funding portfolio during 2000–01 demonstrates (Table 3).

The key point to note from Table 3 and below is the trend towards regional centres of excellence and the manner in which in the UK the Wellcome Trust increasingly sees its role as regenerating parts of the national innovation system for health which has been damaged by a lack of policy or underfunding crises that have had negative effects on important parts of the national system, especially the National Health Service. Thus although, as Table 3 shows for the May 2001 entry, Wellcome grants under the Strategic Research Investment Fund scheme were diffused, a third of the £125 million, some £40 million was awarded to Leicester, Edinburgh, Leeds and Manchester (UMIST) universities, seven awards went to London, three to Oxford, two each to Sheffield, Cambridge and Cardiff, and a further two to Edinburgh. This reflects an emergent picture underlined in the UK government report on biotechnology clusters (DTI, 1999). That proposed regional centres in the above-named places plus regions with collaborating regional universities

Table 2. Top 10 US medical research foundations and corporate foundations

Foundations	Grants 1999 ($ million)	Endowment 2000 ($ billion)	Corporate foundations	Grants 2000 ($ million)
1 R. W. Johnson	372	8.8	Aventis Foundation	41.6
2 D&L Packard	114	9.8	Proctor and Gamble Foundation	30.4
3 California Endowment	91	3.5	Merck Foundation	28.8
4 Whitaker Foundation	50	NA	Pfizer Foundation	25.5
5 B&M Gates Foundation	48	21.2	Eli Lilly Foundation	17.1
6 Burroughs Wellcome	37	0.8	Bristol-Myers Squibb	15.8
7 Rockefeller	36	3.6	Monsanto Foundation	14.0
8 D. Reynolds	35	1.3	Medtronic Foundation	12.0
9 Starr	34	4.5	Abbott Foundation	10.0
10 WM Keck	32	1.5	Glaxo Wellcome	7.0

Source: Lawrence (2001).

Table 3. Wellcome Trust grant announcements 2000–01

Date	Headline	Funding (£ million)	Recipients
April 2000	Joint infrastructure	129	Ulster, Dundee Birmingham JIF
July 2000	Joint infastructure	225	New (SRIF) Programme
July 2000	Genome bioinformatics	8	Cambridge (Sanger)
October 2000	Genome sequencing JV	8	Cambridge (Sanger)
October 2000	C. for molecular medicine	7	Cambridge (Addenbrookes)
April 2001	Science centres/infrastructure	76	ScottishUniversities
May 2001	Scientific research facilities	125	34 SRIF grants
July 2001	Synchrotron	110	Oxford
October 2001	Post-genomic research	300	Cambridge (Sanger)
November 2001	Clinical research facility	3.8	Southampton

Source: Wellcome Trust.

as in Yorkshire ('White Rose' partnership) with Sheffield (2 awards), York (1 award) and Leeds (1) or in Scotland Glasgow (1), Dundee (1) along with Edinburgh, and, in Wales, one centre based in Cardiff, could expect to be candidates for development outside the 'golden triangle' of Cambridge–Oxford–London.

This is predominantly where, given appropriate quality bids, centres of expertise may be expected to become centres of excellence,[5] and the move, first successfully demonstrated with the establishment of numerous centres of research in Stanford University (Gibbons, 2000) of specialist research away from large university teaching departments gets under way. This also applies to another big casualty of the changing research mode, clinical research in hospitals. In the UK, the latter is underlined in Wellcome's policy of funding clinical research facilities (CRFs) because

> while the UK has the inestimable advantage of a National Health Service … the financial pressures on the NHS and healthcare reforms have created many obstacles to patient-oriented research. Not least of these is the enormous pressure on beds; patients requiring treatment obviously take priority, leaving no spare capacity that could be used by researchers (Wellcome Trust, 2002, p. 13).

The Southampton facility (Table 3, November 2001 entry) is one of five CRFs, the first opened earlier that year in Edinburgh; the others will be at Manchester, Birmingham and Cambridge. Thus regionalisation of special clinical research as well as medical and bioscientific centres of excellence is occurring as a policy initiative being implemented by the Wellcome Trust in response to changes induced in the traditional model by government health policy. Specifically, it is seeking to maximise patient treatment capability on internationally low public expenditure, at the expense of clinical research. Thus the government's Culyer Task Force found ways of segmenting costs of NHS research and paying for it with a levy on healthcare purchasing. These funds are only to be used for recurrent costs, while foundations and research councils cover direct research costs. Absence of funding for fixed capital developments led to Wellcome Trust policy to invest in CRFs. They are modelled on US General Clinical Research Centres (GCRCs) of which there are 78. Their existence was initiated by US health insurance companies' refusal to pay for research in hospital beds, and now even outpatient clinics to which research moved are too busy for research. GCRCs cost $170 million per year to run and are funded through grant applications from centres to the National Institutes of Health. The Wellcome Trust programme is funded at £20.5 million.

Thus, as government funding constraints

have placed the NHS under ever-greater financial pressure, clinical research capability is facing diminished capacity. Providers are thus becoming more entrepreneurial in their response and seeking significant funding from non-public sources, notably foundations like the Wellcome Trust co-funded for CRCs thus far by university hospitals and local health service administrations (the NHS Trusts). Having large patient databases for research is a necessity in the new world of molecular medicine and rational drug design. Thus it is not difficult to see the evolution of regionalised 'knowledge value chains' from basic university or research institute centres of excellence such as the Sanger Institute for genomic and post-genomic research, through to medical and clinical research at centres of excellence in university hospitals or schools of biosciences, to biotechnology institutes or centres, and gene centres or gene parks where exploitation and commercialisation are conducted by academic entrepreneurs interacting with clusters of DBFs.

