

The Diebold Project UK

Where are the big gorillas?

High technology entrepreneurship in the UK
and the role of public policy

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ABSTRACT

Since the 1980s successive British governments have sought to promote entrepreneurial activity in high-technology industries, using the example of the US as a guide to policy changes and institutional reforms. Drawing on the experience of two industries, electronics and biotechnology, this paper shows that these policies have been successful in increasing the number of high-technology start-ups. However, one feature of the US scene – technology-based firms which grow very fast from start-up into major international enterprises – has been largely missing in the UK. The paper discusses the possible reasons for this gap, including the difficulties faced by all European companies in US-dominated industries. It suggests that the scarcity of British-owned 'big gorillas' in high technology is not due to distinctively British institutional or managerial weaknesses, and cannot be remedied by government intervention.

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I INTRODUCTION

Throughout the post-war period successive British governments, like their counterparts in other European countries, have been concerned about the ability of their national firms to compete profitably in world markets, and thus to contribute to the growth of exports and employment. In the 1960s and 1970s a favoured instrument of policy in the UK was the promotion of mergers. This was based on the view that, in industries where economies of scale were important, existing British firms were too small to hold their own against American and Japanese rivals; automobiles and computers were two sectors which were reorganised at government behest into larger groups. During the 1970s, and more decisively in the 1980s, policy shifted from a preoccupation with size to a greater emphasis on small and medium-sized firms.

Part of the reason for the change of direction was the failure of the earlier policy; several of the big groups that had been created through state-sponsored mergers had performed poorly. Another factor, especially in the first half of the 1980s when unemployment was running at an exceptionally high level, was the belief that small firms would be the principal source of new jobs, offsetting the contraction that was taking place in the country's larger industrial enterprises.¹ Support for small firms, and encouragement for individuals to start their own businesses, fitted the free-market ideology of the Conservative government that took office in 1979 with Margaret Thatcher as Prime Minister.

There were other forces at work during this period, affecting not just the UK but all the advanced industrial countries. First, many of the big companies which had dominated their markets in the early post-war decades, such as General Motors in the US or Imperial Chemical Industries in the UK, were facing difficult times, arising partly from sluggish growth in demand, partly from increasing international competition. One response was to hive off unwanted businesses, sometimes through management buy-outs; the large, vertically integrated corporation seemed out of tune with the new economic realities.²

Second, radical changes in technology, especially in computers and microelectronics, and later in biotechnology, were creating market opportunities which were more effectively exploited by new firms than by established companies. Some commentators described what was happening as a shift from the era of Fordist mass production to an 'information economy' in which the accumulation and exploitation of knowledge was more important than investment in physical assets.³ Others proclaimed a transition from a 'managed' to an 'entrepreneurial' form of capitalism, characterised by turbulence, uncertainty and a larger role for small firms.⁴

Among the industrial countries it was the US which set the pace in these developments. Older American companies were restructured earlier than their European counterparts, and there was a continuing flow of new entrants in knowledge-based industries. The speed with which resources were moved from declining to growing sectors, and the role played by new firms in this process, was widely seen as an important contributor to the acceleration in US productivity growth that began in the mid-1990s.

The success of the US during this period influenced the thinking of Britain's 'New Labour' government which entered office, under Tony Blair, in 1997. Gordon Brown, Labour's Chancellor of the Exchequer, was an enthusiastic admirer of the American system. While his first task was to establish a reputation for sound macro-economic management (hence the decision to delegate responsibility for monetary policy to the Bank of England), he attached almost equal importance to improving the supply side of the economy. His aim was to raise UK productivity closer to American levels, and to do so, in part, by stimulating entrepreneurial activity. Whereas the preceding Conservative governments had been mainly concerned with support for small business in general, Labour's focus was on measures aimed at boosting the number and size of new ventures which would be capable of rapid growth, especially in high technology – entrepreneurship policy rather than small business policy.⁵

How much have these measures achieved? This paper looks first at the US, discussing the sources of American entrepreneurial success in high-technology industries and the contribution made by government. The next section describes the evolution of policy in the UK, before and after the Thatcher reforms of the 1980s. Sections 4 and 5 review the performance of British start-up firms in the two industries where the gap between the US and the UK has been widest: electronics and biotechnology. These sections highlight the scarcity in the UK of US-style 'big gorillas' – new firms which grow very rapidly to become large, international enterprises – and consider the reasons for this gap. The concluding section assesses how far the UK has caught up with the US in entrepreneurship policy.

¹ David L. Birch *Job creation in America: how our smallest companies put the most people to work*. The Free Press, 1987. For a contrary view, see Steven J. Davis, John Haltiwanger and Scott Schuh *Small business and job creation: dissecting the myths and reassessing the facts*. National Bureau of Economic Research, Working Paper No 4492, October 1993.

² R.N. Langlois *The vanishing hand: the changing dynamics of industrial capitalism*. Industrial and Corporate Change Vol. 12 No 2, April 2003.

³ Zoltan J. Acs *The value of entrepreneurial start-ups to an economy*. Diebold Institute Entrepreneurship and Public Policy Project, Working Paper No 5. www.dieboldinstitute.org/papers.htm.

⁴ D.B. Audretsch and A.R. Thurik *What's new about the new economy? Sources of growth in the managed and entrepreneurial economies*. Industrial and Corporate Change, Vol 10 No 1, March 2001.

⁵ David M. Hart *Entrepreneurship policy: what it is and where it came from* in David M. Hart (ed) *The emergence of entrepreneurship policy*. Cambridge 2003. On the distinction between small business policy and entrepreneurship policy, see David Audretsch *Sustaining innovation and growth: public support for entrepreneurship* in Industry and Innovation, Vol 11 No 3, September 2004.

2 THE US EXAMPLE: WHAT DID GOVERNMENT CONTRIBUTE?

The virtues of the small businessman – self-reliance, energy, sturdy independence – have always ranked high in America's business ideology; the preservation of a strong small business sector has been seen as an essential counterweight to the power of large corporations. The first antitrust act, the Sherman Act of 1890, reflected the widespread belief that big firms were becoming too dominant and that some restraint on their expansion was necessary. However, the Act did not prevent a wave of mergers at the turn of the century, and, although the antitrust authorities were more aggressive in the years leading up to the First World War, there was a continuing trend in most industries towards greater concentration. Some defensive steps were taken during the Depression years, notably the Robinson-Patman Act, which imposed restrictions on the pricing power of large corporations; this measure was particularly directed at the retailing sector, where small shopkeepers were being squeezed out of business by Sears Roebuck and other large groups.

Political anxiety about small business continued after the Second World War. The rising importance of institutional investors, brought about by changes in the tax system, had increased the advantage which older and larger firms had always had over new and small ones in access to capital.⁶ Another consequence of the tax structure, combining high income tax rates with relatively low taxes on capital gains, was to encourage owners of medium-sized firms to sell out to larger groups.

In 1953 the government established the Small Business Administration, with a mandate to "aid, counsel, assist and protect, insofar as is possible, the interests of small business concerns". The definition of small business covered manufacturing firms with less than 500 employees, although slightly larger firms in non-manufacturing sectors were also eligible for support. The agency was authorised to make loans, to provide technical and managerial assistance, and to ensure that the interests of small business were given due weight by the military procurement agencies. In its first four years the SBA made loans of \$236m to some 5,000 businesses.

The SBA's remit was extended in 1958 with the introduction of the Small Business Investment Company scheme, whereby the agency licensed and helped fund privately-owned venture capital firms, which would provide long-term debt and equity finance for small businesses. At that time the provision of venture capital in the US was patchy and poorly organised. One of the pioneers in what was to become an important part of the US financial sector was American Research and Development (ARD), a Boston-based firm founded in 1946, which set out to provide management expertise as well as finance to promising high-technology firms. ARD's most successful investment was in Digital Equipment Corporation, the mini-computer maker which was one of the high-technology stars of the 1960s. On the West Coast there was some informal venture capital activity during the 1950s; successful stock market flotations by two firms based in what later became known as Silicon Valley, Varian and Hewlett-Packard, whetted investor interest in fast-growing, technology-based enterprises.

The SBIC programme provided an additional incentive for wealthy individuals and financial institutions to put money into high-risk ventures. The sponsors of the new investment companies had to learn how to evaluate risk and to assess the business plans of fledgling entrepreneurs; it was "an important first step in the institutionalisation of venture investing".⁷ Several SBICs were formed in California, and it was an attractive vehicle for early-stage investing in one of the great American entrepreneurial success stories, the semiconductor industry. One of the remarkable features of this industry (discussed in Section 4) was the role played by new firms in driving the technology forward. The cost of entry was relatively low, and the scientist-entrepreneurs who were coming into the market had little difficulty in raising the funds they needed.⁸

Towards the end of the 1960s the SBICs began to be replaced by private limited partnerships, an organisational form which avoided the public disclosure requirements imposed on SBICs and offered tax advantages for institutional investors.⁹ Arthur Rock, a New York investment banker who had helped to set up Fairchild Semiconductor, formed his limited capital partnership on the West Coast in 1961; he participated in several of the Valley's most famous new ventures, including Intel. Between 1969 and 1975, 29 limited partnerships were formed.¹⁰

A crucial requirement for the venture capitalists – and for the founder-entrepreneurs and their colleagues, most of whom held shares in their companies, either directly or through stock options – was the availability of an exit route, through initial public offerings (IPOs) on the stock market. The high-technology companies that had gone public in the 1950s, such as Hewlett-Packard, had listed their shares on the New York Stock Exchange, but the 'Big Board' imposed listing requirements which were difficult for young firms to meet. In 1971 the National Association of Securities Dealers set up the NASDAQ stock exchange, largely in response to pressure from the Securities and Exchange Commission to bring order into the unregulated over-the-counter market.¹¹ Over the subsequent decade the new exchange became the preferred market for new, high-technology firms; companies such as Intel and Apple chose to list on NASDAQ, and remained there even when they had reached a size that would have permitted a transfer to the New York Stock Exchange.

The growth of the venture capital industry came to a temporary halt in the difficult economic conditions of the mid-1970s. There were only 4 initial public offerings in 1975, raising a meagre \$16m, compared to 548 in 1969 raising \$1.5bn. The situation was made worse by an increase in capital gains tax and by a change in the treatment of stock options, obliging recipients to pay tax when options were exercised rather than when the stock was sold. At the same time the Employee Retirement Income Security Act of 1974 imposed new rules on pension funds, obliging them to invest with the care of a 'prudent man' and thus to avoid high-risk ventures; this was interpreted as a virtual ban on venture capital investments.

Concern about the dearth of capital for new ventures promoted several changes at the end of the decade. Capital gains tax was reduced from 49 per cent to 28 per cent in 1979, and to 20 per cent in 1981. The Incentive Stock Option Law re-established the earlier practice of deferring the tax liability on holders of stock options to when the shares were sold rather than when the options were exercised. Finally, the Department of Labour ruled that the 'prudent man' principle for pension funds was compatible with a greater degree of portfolio diversification, including venture capital. These changes helped to bring about an enlargement of the venture capital industry, with an increasing proportion of its funds coming from pension funds and other institutional investors.¹²

The formal venture capital industry was complemented by business angels, wealthy individuals who provided the initial funding to get new firms off the ground. "Angels are predominantly affluent, self-made men in their forties or older, with graduate degrees, who tend to invest in the industry where they made their money".¹³ They generally expect to be actively involved in the firms they back, either as consultants or board members, and they tend to invest close to home. A well-known example was Mike Markkula, who had worked at Fairchild and Intel and had amassed a considerable fortune when Intel went public in 1971; he provided advice and seed funding to the founders of another Silicon Valley start-up, Apple.¹⁴

Whether the combination of venture capitalists and business angels provide an adequate flow of capital for start-up firms has been the subject of much debate in the US.¹⁵ Anxieties on this score were particularly acute in the early 1980s, when US industry appeared to be losing ground to German and Japanese competitors, prompting suggestions that government intervention – perhaps even a European-style industrial policy – was needed to promote a faster rate of innovation. One response was the Small Business Innovation Research programme, started in 1982, whereby any Federal agency that had an extramural R & D programme of more than \$100m was obliged to allocate a certain percentage of its budget to small businesses; the average SBIR grant fell between \$400,000 and \$1m.¹⁶

⁶ Carl Kaysen and Donald F. Turner *Antitrust policy* Harvard 1959.