The model can be observed in Greater Boston where all these facilities are in place, where over $1 billion in research funding alone is spent annually, much of it in collaborative partnerships among universities, special research centres of excellence (such as the Whitehead or Dana–Farber Institutes at MIT and Harvard), large hospitals like Massachusetts General or Brigham and Women's, GCRGs, incubation and successful start-up and more mature biotechnology firms like Ariad (founded by Nobel Laureate David Baltimore, discoverer of the key cell regulator enabling Glivec to be produced by Novartis), AlphaGene, Dyax, Genetics Institute, Genome Therapeutics, Genzyme and Progenitor. Reference to the University of Siena database (Orsenigo *et al.*, 2001) shows that non-regional research partners are Aventis, Bayer, Bristol–Myers Squibb, Chugai Pharma, DuPont, Merck and Pharmacia (now Pfizer). These are increasingly engaged as investors, developers (but see below, section 5), distributors and marketers for the products and services of the regional biopharmaceuticals innovation system in Massachusetts, focused on Greater Boston and with its epicentre at Cambridge (Cooke, 2001a). Massachusetts has for many years had a regional science policy to support with tax-breaks and other incentives high-technology industry, once seen as responsible for the 'Massachusetts miracle' in mid-sized computers and now experiencing a resurgence through the promotion of biotechnology, biomedical and venture capital 'clusters' (Best, 2000).

4. Regional Science Policy: The Basic Model and Some National Variants

It has been argued thus far that bioscience underwent a cognitive, methodological and technological evolution that appears to have been expressed as an empirical punctuation point around 1992, although much of that change had been in the pipeline well before that. Some move into Mode 2 knowledge production was enforced as transdisciplinary research networks among research centres of excellence, academic entrepreneurs and successful start-up DBFs began accessing dynamic externalities in the form of knowledge spillovers from co-location in geographical proximity to exploit opportunities for rational drug design. However, such networks remained hierarchical both because of élite science (the 'star' system; Zucker *et al.* 1998) and the continuing involvement of big pharma companies, less as originators than as developers of therapeutic solutions coming from biotechnology. The argument then evolved to discussion of a 'knowledge value chain' in life sciences spanning the arc from basic post-genomic and proteomic research through clinical research and treatment to innovation and commercial exploitation by clustered DBFs. It was then argued that this exists in a few regions of the world, that centres of excellence are competitive and attract or possess large financial resources and that their regional and technological innovation system governances have explicit or implicit science policies. Other governances will seek to emulate these leaders and, indeed, have begun doing so.

In the US and Europe, the regional 'clus-

ters of excellence' include Southern California, centred on San Diego, in northern California it is Silicon Valley and, in Massachusetts, Boston. In Europe, such clusters are found, on a smaller scale than the US, in the UK at Cambridge in the Eastern England regional development agency (RDA) area, possibly also Oxford (South East RDA) and Scotland (a triangle including Dundee, Edinburgh and Glasgow), in Sweden Stockholm–Uppsala and in Germany, Munich in Bavaria although two other BioRegios also exist (Dohse, 2001; Cooke, 2001a, 2002). In these innovative 'biotech cities', it is vital to recognise the regional innovation systems in which they operate. These supply finance (for example, Bavaria sold its state energy company and established a high-tech fund which invests in biotechnology [and ICT] research and commercialisation activity); in Scotland, as we shall see, 'regional' funds for implementing its science policy for biotechnology are pooled among its RDA, Parliament and university funding body the Scottish Higher Education Funding Council (SHEFC). As part of its modest move to regionalise administratively, the Swedish national government in 2001 established VINNOVA, the Swedish Development Agency for Innovation Systems with responsibilities to invest in *regional*, technological systems in biotechnology and other advanced technology sectors. There is also a unique cross-border policy and R&D body (Øforsk) to exploit the new bridge, by building an Öresund regional biosciences innovation system between Denmark's 'Medicon Valley' near Copenhagen and the Ideon Science Park bioscience cluster at Lund near Malmö, where AstraZeneca has a large R&D facility. We shall explore a further Nordic case in depth below, which is the case of Finland.

Observing these developments, regions with aspirations and some perceived or actual potential to emulate the élite can relatively easily be identified. Two in the US are worth briefly exploring. These are North Carolina and Maryland, both of which have emergent regional biotechnology innovation systems. In the case of North Carolina, there has been an effective science policy since the 1950s when the Governor got approval for the Research Triangle Park (RTP). This had the limited objectives of attracting R&D jobs with no presumption that synergies would flow among the facilities locating there. Subsequently, major support was given to boosting the research capabilities of the three universities, Duke, UNC Chapel Hill and NC State, but especially the last two public ones. Duke's private endowment has ensured that its medical school and bioscientific research profile have prospered, while in the 1990s NC State was the recipient of major state funding to develop it as a technology campus with industrial R&D laboratories co-located with science and technology departments. In between, in 1981, the North Carolina Biotechnology Center (NTBC) was established on RTP (as, at approximately the same time, were the NC Supercomputer and Electronics Centers). NTBC was not a research but a commercialisation facility. In early 2002, NTBC housed some 30 biotechnology businesses, including sites of Aventis, BASF, Bayer, Biogen, Eli Lilly and Glaxo SmithKline among the 90 in the RTP and broader Raleigh–Durham–Chapel Hill area, and 142 in the state.

Duke University Medical Center is prestigious in basic and clinical biomedical research with cancer and urology being leading fields for which the centre is ranked sixth in the US. Basic scientific research is wide-ranging and operates in 38 laboratories including biochemistry, cell biology, genetics, immunology, microbiology neurobiology, pharmacology and cancer biology. The Duke Comprehensive Cancer Center is accredited by the National Cancer Institute (NCI) and conducts clinical research, patient care and teaching in cancer immunobiology, prevention, detection and control, cell regulation and transmembrane signalling, cellular and structural biology, experimental therapeutics, molecular oncology and cancer genetics. UNC School of Medicine is unofficially ranked 22nd in the US and its strongest research field is biomedical engineering in

which expertise is found in medical imaging, biomedical computer communication, medical informatics, neuroscience engineering, bioelectronics and sensors, physiological system modelling, biomaterials and real-time computer systems. The Lineberger Comprehensive Cancer Center is one of the NCI national network of Cancer Center Programme facilities specialising in biomedicine.

Maryland is also an important US centre for bioscience, hosting 210 bioscience businesses, half in research services, testing and contract manufacturing, two strong university systems, organisations like FDA and NSF, and a large number of federal research laboratories, notably the NIH system. Much of this activity is clustered along the I-270 'Technology Corridor' (Bethesda–Rockville–Frederick) and around Johns Hopkins University in Baltimore. The Howard Hughes Medical Institute research laboratories are nearby in Chevy Chase. NIH has 25 institutes and centres, including the US National Human Genome Research Institute at Bethesda and the National Cancer Institute at Rockville. The Johns Hopkins University is ranked first among US universities in receipt of federal R&D funds, the School of Medicine is first in receipt of NIH extramural funding and is unofficially ranked second nationally after Harvard Medical School. Its research expertise is focused on AIDS, biomedical engineering, cancer, clinical immunology, genetics, molecular biology, neuroscience, organ transplantation and urology. The University of Maryland, Baltimore, is a rapidly expanding biomedical research centre in partnership with the University of Maryland Medical School System, the Veterans Administration Medical Center and the Medical Biotechnology Center, specialising in molecular genetics and human molecular biology. There is also a UM Biotechnology Institute specialising in basic science applications to health, marine environmental and agricultural biotechnology, protein engineering and structural biotechnology.

4.1 Science and Technology Policies: Market Facilitating

Both states inherited buoyant technology markets from past public investment decisions. On the basis of these strengths and to a high degree influential upon them, both states are among the 13 in the US to have adopted state-wide strategic science and technology policies, from between 1991 and 1995 (American Association for the Advancement of Science, 1999). The main goal of each policy has been enhancement of economic growth and improving standards of living by capitalising on the state's research base. Policies recognised the importance of sustaining and strengthening the R&D capacity of university research and training. In North Carolina, building on the success of Research Triangle Park, strategy focused on further stimulating exploitation of biotechnology and other technologies, and continuing to strengthen R&D capacity. New strategies emphasised stimulating indigenous entrepreneurship and promoting generative rather than redistributive growth. Maryland's strategy included recommendations for exploiting the comercialisation potential of technology from its strong universities and federal research laboratories. Both Maryland's and North Carolina's policies were initiated by their Governors, but others were the result of private initiative. Usually, they began by analysing the strengths and weaknesses of the state economy and research infrastructure. In many cases, they then went on to identify knowledge-based industry clusters, arguing that the state's economic base was passing from an old to a new economy character. Strategic policies were proposed to meet the challenge. In North Carolina's case, this involved seeking input from six task forces and nine focus groups, using the North Carolina Alliance for Competitive Technologies as the governance body for the process. Both Maryland and North Carolina included specific outcome measures, such as quantifiable growth rate of technology businesses, industry support for university R&D and new start-up companies.

However, the AAAS assessment of these policies was that they were insufficiently detailed and mostly failed to address issues of social exclusion.

In 2000, North Carolina published *Vision 2030: Science and Technology Driving the New Economy* based on a new approach emphasising *visioning* based on a state-wide foresight options process. It will be shown later that this is becoming a more widely adopted approach to regional science policy. It also involves cluster identification and regional stakeholding to attempt to commit industry and university administrations to invest in co-funding actual initiatives intended to be implemented. UNC Chapel Hill organised regional conferences, focus groups, cluster analyses and global benchmarking and produced the North Carolina Innovation Index. Recommendations included evolving a knowledge economy through supporting venture capital, public funding and tax incentives, marketing North Carolina globally as a knowledge economy and designing a globally competitive R&D tax credit. Maryland's newest policy statement *The Maryland Technology and Innovation Index* was launched in late 1999 with similar style and content, using comparative benchmarking indicators addressing performance, dynamics and resources using the Maryland Technology Alliance of private-sector, academic, federal and state government organisations as the catalyst.