⁷ Martin Kenney and Richard Florida *Venture capital in Silicon Valley* in Martin Kenney (ed) *Understanding Silicon Valley* Stanford University Press 2000. See also Thomas F. Hellman *Venture capitalists, the coaches of Silicon Valley* in Chong-Moon Lee, William F. Miller, Marguerite Gong Hancock and Henry S. Rowen (eds) *The Silicon Valley Edge* Stanford University Press, 2000.

⁸ John E. Tilton *International diffusion of technology: the case of semiconductors* Brookings 1971, p.89

⁹ Paul A. Gompers and Josh Lerner *What drives venture capital fund raising?* National Bureau of Economic Research, Working paper 6906, January 1999.

¹⁰ George W. Fenn, Nellie Liang and Stephen Prowse *The economics of the private equity market* Federal Reserve System, December 1995.

¹¹ Mark Ingebretsen *NASDAQ, a history of the market that changed the world* Forum 2002.

¹² Gompers and Lerner *What drives venture capital fundraising?*

¹³ John Freear, Jeffrey E. Sohl, and William Wetzel *Angles on angels: financing technology-based ventures – a historical perspective* Venture Capital, Vol 4, No 4, 2002.

¹⁴ Jim Carlton *Apple, the inside story of intrigue, egomania, and business blunders* Random House, 1997

¹⁵ Joshua Lerner *'Angel' financing and public policy: an overview* Journal of Banking and Finance, Vol 22, 1998, pp.773-783.

¹⁶ Charles W. Wessner (ed) *The Small Business Innovation Research Programme, challenges and opportunities* National Academy Press, 1999.

The SBIR programme, which mainly affected the big Federal spenders on R & D such as the Defence Department, the Department of Health, and the National Science Foundation, was criticised by some observers on the ground that government intervention would distort the capital allocation process; others feared that the SBIR programme would divert funds from what should have been a higher priority, Federal support for basic science in universities. A study carried out in the mid-1990s concluded that the programme (which provided over \$6bn to small high-technology firms between 1983 and 1995) did make a difference to firms which received SBIR grants, not least in providing a seal of approval which made it easier to tap other sources of finance.¹⁷ However, the main benefit of the programme had gone to firms operating in those parts of the country – principally California and Massachusetts – which were already well served by private-sector venture capital funds. Public initiatives to provide capital for new firms appeared to have had only a limited economic impact; they complemented private-sector venture capital firms and other agencies that assisted new firms, but could not do much for regions where those mechanisms did not exist.

Another public-private partnership with a similar objective was the Advanced Technology Programme, set up in 1990 under the Trade and Competitiveness Act of 1988. Administered by the Department of Commerce, the ATP provides cost-shared funding to industry “to accelerate the development and broad dissemination of challenging, high-risk technologies that promise broad-based economic benefits for the nation”.¹⁸ Like the SBIR programme, the ATP appears to have supported R & D projects which might otherwise not have gone ahead. An ATP award has a ‘halo’ effect which makes it easier for firms to attract other sources of funding.¹⁹

Meanwhile the Small Business Administration has continued to monitor the availability of finance for start-up firms, paying particular attention to business angels. In the mid-1990s there were about 250,000 active angels investing in about 30,000 small firms each year; but this was thought to be well short of the number of firms that needed risk capital to get started. Angel financing suffered from inefficiencies arising from its lack of organisation and high transaction costs. “Deals depended on informal networks, different states had different regulations, and monitoring was expensive”.²⁰ To deal with these problems the SBA set up an electronic network known as ACE-Net, whereby small corporate offerings could be viewed over the Internet by accredited high net worth investors.

It is clear, then, that throughout the post-war period the US government has taken a close interest in the provision of finance for small business, and for high-technology ventures in particular. This has included direct government contributions through programmes such as SBIR and ATP, and the use of tax and regulatory policies to encourage investors to commit funds to small business. But finance is not the only area where public policy has influenced the environment for high-technology entrepreneurs. Four other areas are also relevant: government procurement; the promotion of competition; support for basic science; and the encouragement of technology transfer between universities and business.

In many of the high-technology industries that have flourished in the US since 1945 government procurement has provided a vital stimulus. The early computer systems were supported by Federal research funds, and the military was the principal customer. Although the main beneficiaries were established office machinery manufacturers such as IBM and Remington Rand, the effect was to widen the market and create opportunities for new entrants. The Federal government was also the biggest customer for traded software; the large domestic market gave American software firms a first-mover advantage which they never lost.²¹

In semiconductors, the surge in innovation that followed the invention of the transistor in 1948 coincided with a growing demand from the Federal government for miniaturised electronic devices. “The market for semiconductors began with the US military, and it was the Cold War that nurtured this industry in its infancy”.²² The guidance and control systems of the Minute Man missile, and of Project Apollo, were based on integrated circuits, and these programmes were supported by R & D funding from the Department of Defense.²³

Dependence on the military had some disadvantages. Some historians attribute the decline of American consumer electronics firms in the face of Japanese competition to the industry’s preoccupation with military electronics, causing companies to focus more on performance than on meeting the needs of the consumer market.²⁴ The invention of the microprocessor, and the consequent growth of the personal computer industry, owed nothing to government procurement. Nevertheless, in other areas defence-related research continued to be important. Thus the Arpanet, the precursor to the commercial internet, was developed in the Defence Department during the 1960s and 1970s. Following partial privatisation in the early 1980s the locus of innovation shifted to the private sector, but the success of American firms in internet-based activities owed a great deal to defence-related programmes in the networking field.²⁵

These government programmes were driven by considerations of national security – there was no industrial policy for computers and semiconductors, and no attempt to foster national champions. (Equally, the Defence Department did not ‘pick winners’ but was keen to back a wide range of suppliers, including untried ones.) On the contrary – and this is the second area where public policy was important – the government has sought to curb the power of dominant companies. The antitrust authorities forced American Telephone and Telegraph to license the transistor widely and not to compete as a supplier of semiconductors in the open market (although it could make them for its internal use). Many of the licensees were new entrants to the electronics sector. Another example was the long antitrust suit against IBM, which led to the ‘unbundling’ of its software from the hardware side of the business, thus enlarging the market for independent software providers.

Antitrust policy has been reinforced by deregulation in industries such as telecommunications which had previously been regarded as natural monopolies. The break-up of AT & T in 1984, followed by the Telecommunications Act of 1996, increased competition in voice and data communications, and the consequent reduction in local telephone charges facilitated the growth of internet services.²⁶ Although many of the new entrants in telecommunications did not survive the stock market collapse in 2000, their presence in the market forced incumbents to make themselves more efficient, and contributed to what has been described as the most creative period in the history of telecommunications.²⁷

A third contribution from government to the success of high-technology enterprise has been its support for scientific research. Again, this policy was not specifically designed to help entrepreneurial firms, but rather to strengthen the nation’s security or to improve social welfare. Health is the biggest element in Federal research outside defence; in recent years federal spending on health-related research has been roughly equivalent to the entire research budget of the US pharmaceutical industry. Most of this spending is administered by the National Institutes of Health, and carried out either in NIH laboratories or in universities.

In the early post-war decades the principal beneficiaries of government-funded health research were the established pharmaceutical companies, but the revolution in molecular biology which began in the 1970s altered the capabilities that were needed in pharmaceutical innovation, allowing scientist-entrepreneurs to set up specialised biotechnology firms. Because the link between academic science and commercial exploitation is closer in biotechnology than in electronics, the role of government-funded research has been even more important in this sector: “What Bell Labs was to semiconductors in the early 1960s, the National Institutes of Health are to bioscience today”.²⁸

¹⁷ Josh Lerner *The government as venture capitalist: the long-run impact of the SBIR program* National Bureau of Economic Research, Working Paper 5753, September 1996.

¹⁸ Charles W. Wessner *The Advanced Technology Programme: assessing outcomes* National Academy Press, 2001.

¹⁹ Maryann P. Feldman and Maryellen R. Kelley *Leveraging research and development: assessing the impact of the US Advanced Technology Programme* Small Business Economics, Vol 20, pp. 153-165, 2003.

²⁰ Zoltan J. Acs and Fred A. Tarpley *The angel capital electronic network (ACE-Net)* Journal of Banking and Finance, Vol 22, 1998, pp. 793-797.

²¹ David C. Mowery *The computer software industry* in David C. Mowery and Richard R. Nelson (eds) *Sources of industrial leadership* Cambridge 1999.

²² R. N. Langlois and W. E. Steinmueller (eds) *The evolution of competitive advantage in the worldwide semiconductor industry* in Mowery and Nelson (eds) *Sources of industrial leadership*.

²³ Richard N. Langlois et al *Microelectronics: an industry in transition* Unwin Hyman 1988, p. 152.

²⁴ David A. Hounshell *The evolution of industrial research in the United States* in Richard S. Rosenbloom and William J. Spencer (eds) *Engines of innovation* Harvard 1996.

²⁵ David C. Mowery and Timothy Simcoe *Is the Internet a US invention? An economic and technological history of computer networking* Research Policy, Vol 31, 2002, pp. 1369-1387.

²⁶ Mowery and Simcoe *Is the Internet a US invention?*

²⁷ Eli M. Noam *Entrepreneurship and government in telecommunications* in Hart (ed) *The emergence of entrepreneurship policy*.

²⁸ Gordon E. Moore *Some personal perspectives on research in the semiconductor industry* in Rosenbloom and Spencer (eds) *Engines of innovation*.

American excellence in basic science was a post-1945 phenomenon, stemming in part from the prestige which science and scientists had acquired during the war. But Federal spending on scientific research has reinforced what is probably the single most important source of American success in high-technology industries – a well-funded university system highly responsive to the needs of business.

The starting-point was the expansion of higher education that followed the Morrill Act of 1862. The Act provided each state with federally owned lands as the financial basis for operating state universities, but the states themselves, not the Federal government, were made responsible for the financing and management of these institutions. What emerged over the next few decades was a competitive, decentralised higher education system consisting of state and private universities, which had to demonstrate to their sponsors – state governments in one case, private donors on the other – that they were providing a good service to local industry.²⁹

The links with business took a variety of forms, including the introduction of course material that was relevant to the needs of new industries – electrical engineering at the end of the nineteenth century, chemical engineering in the 1920s, and computer science after the second world war. During this later period, as the government stepped up its support for research, the universities generated more patentable inventions, some of which were licensed to industrial firms. Patenting and licensing activity increased during the 1960s and 1970s in response to the growing importance of biomedical research.

Where the research was funded by government, the funding agency retained ownership of the intellectual property; if universities wanted to patent and licence inventions resulting from the research, they had to negotiate with the relevant agency for patent rights. To simplify these arrangements, the Bayh-Dole Act of 1980 transferred the ownership of intellectual property resulting from government-funded research to the universities themselves.³⁰ The result was to encourage universities to devote more resources to technology transfer, partly as a means of raising revenue; there was a shift from non-exclusive to exclusive licences, and a greater willingness by universities to take equity stakes in spin-out firms. While the Act did not greatly affect the licensing activities of universities which were already active, such as Stanford and the University of California, it brought other universities into the field.

Whether the Bayh-Dole Act has significantly increased innovative activity in the US remains an open question; some observers believe that it may even have had a negative effect, causing universities to put too much stress on exclusive licences and thus impeding the free flow of scientific knowledge.³¹ That judgement is controversial, but it does underline the need for caution in developing policies to promote technology transfer between academia and business – and in assessing what such policies are likely to achieve.

There is no automatic link between government spending on research, financial incentives for universities to commercialise their intellectual property, and the emergence of fast-growing, science-based companies. The role of Stanford in Silicon Valley is often cited in this connection, but the birth of the semiconductor industry, on which the prosperity of the Valley was based, was not the result of academic research conducted within the university. The story began with the largely fortuitous decision by William Shockley, co-inventor of the transistor at Bell Laboratories, to move from the east to the West Coast and locate his new semiconductor firm in Palo Alto in 1955.³² Three years later eight of Shockley's senior engineers, led by Gordon Moore and Robert Noyce, broke away to form Fairchild Semiconductor. Fairchild was the most innovative of the new semiconductor firms, and, by showing how a group of talented engineers could start a new business and make themselves rich, it served as a model for other entrepreneurs. By 1971, 21 out of 23 semiconductor firms based in Silicon Valley were offshoots from Fairchild. Stanford was not directly involved in this process.

According to Gordon Moore, co-founder of Fairchild and Intel, the defining characteristics of Silicon Valley – its business models and its sustained, technology-based growth – “were neither started nor made fundamentally possible” by the presence of the university. Stanford did play an important supporting role in the subsequent growth of the industry, by providing a stream of well-trained scientists and engineers, some of whom were hired by Silicon Valley companies, and by promoting research co-operation with local firms. Moore describes the role of the university in regional high-technology economies “as an economic institution responsive to the manpower and intellectual needs of the marketplace”.³³

Given the special circumstances which gave rise to the semiconductor industry, it is not surprising that attempts to replicate Silicon Valley in other regions have had only mixed success. Several state governments have sought to foster the creation of high-technology clusters which draw on the special strengths of local universities. In a few cases, such as Research Triangle in North Carolina, which specialises in pharmaceuticals and biotechnology, this approach has worked well.³⁴ But the experience of other regions has been disappointing. Even if a large number of university-linked start-ups are created, this does not necessarily do much for the local economy.³⁵ The biggest contribution to job creation comes from a small number of exceptional firms, such as Fairchild in California or Digital Equipment Corporation in Massachusetts, and whether such firms emerge in a particular region seems to be partly a matter of luck.

There is a clear limit to what governments, either national or regional, can do in this field. Quite apart from the luck factor, the emergence of high-technology ‘gorillas’ such as Intel or Amgen depends on two conditions which are largely outside the government's control. The first is the existence of a large technological or market opportunity, sometimes stemming from a scientific breakthrough from within the industry or from academic research. The second is the presence of individuals with the managerial and firm-building skills to convert start-up firms into big businesses. As is clear from the histories of the electronics and biotechnology industries which are discussed later in this paper, the US has been well endowed with such individuals, and they have created some very successful companies. Whether this reflects some distinctively American cultural trait, or perhaps greater investment in the training and education of managers, is a matter for speculation. It is possible that, for cultural reasons, more talent is attracted into entrepreneurial activity in the US than in other countries, but culture is not something that lends itself easily to government intervention. The main focus, for countries which want to emulate the US, has to be on institutions and policies. The UK's efforts in these areas are discussed in the next section.

²⁹ Nathan Rosenberg *America's entrepreneurial universities* in Hart (ed) *The emergence of entrepreneurship policy*.

³⁰ For a critical account of the Bayh-Dole Act and its consequences, see David C. Mowery, Richard R. Nelson, Bhaven N. Sampat and Arvids A. Ziedonis *Ivory tower and industrial innovation: university-industry technology transfer before and after the Bayh-Dole Act in the United States* Stanford 2004.

³¹ Mowery et al *Ivory tower and industrial innovation*.

³² Timothy J. Sturgeon *How Silicon Valley came to be* in Kenney (ed) *Understanding Silicon Valley*.

³³ Gordon Moore and Kevin Davis *Learning the Silicon Valley way* in Timothy Bresnahan and Alfonso Gambardella (eds) *Building high-tech clusters: Silicon Valley and beyond* Cambridge 2004.

³⁴ For an account of the growth and creation of Research Triangle, see Albert N. Link and John T. Scott *The growth of Research Triangle Park* Small Business Economics, Vol 20, 2003, pp. 167-175

³⁵ Anne S. Miner, Dale T. Eesley, Michael Devaughn and Thekla Rura-Polley *The magic beanstalk vision: commercialising university inventions and research* in Claudia Bird Schoonhoven and Elaine Romanelli (eds) *The entrepreneurship dynamic* Stanford 2001.

3 THE EMERGENCE OF ENTREPRENEURSHIP POLICY IN THE UK

Although small business has never carried the same political weight in Britain as in the US, the need to preserve a strong tier of small and medium-sized enterprises has long been a concern for public policy. As in the US, there has been a continuing debate over whether small firms are ill-served by the financial system. This was one of the issues highlighted by a government-appointed inquiry into banking and finance, the Macmillan Committee, in 1931. The committee found that public equity issues of less than £200,000 were too small to be of interest to existing financial institutions, and recommended that the gap should be filled by a new type of capital-raising agency, specialising in the small business sector.

There was no immediate response from the City of London, but at the end of the Second World War the commercial banks, under pressure from the Bank of England, reluctantly agreed to set up a new, jointly owned institution, the Industrial and Commercial Finance Corporation (ICFC), with a remit to supply risk capital to smaller firms. Although the government was instrumental in getting the ICFC off the ground, it was a private-sector institution, unlike the Small Business Administration in the US, and no government subsidy was involved.

Despite an uneasy relationship with its owners, ICFC made modest progress during the 1950s, and in the following decade it acquired an additional role as a backer of technology-based enterprises. This came about through the absorption of Technical Development Capital, which had been set up by the insurance companies and other financial institutions to help inventors commercialise new technology. Again this was a private-sector rather than a government initiative, but it came at a time of growing anxiety about the 'technology gap' with the US. The hope was that ICFC in its enlarged form would foster in Britain the kind of innovative small firm which was making such an impact in several American industries.

By 1970 Technical Development Capital had invested over £6m in more than 100 companies, including several American-style university spin-offs.³⁶ One example was Oxford Instruments, a manufacturer of low-temperature superconducting magnets, founded in 1959 by Martin Wood on the basis of work on superconductivity that he had been conducting at Oxford's Clarendon Laboratory; the availability of ICFC funds in 1967 provided a lifeline at a crucial stage in the company's development.³⁷

Upgrading the technological capacity of British industry was a major preoccupation for the Labour government which held office from 1964 to 1970. However, the main thrust of government policy was to create larger companies which, it was hoped, would have the financial muscle to win a larger share of world markets. The Industrial Reorganisation Corporation was set up to promote mergers in fragmented industries, working closely with a new government department, the Ministry of Technology. The computer industry was an early target; most of the leading British-owned manufacturers were merged into a single group, International Computers Limited (ICL), which was supported by subsidies for research and development and preferential purchasing on the part of government departments. When a British entrepreneur, Iann Barron, developed a mini-computer in the early 1960s and set up a new company, Computer Technology Ltd, to exploit it, he received little encouragement from government departments. "The Ministry of Technology did not like us because we were too small... Government policy was being formulated by the big companies – they had the people to spare for lobbying and sitting on committees".³⁸ Similarly, the Ministry of Defence relied for the most part on established suppliers such as Plessey and the various electrical firms that came together at the end of the decade to form General Electric Company (GEC). Unlike the US Department of Defence (whose procurement budget was very much larger), British officials did not deliberately seek to encourage innovative small firms.

Thus ICFC and TDC were to some extent rowing against the tide. Quite apart from the direct effect of government industrial policy, merger activity was running strongly during the 1960s. A buoyant stock market facilitated share-based acquisitions, and the government made little use of its power to prohibit anti-competitive mergers. Tax policy, too, tended to favour the larger firms. With capital gains tax at 30 per cent, compared to marginal income tax rates which could be as high as 90 per cent, entrepreneurs starting new businesses had little incentive to expand them. As one businessman wrote later, "most successful entrepreneurs tended to sell out to sleepy, poorly managed listed companies; these companies grew larger still, and increasingly complacent, via relatively cheap and easy acquisitions".³⁹

By the end of the decade there were fears that the process of concentration might be going too far; the share of the 100 largest enterprises in manufacturing employment had risen from 27 per cent in 1958 to 37 per cent in 1968.⁴⁰ Several of the big companies that had been created through merger (including ICL) were performing badly. It was clear that mergers were not a recipe for greater efficiency, and there were calls for a tougher regulatory stance on merger activity. A committee of inquiry set up towards the end of the Labour government's term of office recommended a change in competition policy whereby proponents of a merger would have to demonstrate to the Monopolies Commission, not simply that their merger would not damage the public interest, but that it would be positively beneficial.⁴¹ Although this proposal was not taken up, it was a sign of waning official enthusiasm for giant companies.

In 1969 the government established a committee of inquiry into small firms under John Bolton, who was himself a successful electronics entrepreneur. The Bolton Report showed how far the small business sector had declined since the end of the war and underlined the importance of small firms as a competitive spur to established companies.⁴² It was published in 1971, when a Conservative government was in power, and most of its recommendations, mainly aimed at removing impediments that were holding back the growth of small firms, were implemented.

This approach was taken further by the Labour government when it returned to office in 1974. The new government had a strong commitment to 'regenerate' British industry, and, when the National Enterprise Board was set up, part of its remit was to look for promising high-technology ventures which were difficult to finance through conventional sources.⁴³ Two of its most ambitious 'greenfield' ventures were the creation of new companies in biotechnology and semiconductors, which are discussed in Sections 4 and 5. The NEB also took stakes in smaller firms – many of them in computers and related sectors – in the hope of accelerating their growth.

Support for this shift of policy came from a study carried out by the American management consultants, Arthur D. Little.⁴⁴ Their report drew attention to the dearth of fast-growing, technology-based firms in Britain compared to the US. The number of new technology-based firms set up in Britain since 1950 and still in existence in the mid-1970s was estimated at about 200, compared to several thousand in the US. By far the largest of the British firms was Racal, a specialist in military electronics which employed about 4,000 people; most of the others had less than 500 employees.

The consultants highlighted a range of factors which made the US a more favourable environment for high-technology entrepreneurs: a large domestic market; the availability of private wealth as a source of seed capital for new ventures; a fiscal framework which encouraged the flow of private risk capital into new ventures; the existence of an active market (through NASDAQ) for the trading of shares in new ventures; greater mobility of individuals between academic institutions and private industry; and a large government expenditure programme in high technology areas. The most important step the government could take, in the consultants' view, would be to cut taxes.

³⁶ Richard Cooper and Donald Clarke *30: fifty years of investing in industry* Oxford 1995

³⁷ Audrey Wood *Magnetic Venture, the story of Oxford Instruments* Oxford 2001, p.51

³⁸ Author's interview with Iann Barron, July 22, 1991. See also John Hendry *Innovating for failure: government policy and the early British computer industry* MIT Press, 1989.

³⁹ John Hoskyns *Just in time: inside the Thatcher revolution* Aurum Press, 2000, p.7.

⁴⁰ S.J.Prais *The evolution of giant firms in Britain* Cambridge, 1976, p.8

⁴¹ *A review of monopolies and mergers policy, a consultative document* Cmnd 7198, HMSO 1978.

⁴² *Report of the Committee of Inquiry on Small Firms* Cmnd 4811, HMSO 1971.

⁴³ W.B.Willott *Industrial innovation and the role of bodies like the National Enterprise Board* in Charles Carter (ed) *Industrial policy and innovation* Heinemann, 1981.

⁴⁴ Arthur D. Little *New technology-based firms in the UK and the Federal Republic of Germany, a report for the Anglo-German Foundation for the study of industrial society* London 1977.