4.2 Science Strategy: Science-led Growth from Below

Devolution in the UK has opened up a responsibility for democratically elected executives in Scotland, Northern Ireland and Wales to formulate science policies. Wales developed the EU's first Regional Technology Plan in 1994 and relies on an updated version under the Regional Innovation Strategy 2 programme from Brussels. The Welsh strategy has guided the establishment of expenditure patterns on technology and innovation under the Structural Funds Objective 1 action lines. This includes establishing a Knowledge Exploitation Fund, technology counsellors in universities and other infrastructures in support of *innovation* rather than basic science strategy. Northern Ireland was in a better position because of the existence of the Industrial Research and Technology Unit (IRTU) which, through its annual corporate planning process, designed technology and innovation, if not science policy in the region. It has now become a division of Invest Northern Ireland, the new integrated regional development agency. It is noticeable that, despite its peripherality and political troubles, Northern Ireland has developed a discernible science and technology policy not unlike but more piecemeal than Scotland's. Thus biosciences and ICT (especially telecommunications and Internet software) have been supported with research funding from IRTU, contest-successes for UK grants to enhance academic entrepreneurship and the construction of nine incubators for the two target sectors. The necessity for regional science policy in both Wales and Northern Ireland is demonstrated by the evidence that, at £34 and £24 per student respectively, the UK government's low investment in science funding there compares unfavourably with the £44 per head in England and £58 in Scotland. Research performance, measured since 1986 in the UK Research Assessment Exercise, explains the disparities to some extent. In this context, it is noteworthy that Northern Ireland's most significant biomedical research initiative, the University of Ulster's £14.5 million Centre for Molecular Biosciences, was equally co-funded by the Northern Ireland 'Support Programme for University Research' fund and Atlantic Philanthropies, an Irish American foundation which, since 1982, has invested $1.3 billion in higher education world-wide, 28 per cent of which was in Northern Ireland and the Republic of Ireland. The donor, Charles Feeney, also funded the Sinn Fein office in Washington. The university's vice-chancellor, bemoaning a 20 per cent decline in the region's funding for academic research through the UK system said: "With devolution, we have found

greater awareness of the importance of the research base than when we had direct rule" (Farrar, 2002).

Scotland was first in the UK to seize the opportunity to develop a regional science policy, its Minister of Science publishing in January 2001 *A Science Strategy for Scotland*. It was preceded by a report in 2000 from the Science Strategy Review Group and informed by Scotland's Science Policy Unit. The report shows that about £800 million is spent on scientific research in Scotland annually and that Scottish universities won £141 million or 11 per cent of the UK Research Councils budget in 2000, a percentage point or so above the country's share of the UK population or GDP. The *Science Strategy* makes it clear that, although Scotland's economy performs at about the UK norm, market forces alone cannot be relied on for economic growth to occur but that Scotland's basic science advantage and government activity more generally have to be directed increasingly at sustaining world scientific leadership in a few feasible areas and raising commercialisation and entrepreneurship opportunities arising from science. The report prioritises bioscience and genomics, medical research and e-science as the three areas of world leadership in basic science that the Executive will support in particular. This means maximising targeted science research expenditure for these areas, including improving relationships between university and biological research institute research facilities in Scotland. To assist this, the Executive commits itself to investment in Scotland's joint Science Research Investment Fund.

Making an important commitment towards science funding in the UK as a whole, it aims to assist in setting in place a more transparent research funding methodology to ensure that underfunding of the kind widely perceived to have bedevilled UK science for decades cannot happen again. Scotland's problems of low industrial R&D and a high proportion of small businesses are to be moderated by connecting to economic growth initiatives such as the Scottish Executive's *The Way Forward: A Framework for Economic Development, The Knowledge Economy Cross-cutting Initiative* and the *Digital Scotland Task Force*. Accordingly, it commits to keeping the 'Proof of Concept Fund' (see below), setting up a National Health Service Technology Transfer Office, revitalising UK-originated small business research and technology awards, assisting academic entrepreneurship, using Foresight to identify future scientific challenges and opportunities, and recruiting investment and scientists from overseas.

This is clearly a more interventionist set of commitments than are discernible in the more 'market-following' policies described previously. As in Northern Ireland and Wales, government has to do more because of market arrest, in a context of greater reliance on market forces where they are strong—which in the UK means, in effect, the aforementioned 'Golden Triangle'. Scotland was advantaged in bringing forward its fairly robust commitments to science support by preceding work done by Scottish Enterprise. The £40 million 'Proof of Concept Fund' established in 1999 is a good illustration. It allows scientists in the prioritised sectors, among which biotechnology and ICT were the first to benefit, to buy-out teaching and administration time to conduct research leading to academic entrepreneurship. The fund was formed from contributions by Scottish Enterprise, the Scottish Executive and SHEFC. Notably, no private co-funding was committed to the fund. Scottish Enterprise estimated in late 2002 that 14 biotechnology projects had been funded and that, since March 1999, 28 new biotechnology companies have been created, equivalent to a growth rate of 30 per cent per annum. This compares favourably with the European average of 17 per cent per annum over the same period. Scotland is home to 20 per cent of the biotech companies in the UK and is recognised as one of the fastest-growing regions for start-ups. Thus far, policy to support commercialisation of bioscience has been successful; also, we have seen that Scotland has received major funding, including both Research Council and Wellcome Trust grants in support of its leading university centres of

excellence and their research. Scotland now has a strategic science policy and it remains to be seen if the effectiveness shown without one can be enhanced consequentially.

4.3 Science Strategy: Science-led Strategy from Above

The last case to be explored is that of Finland, a small country that has emphasised the importance of developing centres of expertise in its regions, supporting university-centred basic research, commercial exploitation and cluster-building in biotechnology as it did with global success in relation to ICT and the rise of Nokia to global prominence in mobile telephony. The model is also one in which foresight and envisioning play a role in bringing about a consensus among business, academia and industry to invest in centres of expertise in locations that already show some comparative advantage. Centres of expertise in biotechnology arose from a Ministry of Education national research programme on biotechnology in 1987.

The aim was to develop four regional centres of biotechnological expertise by 1992, planned to be affiliated to those Finnish universities assessed to have the appropriate potential. The selected centres were at Helsinki, Turku, Kuopio and Oulu. The programme was evaluated and continued in 1996, then extended to 2000. Financing came from the Ministries of Trade and Industry, Agriculture and Forestry, and Social Affairs and Health as well as Education. Other centres were added such as Tampere and Seinajoki. The arrangement for enlargement of the network is one whereby, if a municipality is sufficiently committed to serious long-term investment in biotechnology—by funding a number of chairs in universities—for example, then provided it passes exacting tests of expertise, it can become eligible for designation and funding as a centre of expertise. This has led to an excess of demand for centre designation and the programme has been terminated in consequence. Centres specialise within biotechnology: Oulu, Turku, Tampere and Kuopio focus on medical research and co-operation with the pharmaceutical industry; Helsinki and Seinajoki specialise in agro-food biotechnology and some agro-food R&D is also performed in Kuopio, Oulu and Turku (Academy of Finland, 2002).

Tekes, the state technology agency has invested some $90 million in biotechnology, some 27 per cent of its total investment portfolio. The centres of expertise programme receives $4.1 million annually from Tekes and the Academy of Finland. Thus some 40 per cent of these two agencies' budgets is in support of biotechnology. Also, the National Programme for Research on Biotechnology, begun in 1988, invests an annual amount of some $13.5 million in biotechnology. Further expenditure on the genome research programme and the cell biology research programme attract $4.5 million and $1.8 million annually over 6- and 3-year programme periods respectively. In 1993, the Ministry of Education set a new centres of excellence standard, seeking to identify 10 'top units'. By 2000, 26 had actually been established of which 9 are in biosciences and biotechnology. In March 2001, a further $102 million rising to $151 million by 2006 was committed by Tekes, the Academy of Finland, Sitra (Finnish national R&D Fund), Finnish Bioindustries and a substantial group of pharmaceuticals companies to 'Medicine 2000' addressing biomedicine, medicine development and pharmaceutical development research and technology.

Finland's commitment to evolve a strong biosciences and biotechnology capability is remarkable, with proportionately comparable shares of total national R&D budgets (some 40 per cent) as the US. The fact that its agro-food firms are responsible for nutraceuticals innovations like the anti-cholesterol product Benecol (Raisio Ltd), lactobacter drinks and UHT infant food (Valio Ltd), and xylite sweeteners (Danisco–Cultor Ltd) suggests where current strength lies. Orion Pharma and Orion Diagnostica are the two leading biotechnology players, the former having the leading Parkinson's treatment

Comtess newly released, the latter targets the global point-of-care (POC) market for *in vitro* diagnostic products. Orion Pharma collaborates with all the Finnish centres of excellence, but particularly the regional centres at the Universities of Helsinki and Kuopio, the Helsinki Biotechnology Institute and, increasingly, with the Universities of Tampere and Oulu—the latter also being Orion Diagnostica's main research partner. The Finnish national innovation system is highly integrated but state-led with a knowledge value chain involving the Finnish Academy funding basic research, Sitra funding R&D, VTT conducting research and technology transfer, Tekes funding technology development and centres of excellence in universities working directly with large firms, start-ups and spin-offs in clusters on state and locally funded science and medical technology parks like Hermia at Tampere, Oulu Technopolis, and Medipark or DataCity and BioCity at Turku. In the report on Finnish life sciences by Tulkki *et al.* (2001), these regional innovation systems are presented as worked models of the Finnish view of the functioning of Silicon Valley. The key difference is the involvement of large firms and public investment in the commercialisation process, substituting for an arrested market for key innovation support services. In this respect, it has been influential upon the German regional biotechnology clusters commercialisation programme BioRegio that similarly sought a 'corporatist' version of the 'basic research–academic entrepreneurship–venture capital' model that was pioneered in California (Dohse, 2001).