These conclusions were entirely in line with the thinking of the Conservative government which entered office in 1979. One of the policy documents produced in the run-up to the election spoke of launching “a determined programme to remove every possible fiscal, legislative, social, planning and bureaucratic barrier in the way of starting up and growing small businesses”.⁴⁵

In the short term, the new government’s small business policy was directed at countering unemployment, which had reached the unprecedented level of 2.5m in 1981. A new Enterprise Allowance Scheme enabled unemployed persons to draw £40 per week in benefit while working to establish a business, as long as they could contribute £1,000 of their own money; at its peak in 1987-88 some 600,000 people participated in this scheme.⁴⁶

More important for the longer term was a range of financial measures aimed at boosting the small business sector. Under the Small Firm Loan Guarantee Scheme the government provided a guarantee of up to 80 per cent (later reduced to 70 per cent) for approved bank loans taken out by small firms. This was followed by the Business Start-up Scheme, later renamed the Business Expansion Scheme, which enabled private individuals to claim tax relief on their top slice of income on new equity investments of up to £40,000 a year in unquoted companies, provided the shares were held for five years. The 1984 Budget also provided more generous tax treatment for stock option schemes.

These changes gave a fillip to the growth of the venture capital industry. By the end of 1983 some 60 venture capital funds were operating in the UK, compared to fewer than 20 before 1979. One of the leading players was ICFC, which, under its new name of Investors in Industry, or 3i, had broken away from the tutelage of the clearing banks. By the early 1990s the British Venture Capital Association had more than 100 member firms, and the total amount of money invested or available for investment was estimated at about £7.5bn.⁴⁷

As in the US, venture capitalists aimed to hold on to their investments for 3-5 years before seeking an exit through a stock market flotation or a trade sale. The London Stock Exchange, which had largely neglected the small company sector, responded to this demand by creating the Unlisted Securities Market, with simpler listing requirements than those imposed by the main exchange. The USM attracted smaller and younger companies, and by 1986 over 500 companies had listed on the new market, raising some £1bn.⁴⁸

The government was not directly involved in the provision of venture capital; the National Enterprise Board was closed down and most of its investments were sold to the private sector. This non-interventionist stance did not preclude other forms of support for high-technology ventures, although the amounts of money involved were small. For example, the Small Firms Merit Award for Research and Technology (SMART) provided grants for companies with less than 250 employees to undertake feasibility studies and bring development projects up to prototype stage. Like SBIR and ATP in the US, these schemes helped recipients gain access to other sources of finance.

Another strand of policy, influenced by US experience, was to encourage universities to work more closely with industry. An important step was to change the intellectual property regime governing innovations resulting from government-funded research. Since 1948 the exclusive right to such property had rested with a government agency, the National Research Development Corporation. In 1985 the NRDC was converted, along with some residual activities of Labour’s National Enterprise Board, into a new body, the British Technology Group, and the universities were given the right to exploit their own innovations. The effect was similar to that of the Bayh-Dole Act in the US, and it prompted British universities to step up their technology transfer activities.

A much-discussed model for university-business collaboration was the cluster of science-based firms that had grown up around Cambridge University. Silicon Fen, as this region came to be called, was not the product of government policy but resulted from a series of initiatives taken by the university. In 1969 a committee chaired by Sir Neville Mott, head of the university’s Cavendish Laboratory, recommended that the city and the university should encourage the growth of science-based firms in and around Cambridge. The report was followed by the decision by Trinity College to establish the Cambridge Science Park on the outskirts of the town.⁴⁹ Several technology firms were already operating in the area (notably Cambridge Consultants, founded in 1960 and a prolific source of spin-out companies), but the creation of science park helped to accelerate the rate of new firm formation. St John’s College later set up an Innovation Centre, which became an important agency for technology transfer.

At Oxford, too, there had been some increase in entrepreneurial activity during the 1970s. Following the example of Martin Wood at Oxford Instruments, several university academics founded or helped to found new businesses to exploit their innovations. These included Research Machines, a supplier of information and communications technology to schools and universities, and Solid State Logic, a manufacturer of professional audio consoles for music, broadcasting and film.⁵⁰ A new body, Isis Innovation, was set up to market the university’s intellectual property.

By the end of the 1980s the UK had acquired some of the institutional support that had underpinned the growth of innovative high-technology firms in the US. The business environment was also more favourable to entrepreneurial activity, with lower taxes, less government intervention, and a stronger emphasis on promoting competition. The privatisation and de-regulation of sectors such as telecommunications encouraged new entrants, one of which - Vodafone, the mobile telephone company - was to become a major international player in its field (see below).

Not all the government’s initiatives were successful. The Enterprise Allowance Scheme had led to the establishment of many short-lived businesses – “a cycle of uncreative destruction”, as one commentator put it.⁵¹ There were also still shortcomings in the supply of finance. Although the venture capital industry had grown at an impressive rate, it was increasingly concentrating on later-stage investments and management buy-outs or buy-ins, to the detriment of early-stage financing. The gap was partially filled by business angels, but more needed to be done to stimulate this type of investment.

Responding to these criticisms, the government replaced the Business Expansion Scheme, which had been widely abused for tax avoidance purposes, by the Enterprise Investment Scheme, which provided more generous tax reliefs for investment in start-up firms. This was followed by the introduction of Venture Capital Trusts, through which individuals could spread their risks with a range of investments in technology-based firms; shareholders in VCTs would qualify for income tax relief as long as they held their shares for five years.

The recession of the early 1990s had led to a dearth of new issues on the Unlisted Securities Market, and the Stock Exchange came near to closing it down; in 1991 only £11.6m was raised on the USM compared to £308m in 1988. (The decline was partly due to a change in the rules which made it easier to obtain a listing on the main exchange.) The Stock Exchange, under some government pressure, agreed that a separate market for smaller firms was still needed, and it set up the Alternative Investment Market (AIM) in 1995. It also agreed, at the request of the venture capital community, to introduce special rules for biotechnology firms, making it possible them to obtain a listing without the usual requirement of a five-year profit record.

⁴⁵ Hoskyns *Just in time* p.68

⁴⁶ David J. Storey *Understanding the small business sector* Routledge, 1994

⁴⁷ Steven Abbott and Michael Hay *Investing for the future: new firm funding in Germany, Japan, the UK and the USA* Financial Times/Pitman Publishing 1995.

⁴⁸ Randal Michie *The London Stock Exchange, a history* Oxford 1999, p.573.

⁴⁹ Segal Quince Wicksteed *The Cambridge Phenomenon, The growth of high technology industry in a university town* published by Segal Quince Wicksteed, Cambridge, 1985. See also Suma Athreye *Agglomeration and growth: a study of the Cambridge high-tech cluster* in Bresnahan and Gambardella (eds) *Building high-tech clusters*.

⁵⁰ Helen Lawton Smith and others *Enterprising Oxford, the growth of the Oxfordshire high-tech economy* Oxfordshire Economic Observatory, 2003.

⁵¹ F.J. Greene, Kevin F. Mole and D.J. Storey *Does more mean worse? Three decades of enterprise policy in the Tees Valley* *Urban Studies*, Vol 41 No 7, June 2004

By the time the Conservatives left office in 1997 the environment for small firms was far better than it had been twenty years earlier. This was a legacy on which the new government, having abandoned its old attachment to 'national champions', was determined to build. Echoing the rhetoric of Margaret Thatcher, the government declared that entrepreneurship and innovation were central to the creative process in the economy, and that fiscal and cultural barriers to entrepreneurial activity had to be removed.⁵² The UK needed to move more quickly towards a knowledge-based economy, and high-technology entrepreneurs would play a central role in the transition.

Labour's entrepreneurship policy had two main strands – improving the supply of finance for start-up and early-stage firms, and promoting the transfer of technology from universities to business; the latter was linked to regional policy, influenced by the belief that universities should be more involved in upgrading the technological base of the regions in which they were located. At the same time government ministers, led by Gordon Brown, the Chancellor, launched an energetic campaign to promote an 'enterprise culture', urging schools to take a greater interest in the subject and encouraging universities to include entrepreneurship in their curriculum.

In his first budget Mr Brown announced a package of reforms to increase the flow of funds into small business, including a reduction in capital gains tax on long-term investment and a new version of the Enterprise Investment Scheme, providing more tax incentives for angel investors. This was followed by the launch of an Enterprise Fund, combining public support and private finance to increase the flow of funds to smaller enterprises; some of this funding would go to a network of Regional Venture Capital Funds.

High technology was a particular target of attention – hence the appointment of a committee under Sir Peter Williams, chairman of Oxford Instruments, to identify financing barriers experienced by high-technology firms.⁵³ The committee recommended further reform of the capital gains tax regime, more generous tax treatment of stock options, and more encouragement for pension funds to invest in venture capital. On pension funds, the government accepted the conclusion of a subsequent report that existing rules for pension fund investment unduly restricted their ability to invest in venture capital.⁵⁴

At the start-up stage the government sought to increase the supply of funds both by direct intervention – it sponsored a number of Early Growth Funds which made investments of up to £100,000 in innovative and knowledge-intensive businesses – and by stimulating activity by business angels. The financial promotion rules were altered to make it easier for start-ups and other small firms to offer their shares to business angels without having to be subject to regulation under the Financial Services Act. The government also helped to set up the National Business Angels Network.⁵⁵

Even after these initiatives the government continued to worry about the existence of an 'equity gap' facing businesses seeking modest amounts of growth capital – principally in the range of £250,000 to £1m, below the level likely to interest venture capitalists and too large for most business angels.⁵⁶ At the end of 2004 the government was considering the introduction of Enterprise Capital Funds, loosely modelled on the Small Business Investment Companies in the US. The government would offer debt at favourable interest rates to privately owned and managed funds, the funds would defer repayment until they had generated the necessary cash flow, and profits would be shared between the government and the private investors.⁵⁷

Independent evaluation of the Enterprise Investment Scheme and the Venture Capital Trusts indicated that both schemes had achieved their immediate objectives, to the extent that most of the investments they supported would not have gone ahead in the absence of the schemes.⁵⁸ However, there was rather more doubt about the Regional Venture Capital Funds. Given that these trusts would focus on small-scale, early-stage ventures, requiring hands-on monitoring and support, it was

not clear whether there was a sufficient supply of skills to manage them. There was also the 'crowding out' problem. According to one critical assessment, "the likely effect of creating an additional supply of early stage capital, operating on a less than fully commercial basis as a result of government financial support, in a situation where there is a restricted supply of viable, high potential businesses, will be to create distortions in the market which over the longer term could drive out existing private sector venture investors".⁵⁹

Despite these criticisms there was not much doubt that the changes made by the Labour government since 1997 had improved the availability of finance for high-technology entrepreneurs. The venture capital industry was the largest and most active in Europe, and AIM had established itself as the preferred European market for Initial Public Offerings; in 2004 it attracted over 60 per cent of all European IPOs. Some commentators suggested that the task for entrepreneurship policy was no longer to increase the supply of finance but rather to increase the number of investment-ready proposals from entrepreneurs.⁶⁰

The other strand of government policy was to improve the transfer of technology from universities to business. From the start of its term of office the government sought to reward universities for activities that enhanced interaction with business to promote technology transfer.⁶¹ It set up a third stream of funding for universities (alongside funding for teaching and research) through the Higher Education Innovation Fund, which was designed to encourage universities to devote more resources to contract research, licensing and the formation of spin-out companies.

The Lambert Review of business-university collaboration, published in 2003, found that the commercialisation of university intellectual property was hindered by a lack of clarity over ownership of IP, and by the variable quality of technology transfer offices; a new protocol for the ownership of IP was recommended.⁶² The Review also suggested that the ready availability of public and private funds for high-technology start-ups during the 1990s had caused universities to put too much emphasis on spin-outs and not enough on licensing. In the US 4,058 new licenses were agreed in 2001 and 494 spin-outs were formed; the corresponding figures in the UK were 648 and 158. Too many of the UK spin-outs were of doubtful quality.