5. Conclusions

This paper started with a question about the existence and observability of a new phenomenon, regional science policy. Its likelihood was implied by a number of important changes in global politics (ending of the Cold War), scientific research funding (major transfers from defence to healthcare), knowledge production (Mode 1 to Mode 2) bioscientific research approach (molecular biology), drug research methodologies (chance discovery to rational drug design), R&D leadership (big pharma laboratories to university centres of excellence) and innovation leadership (big pharma to DBF clusters). So developed are these relationships that inevitable ethical clashes have arisen. Thus, troubled US firm Bristol–Myers Squibb, in trying to forge closer DBF links, invested $2 billion in 20 per cent of ImClone to access Erbitux, a colon cancer drug. One of ImClone's key shareholders was Martha Stewart, doyenne of US home-making who in 2004 was found guilty of insider dealing. The problem arose when FDA approval was withheld due to faulty clinical trialing by ImClone. This case has caused big pharma to question its absorptive capacity; it has become mainly marketer-distributor to DBFs like ImClone, or Celltech with a similar deal with Pharmacia (now Pfizer, which in 2003 halted the deal), and Isis Pharmaceuticals with Eli Lilly. Attempts by Bristol–Myers to take over the development due diligence function with ImClone failed.

Clearly, with some 500 DBFs world-wide researching 1300 compounds for new biotechnology products, it is no surprise that up to 30 per cent of big pharma R&D budgets are now spent on alliances with extramural partners when the top 20 pharmaceuticals firms in 2001 spent $28 billion on intramural R&D for a yield of only 28 new drug approvals. Pfizer, currently the world's largest pharmaceuticals firm, has over 1000 alliances with DBFs and universities in response to the drought. So the knowledge-based clusters and the university or research institute centres of excellence at their hearts continue to be the pacemakers in molecular bioscience research and rational drug design. The paper showed also how changes in funding regimes for healthcare, diminishing the traditional 'free-rider' system of clinical research in hospitals in favour of development of clinical centres of excellence was hastening this process. Moreover, the vast amounts of Research Council and foundation research funding for centres of excellence accelerate it even further. Of course, such regional clus-

ters, drawing on national funding to meet global market demand, are by no means ubiquitous. This is because, abundant though funding is, it is increasingly excellence-driven when it comes to funding allocations. Under such circumstances, alliance and partnership-based cluster governance have been shown to be an asset and the functional presence of regional innovation systems with the full knowledge value chain in place and the lobbying and grantsmanship expertise that comes with a sophisticated science and innovation support system are invaluable.

While regions became familiar with the importance of regional innovation systems and strategies in the 1990s (Cooke, 2001c), the current evolutionary position in Life Sciences research requires learning to apply those skills to creation of the infrastructure of excellence that provides the foundation for regional technological systems—namely, strong and varied basic and applied research capabilities. The logic of this points to the future rise of the formulation and implementation of regional science policy. This is evolving as in the UK where two northern English regions have established Regional Science Councils and one, the North West, published its Regional Science Strategy in 2002. Finland decentralised development through its science strategy; Scotland built from below. Both are peripheral, with relatively weak market mechanisms but a strong science base. Each has developed focused science policies with strong public funding targeted at a few world-class Life Sciences sectors. North Carolina moved to the kind of foresight-led, envisioning, stakeholder plus action leadership process pioneered in Massachusetts, then adopted in Scotland and later in Germany's regional cluster solution to its biotechnology innovation deficit, BioRegio. National funding bodies have to respond by making more transparent the allocation of research funding, as demanded in Scotland's science strategy. They can devolve regional funds or designate annual *tranches* for regional science development. Most scientists react in horror to this citing criteria of excellence and equivalence in regard to research grants, infrastructure funding or investment in the ever-developing centres of excellence located in regional clusters. Safeguards would be needed to prevent the target-inflation and excessive spread of investment revealed in the Finnish programmes. But equally, if regions show enterprise in mobilising strategic capabilities, they merit appropriate reward for so doing. This exists in the US Experimental Program to Stimulate Competitive Research (EPSCoR) that assists 22 less favoured states by accepting marginally lower-scoring science grant applications than elsewhere (www.her.nsf.gov/epscor). Regional science policy is beginning to prove a key precondition for the fulfilment of regional development visions in the knowledge economy.

Notes

1. For the UK, results from the DTI study of clusters reveal extraordinarily high location quotients for biotechnology businesses in Cambridge and Oxford, also the main university and other public R&D locations (DTI, 2001). In the US, the Brookings Institution reports (for example, Cortright and Mayer, 2002) consistently show there to be some nine main Life Sciences clusters in the US. In Canada, the work of Niosi and Bas (2001) shows high concentrations and intra-cluster innovative interaction in Montreal and Toronto. Comparable results exist for Germany (Kettler and Casper, 2000); France (Lemarié *et al.*, 2001), Sweden (VINNOVA, 2001) and Israel (Kaufmann *et al.*, 2003). The sample of one regional biotechnology 'cluster failure' written about by Orsenigo (2001) suggests Italy's *exceptionalism* regarding advanced technology activity among G7 countries—something underlined by Tavoletti (2004) who shows the highest unemployment for all skill/qualification categories (including workers having received *no* formal education at any level) in all Italian regions to be that of post-doctoral students.
2. To magnify the 'multiscalar' dimension here would require a further paper. An anonymous referee suggests that Bunnell and Coe (2001) and Mackinnon *et al.* (2002) "need to be acknowledged and cited" and this is duly done. They say it is wrong to emphasise the regional level and wrong to overlook regional specificity. This is an improvement upon positions such as that of Bathelt (2003)

in the same journal that only nations have specificity and that they are also *closed* systems. The geographical scale debate seems in danger of generating more heat than light. At a general level, Cooke *et al.* (2000) showed how multilevel governance of innovation in Europe has resulted in *innovation* measures often having been taken regionally by stimulus from European Commission policies, while member-states devoted more attention and many more resources to science policies. The regions in question are supralocal, subnational or meso-level entities with policy legitimacy in the relevant field. In the EU, for example, many, but not all, happen to be EU NUTS 2 regions—a statistical artifice in some cases, an isomorph of a legitimate meso-level entity in others. In yet others, NUTS 2 areas aggregate to a legitimate meso-level policy entity. Here, regions are meso-level policy entities with legitimacy for implementing innovation measures emanating supranationally, or from state-level (for example, in England) or from within the region (such as N. Ireland's 'Think, Create, Innovate' strategy). Economists who specialise in science, innovation and technology studies have little or no understanding of the presence of regions and their institutions as, albeit often weak, actors in innovation and, as this paper shows, tentatively in science policy too—hence the need to reiterate it. Geographers, of course, are more fortunate.

3. As a consequence of the disaster that resulted in deformed births after mothers had taken thalidomide to control morning sickness, trialling of candidate treatments goes through three lengthy phases. The first is usually mammalian, the second with small groups of patients with the drug's target disease, and the third a large sample of patients with controls that yield statistically valid results.
4. An anonymous referee indicates the unlikelihood of readers of *Urban Studies* being technically literate in bioscientific terminology. Hence, 'bioinformatics' involves capturing molecular or genetic information on databases that identify chemical compounds that may inhibit particular disease-causing molecular or genetic combinations. 'Biosciences' are those that involve study of medicine, biology, biochemistry, pharmaceutical and other treatments, medical devices and instruments, research and testing relevant to intervention with and improvement of human, animal and plant life. 'Big pharma' is a term used by academe, government and industry as an abbreviation of large pharmaceuticals companies. 'Biotechnology' involves tools like genetic engineering to create treatments that counter diseases (such as the example of Glivec in Table 1). 'Orphan drugs' are used in diseases or circumstances which occur so infrequently that there is no reasonable expectation that the cost of developing and making available a drug for such disease or condition will be recovered from sales of such drugs. Firms gain exclusivity and fee waivers for producing such drugs. 'High throughput screening' occurs when a compound interacts with a target in a productive way so that the compound then passes the first milestone on the way to becoming a drug. Compounds that fail this initial screen go back into the bioinformatics library from whence they came, perhaps to be screened later against other targets.
5. Centres of excellence are generally considered to be more exacting, higher-quality designations than centres of expertise. Although numerous governments, like that of Finland, began with the former, regional politics caused the latter to replace them so that more regions could qualify. This action is criticised further on in this paper.

References

ACADEMY OF FINLAND (2002) *Biotechnology in Finland*. Helsinki: Academy of Finland.

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE (1999) *US R&D Budget and Policy Programme*. Washington, DC: AAAS.

ASHCROFT, B., DUNLOP, S. and LOVE, J. (1995) UK innovation policy: a critique, *Regional Studies,* 29, pp. 307–311.

BATHELT, H. (2003) Growth regimes in spatial perspective 1: innovation, institutions and social systems, *Progress in Human Geography,* 27, pp. 789–804.

BEST, M. (2000) Silicon Valley and the resurgence of Route 128, in: J. DUNNING (Ed.) *Globalization, Regions and the Knowledge Economy,* pp. 459–484. Oxford: Oxford University Press.

BUNNELL, T. and COE, N. (2001) Spaces and scales of innovation, *Progress In Human Geography,* 25, pp. 569–589.

BURNELL, S. (2002) Biomed researchers applaud NIH budget, *UPI Science News*, 31 January, p. 12.

COOKE, P. (2001a) Biotechnology clusters in the UK, *Small Business Economics,* 17, pp. 43–59.

COOKE, P. (2001b) New economy innovation systems: biotechnology in Europe and the USA, *Industry and Innovation,* 8, pp. 267–289.

COOKE, P. (2001c) Regional innovation systems, clusters and the knowledge economy, *Industrial and Corporate Change,* 10, pp. 945–974.

COOKE, P. (2002) *Knowledge Economies*. London: Routledge.

COOKE, P. (2004) *Globalisation of biosciences: knowledge capabilities and economic geography*. Paper presented at the *Association of American Geographer's Centennial Conference*, Philadelphia, March.

COOKE, P. (forthcoming) Rational drug design, the knowledge value chain and bioscience megacentres, *Cambridge Journal of Economics*.

COOKE, P., BOEKHOLT, P. and TÖDTLING, F. (2000) *The Governance of Innovation in Europe*. London: Pinter.

CORTRIGHT, J. and MAYER, H. (2002) *Signs of Life: The Growth of Biotechnology Centres in the US*. Washington, DC: The Brookings Institution.

DICKEN, P. (2001) *Globalising processes and local economies*. Paper presented to the *Institute for Regional Innovation (Invent) Conference 'Global–Local: Regional Economic Development in an era of Globalisation and Localisation'*, Vienna, December.

DOHSE, D. (2001) Technology policy and the regions: the case of the BioRegio contest, *Research Policy,* 29, pp. 1111–1133.

DTI (DEPARTMENT OF TRADE AND INDUSTRY) (1999) *Biotechnology Clusters*. London, Department of Trade and Industry.

DTI (2001) *Business Clusters in the UK: A First Assessment*. London: DTI.