Nevertheless, to the extent that British universities were now more aware of industry's needs, and more actively involved in technology transfer, this was an advance on the situation which prevailed ten or twenty years earlier. Here, as in the provision of capital for entrepreneurial firms, the Labour government had moved the UK nearer to the US model. Yet one element was still missing. The UK continued to lag behind the US in its ability to foster 'big gorillas' – technology-based firms that grow very quickly from the start-up stage into major international enterprises.⁶³ This was particularly true in electronics and biotechnology, two industries that are discussed in the next two sections

⁵² *Our competitive future: building the knowledge-driven economy* Department of Trade and Industry, Cmnd 4176, HMSO 1998.

⁵³ *Financing of high technology businesses, a report to the Paymaster General* November 1998.

⁵⁴ *Institutional investment in the United Kingdom: a review by Paul Myners* HM Treasury 2001.

⁵⁵ Colin M. Mason and Richard T. Harrison *Business Angel Networks and the development of an informal venture capital market in the UK: is there still a role for the public sector?* *Small Business Economics*, Vol 9, pp. 111-123, 1997.

⁵⁶ Gunseli Baygan *Venture capital policy review: United Kingdom* STI Working paper 2003/1, OECD Paris 2003.

⁵⁷ *Bridging the finance gap: next steps in improving access to growth capital for small businesses* HM Treasury, Small Business Service, December 2003.

⁵⁸ *Research into the Enterprise Investment Scheme and Venture Capital Trusts, a report prepared for the Inland Revenue* by Nic Boyns, Mark Cox and Rod Spiers of PACEC and Professor Alan Hughes of the Centre for Business Research, Cambridge University, April 2003.

⁵⁹ Colin M. Mason and Richard T. Harrison *Closing the regional equity gap? A critique of the Department of Trade and Industry's Regional Venture Capital Funds Initiative* *Regional Studies*, Vol 37 No 8, pp.855-868, November 2003.

⁶⁰ Colin M. Mason and Richard T. Harrison *'Investment readiness': a critique of government proposals to increase the supply of venture capital* *Regional Studies* Vol 35 No 7, October 2001.

⁶¹ *Our competitive future: building the knowledge-driven economy*.

⁶² *Lambert Review of Business-University Collaboration, Final Report* HM Treasury, December 2003.

⁶³ This was part of the 'enterprise challenge' identified by the government in 2002: *Enterprise Britain: a modern approach to meeting the enterprise challenge* HM Treasury and Small Business Service, November 2002.

4 ENTREPRENEURSHIP IN ELECTRONICS AND INFORMATION TECHNOLOGY

The electronics industry – now more commonly referred to as information technology – has gone through a period of rapid technical change over the last fifty years. The two epochal events in the first decade after the War were the introduction of the electronic computer and the invention of the transistor; the latter setting off a wave of innovation in semiconductor devices which not only transformed the electronics industry but had a profound effect on other sectors.

For reasons which were touched on in Section 2 – principally a large and growing domestic market, stimulated by military demand – American firms established an early lead in computers and semiconductors. In both cases start-up firms played a significant role.

In computers, although the eventual winner in the mainframe era was IBM, several of the American engineers who had worked on electronic data processing during the war formed their own firms after the war. William Norris, who had worked on code-breaking during the war, helped to set up Engineering Research Associates (ERA) in 1946, and this firm was one of the first to develop a general-purpose digital computer. ERA was later bought by Remington-Rand, but Norris broke away to form Control Data Corporation, and this company was a strong competitor to IBM, specialising in large, high-performance computers for scientific applications.⁶⁴

Another start-up firm was Digital Equipment Corporation (DEC), established in 1957. The founder, Kenneth Olsen, a scientist at the Massachusetts Institute of Technology, conceived the idea of a mini-computer, offering high performance at lower cost than IBM's mainframes, and better suited to the needs of smaller businesses. DEC's success attracted imitators, and several other mini-computer firms, including Wang Laboratories, Scientific Data Systems and Data General, were started during the 1960s; most of them were in the Boston area, helping to create a concentration of high-technology enterprises along Route 128 just outside the city.⁶⁵

In semiconductors, some of the companies that obtained transistor technology from American Telephone & Telegraph were long-established manufacturers of thermionic valves (the component that the transistor replaced), but it was new entrants, notably Fairchild, that provided most of the dynamism in the industry. Fairchild, Motorola and Texas Instruments were the principal US semiconductor manufacturers in the 1960s, and they were quick to extend their lead internationally.

Faced with American dominance in what was seen as a strategically important industry, European governments sought to create and sustain nationally-owned firms. In computers, the UK appeared to be the best placed of the European countries. Thanks to the military-related research which had been done during the war, British expertise in computer science was roughly on a par with that of the US. The first fully operational computer, the EDSAC, was commissioned at Cambridge University in 1949, and other projects were under way at Manchester University and at the government's National Physical Laboratory. Much of this work was financed by the government and aimed at military applications but, as in the US, the prospect of a large commercial demand attracted office machinery firms and electronics companies. The National Research Development Corporation, a government agency charged with promoting the commercialisation of publicly funded research, encouraged the leading firms to work together, but the industry lost ground to American firms during the 1950s.⁶⁶

In 1959 the two leading office machinery firms, BTM and Powers-Samas, merged to form International Computers and Tabulators, but this did little to strengthen the industry. For the Labour government which took office in 1964, the best hope lay in further consolidation; the outcome was the creation of International Computers Ltd (ICL), a grouping which

absorbed virtually all the British-owned manufacturers. ICL was intended to be a counterweight to IBM, but it was never able to catch up. A better strategy might have been for British firms to look for niches in the market which IBM did not dominate, as DEC did in the US. The only European firm to follow DEC's example on a substantial scale was Nixdorf in Germany; it was the most successful European computer firm in the 1970s.⁶⁷

In semiconductors, several British electronics companies took out licenses from AT & T but, as the transistor gave way to the integrated circuit and then the microprocessor, British firms chose to concentrate mainly on specialised devices for military applications, where competition from the US was less fierce. For high-volume semiconductors the UK market became dependent either on imports from the US or on local production by subsidiaries of American firms; by 1978 US companies supplied 90 per cent of the market for standard devices.

Computers and semiconductors did not, of course, represent the whole of the electronics industry, and there were other sectors where opportunities for British start-ups were better. In electronic instruments, for example, a fragmented sector with no dominant incumbents, several promising firms were formed. Some of the founders, like Martin Wood at Oxford Instruments, were academics seeking to commercialise their research. Others were engineers who had 'spun out' from larger electronics companies. For example, Bernard Eastwell came out of Mullard, a big manufacturer of electronic components, to form VG Instruments. Tony Davies was a young Plessey engineer who formed Membrain, a manufacturer of automatic testing equipment for printed circuit boards and other electronic devices. In defence electronics, Raymond Brown and Calder Cunningham, both of whom had also worked for Plessey, set up Racal, a manufacturer of two-way radios; an initial order from the British Navy was the basis for a substantial export business, mainly in developing countries.

On the consumer side, the booming demand for radio and television, hi-fi equipment and the like attracted a number of entrepreneurs. Among the older businessmen who had started their careers before the war, Michael Sobell built Radio and Allied Industries into one of the country's most profitable manufacturers of TV sets; it merged in 1959 with General Electric Company (GEC). (Sobell's son-in-law, Arnold Weinstock, became managing director of GEC and was the architect of that company's emergence, largely through acquisitions, as the country's largest electrical/electronics group.) Like other British TV set manufacturers, GEC lost ground to Japanese competition in the 1970s. It subsequently formed a joint venture with Hitachi, which later acquired full control of the business.

From the post-war generation Clive Sinclair began his business career in 1962 (when he was 22) with a product called a micro-amplifier – the start of a life-long preoccupation with miniature electronic devices; it was followed by the Microvision pocket TV receiver and a range of electronic calculators.⁶⁸ Alan Sugar founded what was to become the Amstrad company in 1968, importing electronic equipment from the Far East. Though he started small, Sugar had large ambitions – he wanted the Amstrad name to be as well known as Hoover.⁶⁹ Peter Michael, an ex-Plessey engineer, started a consulting business in 1967, briefly considered entering the mini-computer market, then developed a device, known as Quantel, for encoding and storing TV pictures.⁷⁰

Computer services and software, where entry barriers were lower than in hardware, attracted several talented entrepreneurs, including John Hoskyns, an ex-IBM manager at the Hoskyns Group, Roger Foster at ACT (Applied Computer Techniques), and Alex d'Agapayeff at CAP (Computer Analysts and Programmers). During this period Britain's software industry was the most dynamic in Europe and the one most similar in structure to the American industry.⁷¹ Thus despite the unfavourable environment – a poorly performing economy and high personal taxation – entrepreneurial ambition was by no means lacking in Britain in the early post-war decades. The difference with the US was that the British firms grew more slowly. When Arthur D. Little, the consultants, conducted their study of new technology-based firms in 1977, they identified about a dozen significant technology-based firms which had been formed in the UK between 1950 and the end of the 1960s, and which still existed in the mid-1970s. Most had remained small, and several of them had been acquired by non-British companies.

⁶⁷ Kenneth Flamm *Creating the computer* Brookings 1988, p.170.

⁶⁸ Ian Adamson and Richard Kennedy *Sinclair and the rise of 'sunrise' technology* Penguin 1986.

⁶⁹ David Thomas *Alan Sugar, the Amstrad story* Century 1990.

⁷⁰ Tom Lloyd *Dinosaur & Co, studies in corporate evolution* Routledge 1984.

⁷¹ Martin Campbell-Kelly *From airline reservations to Sonic the hedgehog, a history of the software industry* MIT Press 2003, p.77.

⁶⁴ James C. Worthy, William C. Norris *Portrait of a maverick* Ballinger, 1987.

⁶⁵ Nancy S. Dorfman *Route 128: The development of a regional high technology economy* Research Policy, Vol 12, 1983, pp.299-316.

⁶⁶ Hendry *Innovating for failure*.

The exception was Racal, which had floated on the stock market, absorbed its principal UK competitor, and begun to diversify outside military radio. In 1971 it bought a stake in Milgo, an American producer of data communications equipment, and later acquired full control. Racal was breaking out of its initial niche and becoming a more broadly-based electronics group. The driving force was Ernest Harrison, who had joined the company as chief accountant and was appointed chairman and chief executive in 1966.

The sluggish growth of the sector as a whole was partly due to the fact that British firms were poorly represented in the fastest-growing branches of the industry, most of which were dominated by the Americans. This was a matter of growing concern to governments during the 1970s. Since the established electronics companies were unwilling or unable to tackle these sectors, the solution seemed to lie in promoting smaller, entrepreneurial firms on the US model. Hence when the Labour government set up the National Enterprise Board in 1975, it was encouraged to acquire stakes in small, high-technology enterprises which, with greater financial backing, had the potential to become world leaders. These included Clive Sinclair's Sinclair Radionics, as well as a manufacturer of computer peripherals (Data Recording Instrument), and two computer services firms, CAP and Systems Designers.

The NEB also supported a new semiconductor project, known as Inmos, devised by a group of American and British entrepreneurs. NEB officials had formed the view that the UK had become dangerously dependent on non-British suppliers for memories and microprocessors, and that, since the existing British-owned producers were concentrating almost entirely on custom or semi-custom chips, government support for a new entrant was appropriate.⁷²

While the NEB was attempting to remedy what it saw as a lack of ambition in the existing electronics firms, several British entrepreneurs had seen an opportunity in the new field of micro-computers, pioneered in the US by Tandy, Commodore, Apple and others. Barriers to entry were low, since the manufacturers could buy in most of the components they needed from outside suppliers.