DUNNING, J. (ed.) (2000) *Globalization, Regions and the Knowledge Economy*. Oxford: Oxford University Press.

FARRAR, S. (2002) Sinn Fein backer pays for centre, *The Times Higher Education Supplement*, 8 February, p. 3.

GEREFFI, G. (1999) International trade and industrial upgrading in the apparel commodity chain, *Journal of International Economics,* 48, pp. 37–70.

GIBBONS, J. (2000) The role of Stanford University, in: C. M. LEE, W. MILLER, M. HANCOCK and H. ROWEN (Eds) *The Silicon Valley Edge: A Habitat for Innovation and Entrepreneurship*, pp. 200–217. Stanford, CA: Stanford University Press.

GIBBONS, M., LIMOGES, H., NOWOTNY, S. *ET AL.* (1994) *The New Production of Knowledge*. London: Sage.

GRIFFITH, V. (2002) Biotech groups stuck on a rollercoaster ride, *Financial Times*, 1 February, p. 29.

HUMPHREY, J. and SCHMITZ, H. (2000) *Governance and upgrading: linking industrial cluster and global value chain research*. Working Paper 120, Institute of Development Studies, Sussex University.

IRVINE, J. and MARTIN, B. (1984) *Foresight in Science: Picking the Winners*. London: Pinter.

KAUFMANN, D., SCHWARTZ, D., FRENKEL, A. and SHEFER, D. (2003) The role of location and regional networks for biotechnology firms in Israel, *European Planning Studies,* 11, pp. 823–840.

KETTLER, H. and CASPER, S. (2000) *The Road to Sustainability in the UK and German Biotechnology Industries*. London: Office of Health Economics.

LAGENDIJK, A. (2001) Scaling knowledge production: how significant is the region?, in: M. FISCHER and J. FRÖHLICH (Eds) *Knowledge, Complexity and Innovation Systems*, pp. 79–100. Berlin: Springer-Verlag.

LATOUR, B. (1998) From the world of science to the world of research?, *Science,* 280, pp. 208–209.

LAWRENCE, S. (2001) *Health Funding Update*. New York: The Foundation Centre.

LEMARIÉ, S., MANGEMATIN, V. and TORRE, A. (2001) Is the creation and development of biotech SMEs localised? Conclusions from the French case, *Small Business Economics,* 17, pp. 61–76.

LUNDVALL, B. and BORRÁS, S. (1997) *The Globalising Learning Economy*. Luxembourg: European Commission.

MACKINNON, D., CUMBERS, A. and CHAPMAN, K. (2002) Learning, innovation and regional development: a critical appraisal of recent debates, *Progress in Human Geography,* 26, pp. 293–311.

NIOSI, J. and BAS, T. (2001) The competencies of regions: Canada's clusters in biotechnology, *Small Business Economics,* 17, pp. 31–42.

NOWOTNY, H., SCOTT, P. and GIBBONS, M. (2001) *Re-thinking Science*. Cambridge: Polity.

ORSENIGO, L. (2001) The (failed) development of a biotechnology cluster: the case of Lombardy, *Small Business Economics,* 17, pp. 77–92.

ORSENIGO, L. PAMMOLLI, F. and RICCABONI, M. (2001) Technological change and network dynamics: lessons from the pharmaceutical industry, *Research Policy,* 30, pp. 485–508.

PAMMOLLI, F., RICCABONI, M. and ORSENIGO, L. (2000) Variety and irreversibility in scientific and technological systems, in: A. NICITA and U. PAGANO (Eds) *The Evolution of Economic Diversity*. London: Routledge.

POWELL, W., KOPUT, K. and SMITH-DOERR, L. (1996) Interorganizational collaboration and the locus of innovation: networks of learning in biotechnology, *Administrative Sciences Quarterly,* 41, pp. 116–145.

SCOTTISH EXECUTIVE (2001) *A Science Strategy for Scotland*. Edinburgh: Scottish Executive.

SENKER, J. and ZWANENBERG, P. VAN (2001) *European biotechnology innovation systems*. Final Report to EU-TSER Programme, Science Policy Research Unit, University of Sussex.

SWANN, P., PREVEZER, M. and STOUT, D. (Eds) (1998) *The Dynamics of Industrial Clustering*. Oxford: Oxford University Press.

Small Business Economics (2001) Special Issue ed. G. Fuchs, *Small Business Economics,* 17, pp. 1–153.

TAVOLETTI, E. (2004) Higher education and high unemployment: does education matter? An interpretation and some critical perspectives, in: P. COOKE and A. PICCALUGA (Eds) *Regional Economies as Knowledge Laboratories,* pp. 75–86. Cheltenham: Edward Elgar.

TEICH, A. (1999) The science of health and the health of science, *Information Impacts*, 12 November.

TULKKI, P., JÄRVENISVU, A. and LYYTINEN, A. (2001) *The Emergence of Finnish Life Sciences Industries*. Helsinki: Sitra.

VINNOVA (2001) *The Swedish Biotechnology Innovation System*, Stockholm, VINNOVA.

WELLCOME TRUST (2002) Clinical research facilities: an introduction, *Wellcome News, 12 February.*

ZUCKER, L., DARBY, M. and ARMSTRONG, J. (1998) Geographically localised knowledge: spillovers or markets?, *Economic Inquiry,* 36, pp. 65–86.