An early entrant was Acorn Computers, set up by Chris Curry and Hermann Hauser in Cambridge in 1979. Curry had started his career with Pye, a Cambridge electronics firm that was subsequently acquired by Philips, and later joined Clive Sinclair, helping to develop his electronic calculator. Seeing the potential of the micro-computer, he left Sinclair and joined forces with Hauser, an Austrian-born physicist who was working in the university's Cavendish Laboratory. Their breakthrough came in 1981, when Acorn was chosen by the British Broadcasting Corporation to supply the official BBC computer for a series of television programmes on computer literacy.⁷³ Another contender was Roger Foster's ACT. It had started by importing a microcomputer from Victor in the US, and in 1982, when its supplier ran into financial problems, it designed its own machine, known as Apricot, manufactured in a new factory in Scotland.

Meanwhile Clive Sinclair, whose relations with the NEB were deteriorating, set up a separate company known as Science of Cambridge, later re-named Sinclair Research, which launched its first microcomputer, the MK 14, in 1978. Then came the hugely successful ZX 80, manufactured for Sinclair by Timex, the watch company, in Dundee. This was followed by the ZX81 and the Spectrum, which established Sinclair's reputation as Britain's leader in the microcomputer revolution.⁷⁴ (As a reward for his efforts and as a sign of the Thatcher government's enthusiasm for entrepreneurs, Sinclair received a knighthood.)

In 1982 Fortune Magazine reported that 'for the moment the world's top producer of tiny computers is a slightly astonished English company headquartered in a jumble of tiny rooms and vertiginous staircases across from Gothic King's College, Cambridge'.⁷⁵ For its assault on the US Sinclair formed a marketing alliance with Timex, and the ZX81 had some early success. But within little more than a year of the launch American companies were matching Sinclair's prices with products that offered better performance. Timex withdrew from the US microcomputer market in 1984, and Sinclair subsequently sold its brand name and designs to Amstrad.

The US market also proved a graveyard for the other two home computer makers. Apricot made a distribution agreement with a group of disaffected Apple dealers, but it never achieved the volume that was needed for a profitable operation, and by the end of the decade Roger Foster was looking for a buyer. The Apricot subsidiary was sold to Mitsubishi of Japan in 1990, and ACT reverted to its original business of software and services. Acorn also ran into a cash flow crisis in the mid-1980s, partly arising from an expensive foray into the US, and it had to be rescued by Olivetti of Italy, which acquired a majority stake. According to one account, Acorn's entrepreneurial founders had been outstandingly successful, but were too inexperienced to take appropriate remedial action when the crisis loomed. Acorn was also held back by its attachment to a proprietary operating system when Microsoft's MS-DOS was becoming the industry standard.⁷⁶

Alan Sugar, having taken over the Sinclair business, had global ambitions – he boasted that Amstrad would one day be as big as Sony – and until the late 1980s the company appeared to be riding high. But the business was hit by a series of problems in personal computers, partly caused by defective disc drives in two models imported from the US, and Amstrad withdrew from the market; Sugar later claimed that, if the computers had worked properly, Amstrad would have become as big as Compaq. "You do not recover from a knock like that in a fast-moving industry like the PC".⁷⁷

These failures, while partly due to management errors, underlined the central problem facing any UK-based manufacturer of computers or computer-related equipment – how to break into the largest and most profitable market, the US. Another example was Rodime, a Scottish manufacturer of hard disk drives set up in 1980 by a group of engineers from Burroughs, the American office machinery manufacturer. This was a classic American-style spin-off, exploiting technology which Burroughs had been unwilling to develop internally. Rodime had no difficulty in raising finance, first from 3i and later from investors in New York; two thirds of Rodime's sales were in the US. Rodime established a reputation as an innovator – it was the first to introduce a commercial 3.5 inch drive, and appeared to be holding its own with the US leaders. But the market was over-crowded, and prices were under constant pressure. Rodime was slow to shift assembly to the Far East, as most of its US rivals were doing; instead, it established a manufacturing base in Florida (to serve IBM's personal computer division), and this proved to be a mistake. Rodime ceased manufacturing disk drives in 1991.

According to one of those involved, Rodime's founders were good at running a start-up business, but not capable of running a complex international organisation. But it was always going to be hard for Rodime, and for the other three British firms which entered the disk drive business, to compete in a US-dominated market. Part of the disparity with the US was simply the small number of UK firms; with only four candidates for survival, the odds on any individual firm succeeding were low. None of them were able to gain enough volume to achieve a sustainable market position.⁷⁸

By the 1990s success in personal computers and disk drives had become dependent on high-volume, low-cost production, and the ability to shift rapidly from one generation of technology to the next. It was difficult to compete in such markets from a non-American base. An alternative was to focus on niches which were too small to interest the big American companies; this was the strategy pursued by such firms as Oxford Instruments. But the danger was that these niche players would either be condemning themselves to permanent slow growth or, if the niche proved attractive, it would draw in stronger competitors.

During the 1980s one of the most successful British electronics firms was Psion, a manufacturer of hand-held 'organisers'; it had been founded by David Potter, a South African who had studied at Cambridge and at Imperial College. Psion built a profitable business with only a minor presence in the US and did well up to the mid-1990s. But at this stage the consumer hand-held market in which Psion had specialised was increasingly converging with the mobile phone. As Potter said later, "we created the organiser market but now it is becoming huge – and frankly we do not have the scale to compete with that".⁷⁹

⁷² W. B. Willott *The NEB involvement in electronics and information technology* in Charles Carter (ed) *Industrial policy and innovation* Heinemann, 1981

⁷³ Tom Lloyd *Dinosaur & Co, studies in corporate evolution* Routledge 1984, Ch 6.

⁷⁴ Adamson and Kennedy *Sinclair and the rise of 'sunrise' technology*.

⁷⁵ Fortune, March 8, 1982

⁷⁶ Elizabeth Gamsey and Paul Heffernan *Growth setbacks in new firms* Cambridge University Centre for Technology Management Working Paper No 2003, January 2003.

⁷⁷ Financial Times, August 4, 1997.

⁷⁸ Henry Chesbrough *Arrested development: the experience of European hard disk drives in comparison with US and Japanese firms* Journal of Evolutionary Economics, Vol 9, 1999, pp.287-239.

⁷⁹ Financial Times, July 14, 2001.

Psion subsequently shifted its focus away from hardware towards software for mobile phones. Out of that work came Symbian, an operating system for mobile phones which has been adopted by many of the leading manufacturers.⁸⁰ Symbian was set up as a separate business and several mobile telephone manufacturers, including Nokia and Motorola, were brought in as partners. By 2004 Psion's stake had been reduced to just over 30 per cent, and in March of that year these shares were sold to Nokia. Symbian remains a British company, albeit foreign-owned, but Psion itself, for all its achievements, was not able to establish itself as a dominant player in a major global market.

What was becoming clear from these experiences was that if British firms wanted to play on the world stage, they had to develop a unique technology that was complementary to, but not directly competitive with, the products and services of the leading US operators. A successful exponent of this strategy was ARM (originally called Advanced RISC Machines), a semiconductor design firm. Founded in Cambridge in 1990 as joint venture between Acorn and two American companies, it specialised in low-cost chips based on Reduced Instruction Set Computing (RISC) – a technology that had previously been confined to high-powered workstations. ARM's business model owed a good deal to lessons learned from Acorn's failure.⁸¹ Instead of sub-contracting the manufacture of its chips, it licensed the technology to other semiconductor manufacturers, and its aim from the start was to make its RISC chip the global standard – the same strategy that Intel had used, on a far bigger scale, to become the dominant microprocessor supplier for personal computers. As Sir Robin Saxby, ARM's chairman, explained, "I want to be the engine inside every digital product".⁸² The company was listed on the London Stock Exchange and NASDAQ in 1998.

ARM was the first of the Cambridge high-technology firms to be valued in the stock market at over £1bn – at the peak of the stock market boom at the end of the 1990s it was worth nearly £10bn. Although the valuation came down sharply when the market collapsed, its business model proved robust, and it continued to develop new applications for its chips. In 2004 it took steps to strengthen its position in the US, and to broaden its product line, by buying a US chip designer, Artisan Components, for about £500m; the take-over was partly financed by issuing new ARM shares.

ARM had become the star of Silicon Fen, but several other offshoots of Acorn also did well, and by the end of the 1990s more than 30 firms had been started by ex-Acorn managers. Hermann Hauser, one of the Acorn's founders and later a successful venture capitalist, claimed that Acorn was to Silicon Fen what Fairchild had been to Silicon Valley.⁸³

Yet ARM was still a small firm by the standards of the big US technology companies, although this partly reflected its focus on software and design rather than manufacturing; it had 760 employees in 2004 (before the Artisan acquisition), of which 400 were in Cambridge. Most other Cambridge technology-based firms were smaller, and this has often been seen as a weakness in Silicon Fen, and in the British electronics industry as a whole.⁸⁴ The US electronics industry contains several companies which have become large either by dominating a high-volume segment, like Intel in microprocessors, or by broadening out from an initial niche to become a major player in a set of related sectors. Hewlett-Packard began as a specialist in measuring instruments and later, through organic growth and acquisitions, developed a large business in computers and printers.

Of the British electronics firms that were started after 1945, the only one that came close to this latter model was Racal. But Racal relied to a greater extent than Hewlett-Packard on opportunistic acquisitions (two of the biggest were Decca in 1980 and Chubb, the security systems manufacturer, in 1984), and it was less committed to developing in-house technology to sustain its various businesses. Racal's growth was partly based on Ernest Harrison's ability to spot business opportunities and move quickly to exploit them, while hiving off activities which were likely to do better on their own, or under different ownership. Harrison himself admitted that he was better at buying and selling businesses than running them.⁸⁵

Racal's greatest success was in giving birth to what was to become the world's leading mobile telephone operator, Vodafone.⁸⁶ In 1982 Racal applied for one of the two cellular telephone licenses being offered for sale by the Thatcher government. Although Racal had no experience in running public telephone networks, its background in radio communications made mobile telephony a logical diversification, and Racal's network – one of the first-generation, analog-based networks – was launched in 1985. Three years later Harrison and his senior Vodafone colleague, Gerald Whent, began bidding for licenses in other countries, usually in partnership with local operators. This was the start of the company's global expansion, taken much further after Vodafone was de-merged from Racal and floated on the stock market in 1991. In the second half of the 1990s, when Vodafone became a stock market favourite, Whent and his successor, Chris Gent, used the company's highly rated shares as the currency with which to make even bigger acquisitions – culminating in AirTouch in the US and Mannesmann in Germany.

Vodafone's share price fell sharply when the stock market collapsed, but, in contrast to other telecoms new entrants (and an even larger number of internet-based firms), Vodafone had managed its financial affairs prudently, and it came through the crash largely unscathed. Vodafone is, of course, a service company, not a manufacturer, and it relies for its technology mainly on its equipment suppliers. But this does not detract from the company's achievement in building a global business and a powerful international brand.

Vodafone is the only genuine British owned 'big gorilla' in the telecoms/information technology sector, and its success is in marked contrast to other British firms that had tried to ride the internet boom of the late 1990s. For example, Dixons, the electrical retailer, set up an internet service provider called Freeserve in 1998, and within a few months it had taken on 1m accounts. When the company was floated in the following year (20 per cent of the equity was sold, with Dixons retaining the rest), the issue was 20 times over-subscribed. But to have continued to develop the business after the stock market crash would have required managerial and financial resources which Dixons did not have. In 2000 Freeserve was sold to Wanadoo, the internet subsidiary of France Telecom.

The Freeserve/Wanadoo deal was one of a large number of transactions over the past twenty years in which British-owned electronics and information technology concerns have been sold to non-British groups. Even Racal did not survive as an independent British-owned business; it was sold to Thales, the French defence electronics firm, in 2000. At that time, Racal, following the de-merger of Chubb and Vodafone, was back to its roots as a defence and industrial electronics concern. The defence sector was going through a process of consolidation on a European scale, and Harrison believed that Racal was too small in international terms to be one of the consolidators.

Many of the sell-outs have taken place for the same reasons that contributed to the demise of the three British personal computer makers in the 1980s – the difficulty of establishing a market position in the US. When Spider Systems, a Scottish computer networking company, was building up its business in the early 1990s, it used the slogan "Not every world leader is American" – it wanted everyone to know that it was thinking big. Yet, to achieve that objective, it needed to compete in the US. To make acquisitions there with its own shares, it would probably have had to seek a flotation on NASDAQ. But, to do that, according to Spider's managing director, "We would have needed 25 per cent of our business in the US – we had around 5 per cent".⁸⁷ Spider was sold to an American company in 1995.

Another Scottish firm, Kymata, was founded in 1998 with the aim of becoming a world player in optical components. "We are working at the front end of an enormous industry", the chief executive said, "and there are huge rewards for being big and first".⁸⁸ Kymata had no difficulty in raising finance and at its peak the business was valued at about £500m. But it was hit by the collapse of the telecoms boom, and in 2001 it was bought by Alcatel of France for £82m.

⁸⁰ Financial Times, July 12, 2001.

⁸¹ Elizabeth Garnsey and Paul Heffernan *Growth and performance of young IT firms in the UK* presentation to Diebold Conference on Entrepreneurship and Public Policy, London, April 2004.

⁸² Financial Times January 27, 2000.

⁸³ Letter to Financial Times, January 27, 2000.

⁸⁴ Annalee Saxenian *The Cheshire Cat's grin: innovation and regional development in England* Technology Review, Feb/March 1988. See also Suma Athreye *Agglomeration and growth: a study of the Cambridge high-tech cluster*.

⁸⁵ Interview in Sunday Telegraph, January 16, 2000.

⁸⁶ For an account of Vodafone's growth, see Martin Fransman *Why Vodafone? Explaining the global success of this British company* Edinburgh University, mimeo, 2003.

⁸⁷ Financial Times, June 27, 1995.

⁸⁸ Financial Times, November 16, 2000

As international competition in information technology has increased, British firms have faced a strategic choice: are they big enough to compete in the big league, should they specialize in a sector of the market where they have, or might develop, a competitive advantage, or should they sell out? In sectors where scale and learning advantages were important, and where American firms had an early-mover advantage, the first of these three options was generally unattractive. In packaged software, for example, British firms have found it hard to compete against the American leaders such as Microsoft, IBM and Oracle. The only viable strategy was to specialise, which was what Sage – the only British-owned firm among the top ten European software vendors in 2004 – has done. This company (which was founded in 1981) developed a profitable niche in financial and accounting software for small and medium-sized businesses; a well-timed acquisition in the mid-1990s gave it a foothold in the US.

Another sector which appears to be polarising between large, global suppliers and small specialists is information technology services. This is reflected in the ownership changes which have taken place in the UK over the past twenty years (Table 1). Of the top ten vendors in 1985, all but one was British. By 2002 only one of those nine, LogicaCMG – the product of a merger between Logica of the UK and CMG of the Netherlands – was British-owned. While this company aims to compete in the big league, other British IT services firms have chosen to specialise – for example iSOFT, which serves the healthcare sector.

Table 1 Changing ownership of UK software and IT services suppliers

Top ten firms in 1985	Ownership in 2002
Thorn-EMI Software	IBM (US)
Hoskyns	Cap Gemini (France)
Istel	AT & T (US)
IBM-INS	
ICL	Fujitsu (Japan)
Logica	no change
CAP	SchlumbergeSema (France)
Centrefile	Ceridian (US)
SCICON	EDS (US)
Systems Designers	EDS (US)

Source: Ovum Holway

Being acquired by a foreign firm does not, of course, imply failure. Some British entrepreneurs timed their exit well, made large profits for themselves and their backers, and gave their business, under a new parent, more scope for growth than it would have achieved as an independent concern. One example was Element 14, a chip designer that spun out of Acorn. Led by Stan Boland, who had been chief executive of Acorn, this firm raised funds from venture capitalists in the US as well as the UK and developed high-performance chips for DSL (digital signal processing) broadband access. In 2000 it received a take-over offer from Broadcom, an American semiconductor firm, and Boland sold the business for \$640m; now a division of Broadcom, it is a global leader in the ADSL market. Boland went on to set up another chip design company, Icera Semiconductor, based in Bristol, focused on chipsets for 3G cellular phones. His aim is to bring the first products to market in 2005 and later to take the company public. "We are aiming to get to that position in a 2008 timeframe", he said, "at which point we would expect a billion-dollar-plus IPO".⁸⁹ Icera already employs 65 staff, mostly engineers, and has raised \$33m in venture funding. Boland is one of several 'serial entrepreneurs' who have been involved in numerous start-up firms.

While the recycling of capital and entrepreneurial talent into new firms is healthy, the UK has so far generated very few large, nationally owned electronics firms. How much does this matter? American entrepreneurs, in Silicon Valley and elsewhere, have undoubtedly benefited from the presence of larger firms, most of which had been small start-ups themselves some twenty years earlier. They are valuable as role models, as customers for the new entrants' products and as a source of experienced management. According to Gordon Moore, co-founder of Intel, successful start-ups almost always begin with an idea that ripened in the research organisation of a large company. "Lose the large companies or the research organisations of large companies, and start-ups disappear".⁹⁰

The absence of 'big gorillas' is not a purely British phenomenon. There are not many examples in Continental Europe of companies which have successfully challenged the Americans in global information technology markets. The problem has been the same as in the UK: how to establish a defensible position in an industry where most market segments are dominated by powerful American incumbents.

One solution is to identify, or better still create, a segment which is not so dominated. A notable example is the German software company, SAP, a world leader in enterprise resource planning (ERP) software. Founded in 1972 by five programmers from IBM, SAP got its start by developing a 'real time' financial accounting programme for an ICI synthetic fibre plant in Germany. Although the software was designed for ICI, it was applicable with some modification for other customers and over the next decade SAP sold its R/2 product to more than two hundred German companies. SAP was a first mover in a new branch of the software market. According to one account, "the isolation of the German market enabled the unique R/2 product to evolve relatively free from competition from US firms, whose products were generally designed for the US market and were rarely well internationalised".⁹¹ When SAP entered the US in 1988, it had perfected a software package which American companies could not match.

SAP, while a brilliant entrepreneurial success, was the product of particular conditions in the German market, including a large manufacturing sector which provided a ready market for ERP software. There are some similarities with Nokia, the Finnish mobile telephone manufacturer. Nokia was not a new company, but it was, in effect, a new entrant to the telephone business, and its remarkable success was helped by two factors. First, the Nordic countries were the first to organise their mobile telephone networks on a trans-national basis, giving local manufacturers (including Ericsson in Sweden as well as Nokia) the opportunity to obtain scale and learning advantages earlier than their European rivals. Second, the nascent mobile telephone business was one of the very few segments of the electronics industry which was not dominated from the start by US firms. The establishment of the GSM standard for the second-generation mobile telephone networks gave Nokia the chance to extend its early-mover advantage to the European market as a whole, and the Americans, operating in a market that was fragmented by several incompatible standards, were left behind.⁹²

The only British counterpart to SAP and Nokia is Vodafone, and this company, too, benefited from helpful conditions in its domestic market - the early de-regulation of the telecommunications industry, a lack of protection for the incumbent (British Telecom) and a highly developed capital market which facilitated share-based acquisitions.

Like their US counterparts, these three companies took advantage of a market opportunity and a supportive domestic environment. To this should be added skilful management, and a dose of luck. As far as the UK is concerned, thanks to the reforms that have taken place over the past twenty years, there is no institutional obstacle that should prevent other firms from emulating Vodafone's example. Moreover, there is now a supply of experienced and ambitious high-technology managers, some of whom have worked in large US companies as well as British start-ups. Whether their firms become as big as ARM or Vodafone will depend on whether their technology is sufficiently distinctive and scalable to support a global position, and on whether they can acquire the firm-building and market-building skills that those two companies have displayed.

⁸⁹ Financial Times, July 12, 2004

⁹⁰ Gordon E. Moore *Some personal reflections on research in the semiconductor industry* in Richard S. Rosenbloom and William J. Spencer (eds) *Engines of innovation* Harvard 1996.

⁹¹ Martin Campbell-Kelly *From airline reservations to Sonic the hedgehog, a history of the software industry* MIT Press, 2003.

⁹² John E. Richards *Clusters, competition and 'global players' in ICT markets: the case of Scandinavia* in Timothy Bresnahan and Alfonso Gambardella (eds) *Building high-tech clusters: Silicon Valley and beyond* Cambridge 2004.

5 ENTREPRENEURSHIP IN BIOTECHNOLOGY⁹⁴

In 1953 Francis Crick and James Watson, working at Cambridge University, discovered the double helix structure of DNA, and set in train a series of advances in molecular biology out of which the modern biotechnology industry was born. Two key innovations were made in the 1970s. The first was the recombinant DNA technique, developed by Herbert Boyer at the University of California at San Francisco and Stanley Cohen at Stanford in 1973. This was a method of producing hybrid gene material by joining pieces of DNA from different organisms and then inserting this hybrid material into a host cell.⁹³ The second came in Britain two years later. Cesar Milstein and Georges Koehler, working at the Medical Research Council's Laboratory of Molecular Technology in Cambridge, found a way of fusing two cells to form a clone, or hybridoma, which combined the characteristics of both the original cells.

These innovations paved the way for a new approach to the development of drugs, but the established pharmaceutical companies were slow to recognise it. Their expertise lay in organic chemistry, not in molecular biology, and they saw no immediate need to switch from a technology which was delivering a steady stream of new drugs. As in other examples of disruptive technical change, such as the replacement of the thermionic valve by the transistor, the leaders were not the incumbents, but new enterprises devoted to the new techniques.⁹⁴

Some commercial ventures in molecular biology had been started even before the invention of recombinant DNA. Cetus was founded in 1971 in Berkeley, California, with support from Kleiner Perkins, a venture capital firm based in San Francisco. But despite Cetus's impressive academic credentials it was outshone by a younger company in which Boyer himself participated. This was Genentech, which brought together Boyer's scientific skills with the financial expertise of Robert Swanson, a partner in Kleiner Perkins. Founded in 1976, it focused initially on the development of proteins such as insulin and human growth hormone whose therapeutic properties were already well known.⁹⁵ Kleiner Perkins was one of several Californian venture capitalists who applied to biotechnology the skills they had learned in micro-electronics.⁹⁶

Genentech was followed by several other firms, including Biogen (co-founded by Walter Gilbert, a Nobel laureate from Harvard), Amgen and Hybritech; the last of these, founded in 1978, was the first company to focus on monoclonal antibodies. The financing arrangements were similar to those that had been used in semiconductors – seed money from family, friends and business angels, then equity finance from venture capitalists, followed within a few years by an Initial Public Offering (IPO), usually on the NASDAQ exchange. Between 1980 and the end of 1983 more than a dozen biotechnology companies were floated.

A notable feature of the new industry was the close link between academic science and commercial exploitation - much closer than in computers and semiconductors. Partly for this reason, most of the new firms were set up around universities. Two of the largest biotechnology centres were in California – in the San Francisco area and in San Diego – but there were also important clusters at Worcester in Massachusetts, around Research Triangle Park in North Carolina, and in Maryland, where the state university set up a Centre for Advanced Research in Biotechnology, located close to laboratories run by the National Institutes of Health.⁹⁷ Three of the key ingredients in a successful biotechnology cluster were a strong scientific infrastructure (in the form of universities or government laboratories), easy access to business angels and venture capitalists, and the presence in the region of firms in complementary industries, especially information technology.⁹⁸

In the early days of the industry some of the new biotechnology firms were expected to become fully-fledged competitors to the established pharmaceutical companies. But to do this they would need, not just research expertise, but competence in development, production, clinical testing and marketing. While some firms such as Amgen did follow the integrated route, the trend was towards interdependence between biotechnology and 'Big Pharma' – a variety of collaborative arrangements including licensing deals, joint research projects, minority investments and some outright acquisitions. Some biotechnology firms specialised in developing tools or technology platforms which would help pharmaceutical firms speed up the drug discovery process.

The new industry was born in the US. The most obvious follower was the UK, since British academic science in molecular biology was on a par with the US, and one of the two key discoveries had been made in Britain. But there was no immediate response from British scientists, and British industry missed out on the first wave of the biotechnology revolution. It was not until the end of the decade that steps were taken to catch up. The Labour government's National Enterprise Board had the task of supporting high-technology industries which the private sector was unable or unwilling to finance, and biotechnology was an obvious candidate for attention. The leading British pharmaceutical companies were showing little interest, and the best way of getting biotechnology off the ground in the UK seemed to be through the creation of a new firm on the Genentech model.

Early in 1979, shortly before the election which brought the Conservatives to power, the government set up a committee to investigate the industrial applications of biotechnology. The committee's report recommended that a new biotechnology firm should be established. Government support would be necessary, in the committee's view, since there was little prospect of any such venture being set up by the private sector. The report suggested that the NEB should examine the possibility of setting up such a firm, working in collaboration with the National Research Development Corporation.

This proposal seemed unlikely to find favour with the Thatcher government, which was committed to reducing the role of the state in industry. In the case of biotechnology, however, the Prime Minister was persuaded that the NEB could play a catalytic role in getting the industry started; she agreed that a new company could be set up, as long as the private sector was fully involved. The outcome was the creation of a new company, Celltech, with 44 per cent of the equity held by the NEB and the rest by four private-sector institutions. These were: Prudential Assurance, one of the UK's biggest institutional investors; Midland Bank; Technical Development Capital, the technology arm of 3i; and British and Commonwealth Shipping.⁹⁹

The company got off to a slow start, and there was criticism from the shareholders that the scientists were spreading their efforts too thinly. In 1983, when new shares were issued to raise an additional £6m, one of the original investors, Technical Development Capital, sold its holding and its place was taken by Biotechnology Investments Ltd (BIL). This was an investment trust specialising in biotechnology which had been set up by N.M. Rothschild, the merchant bank. But despite some successful collaborations with established pharmaceutical companies, Celltech's commercial direction remained uncertain, and the chances of its catching up with the leading US biotechnology firms seemed remote. BIL sold its shares in Celltech in 1987, apparently because of dissatisfaction with the company's management.

By this time several other biotechnology firms had got started. British Biotechnology was set up by two scientists, Brian Richards and Keith McCullagh, who had been working at the UK laboratory of Searle, the American pharmaceutical firm. In 1985 Searle was taken over by Monsanto, and the new owners closed down the UK laboratory. Richards and McCullagh struck out on their own to exploit technology which they had been working on at Searle – the use of enzymes to break down links between body cells.

⁹³ L.Orsenigo *The emergence of biotechnology* Pinter, 1989, p.38.

⁹⁴ F.Malerba and L.Orsenigo *The dynamics and evolution of industries* Industrial and Corporate Change, Vol 5 No 1, 1996.

⁹⁵ Maureen McKelvey *Evolutionary innovations, the business of biotechnology* Oxford 1996, Ch 6.

⁹⁶ Martin Kenney *Schumpeterian innovation and entrepreneurs in capitalism: a case study of the US biotechnology industry* Research Policy, Vol 15, 1996, pp.21-31.

⁹⁷ Martha Prevezer *Clustering in biotechnology in the USA* in G.M.Peter Swann, Martha Prevezer and David Stout (eds) *The dynamics of industrial clustering* Oxford 1998.

⁹⁸ Andrew A. Toole *Understanding entrepreneurship in the US biotechnology industry* in Hart (ed) *The emergence of entrepreneurship policy*.

⁹⁹ For a description of these events and Celltech's subsequent history see Mark Dodgson *Celltech, the first ten years of a biotechnology company* Science Policy Research Unit, Sussex University, Discussion Paper, February 1990.

British Biotechnology was an American-style spin-off. Another entrepreneur who was strongly influenced by the American approach – and who later became an influential advocate for the British biotechnology industry – was Chris Evans. After studying biochemistry at Imperial College and Hull, he took a PhD in genetic engineering at the University of Michigan before working for several US pharmaceutical firms. He returned to the UK in the mid-1980s to set up his own company, Enzymatix, in Cambridge. This was an enzyme-based biotechnology business which Evans expanded to form eight divisions; two of them were later spun out to form separate companies – Chiroscience, specialising in chiral technology, and Celsis, a diagnostics company.

None of these ventures involved support from public funds, as Celltech had done, but the government's decision in 1985 to change the intellectual property regime (see page 14) provided a useful boost for the biotechnology industry. The universities now had a stronger incentive to license their intellectual property to existing firms in exchange for royalties, or to create new firms in which they would take an equity stake.

In Oxford Isis Innovation participated in the spin-out of several biotechnology companies, including Oxford Asymmetry and Oxford GlycoSciences. At Cambridge, one of the first spin-outs was Immunology (later renamed Cantab Pharmaceuticals), founded by Dr Alan Munro, Head of Immunology at the university's Department of Pathology. Another Cambridge firm, set up in 1990, was Cambridge Antibody Technology (CAT). This was the fruit of collaboration between a group of scientists at the MRC's Laboratory of Molecular Biology, led by Dr Greg Winter, and David Chiswell, then working at Amersham International. (Amersham had originally been the radiochemical centre of the Atomic Energy Authority; privatised as a separate company in 1991, it specialised in diagnostics, and became an important source of management talent for British biotechnology companies.)

Oxford and Cambridge were beginning to develop biotechnology clusters comparable to those that had grown up in the US, and the venture capital industry was taking a greater interest in the sector. While Rothschild's BIL was still the leader – it was one of the early backers of British Biotechnology – it was facing competition from other merchant banks, notably Schroders, and from specialist firms such as Abingworth (which helped to found Cantab Pharmaceuticals), Apax Partners and Advent. Thanks to pressure from the venture capitalists, the London Stock Exchange agreed in 1993 to allow loss-making biotechnology firms to be listed as long as they met certain conditions: they had to have a market value of £20m and intend to raise at least £10m at the time of listing, and they had to have at least a three-year record of operations in laboratory research and development.

British Biotechnology was the first to take advantage of the new rules, raising £30m in new equity, and it was followed by several other flotations including Celsis and Chiroscience, two of the companies created by Chris Evans. Celltech also went public at this time, and by the end of 1995 about 25 biotechnology firms were listed on the London Stock Exchange. British Biotechnology was widely regarded as the flagship of the industry, and there were hopes that its cancer treatment, Marimastat, could become the industry's first blockbuster drug. By early 1996 the company, though still making losses, was valued in the stock market at over £2bn.

Barriers to entry were lower in biotechnology than they had been in semiconductors, and UK biotechnology firms had an advantage which was not shared by comparable start-ups in electronics – the presence in the UK of a large and successful pharmaceutical industry, including British-owned firms such as Glaxo, Beecham and Wellcome as well as foreign-owned firms such as Pfizer which had built research and manufacturing facilities in the UK. While these 'Big Pharma' companies did not necessarily favour UK-based biotechnology firms when considering licensing deals and other forms of cooperation, they provided a valuable source of technical and managerial talent. As US experience had shown, fast-growing biotechnology firms needed professional managers, and some executives from the big pharmaceutical firms were attracted by the prospect of working in smaller firms that promised high risks but also – thanks to stock options – high rewards.

Yet most of these small firms were dependent on one or two drugs which might fail unexpectedly. In the UK, 1997 was a disastrous year. Two of British Biotechnology's most important drugs, Marimastat, the anti-cancer drug, and Zacutex, targeted at acute pancreatitis, showed disappointing results in clinical trials, and the company came under fire from the US Securities and Exchange Commission for making inflated claims. Investors lost confidence, and the shares fell from a peak of 326p in 1996 to 94p early in 1998. Celltech was also going through a difficult time. An asthma treatment that was being developed in cooperation with Merck of the US was abandoned early in 1996, and the same fate befell a treatment for septic shock being developed with Bayer. When the two companies announced their decision to stop all further work on the project, Celltech's share price fell by almost a half.

These setbacks came at a time when American biotechnology firms were still growing strongly and new competitors were appearing on the scene in Continental Europe, principally Germany. Yet the British industry was less fragile than it seemed, and over the next few years confidence was gradually rebuilt. Part of the revival was due to the rise of younger companies, such as Cambridge Antibody and Oxford GlycoSciences. Celltech, too, was showing better results from its research programme. Its rising share price enabled it to make some sizeable acquisitions, including that of Chiroscience, which broadened the company's portfolio of drugs under development.

Behind the quoted sector came a steady flow of start-ups, some of which were targeting the emerging field of genomics. For example, Oxagen was founded in 1997 to apply techniques of genetic analysis developed by scientists at the Wellcome Trust Centre for Human Genetics at Oxford University. Seed finance came from the university, the Wellcome Trust and two private investors, and Oxagen later raised venture capital finance from Advent and 3i. Another newcomer was Cambridge-based Astex Technology, co-founded by Tom Blundell, head of the university's biochemistry department. This company, which raised start-up finance from Abingworth and a US venture capital firm, specialised in structural proteomics – analysing the structure of proteins through high-throughput X-ray crystallography technology.

Cambridge had become a magnet for biotechnology entrepreneurs, not only scientists spinning out from the university, but also founder-entrepreneurs from other parts of the country. Roughly half the scientists working in Cambridge biotechnology firms came direct from an academic laboratory, but the rest came from other firms in the life sciences industry. The fact that a number of scientists had survived failure and gone on to find jobs in subsequent start-ups indicated that a flexible labour market resembling that in Silicon Valley was beginning to appear in Cambridge.¹⁰⁰

There were smaller clusters in other areas. In Dundee an outstanding research team at the local university had generated a viable group of biotechnology enterprises. One of the first spin-outs was Shield (now Axis-Shield), a diagnostics group which went public in 1993. By 2001 there were some 30 biotechnology firms in and around Dundee, of which the most prominent was Cyclacel, founded by Sir David Lane, Professor of Molecular Oncology, to exploit the anti-cancer gene p53.

What had happened in biotechnology since the 1980s could reasonably be claimed as a success for government policy. In addition to improving the overall climate for entrepreneurs, the Thatcher government recognised the need for increased funding of scientific research, and for better coordination between the various research councils concerned with biotechnology. In 1981 a biotechnology directorate was set up within the Science and Engineering Research Council. Its task, in liaison with the Medical Research Council, was to promote biotechnology as a strategic area of research and to encourage greater cooperation between industry and academics.¹⁰¹ The government also set up a biotechnology unit within the Department of Trade and Industry. This unit had a small budget for supporting biotechnology ventures, mainly in the form of grants to cover consultancy costs and modest contributions to research and development.

¹⁰⁰ Steven Casper and Fiona Murray *Examining the marketplace for ideas: how local are Europe's biotechnology clusters* in Maureen McKelvey, Annika Rickne and Jens Laage-Hellman (eds) *The economic dynamics of modern biotechnology* Elgar 2004. For a recent assessment of the Cambridge cluster; see *The Cambridge Cluster Report 2004* published by Library House, Cambridge, in association with Grant Thornton.

¹⁰¹ Margaret Sharp *Biotechnology in Britain and France* in Margaret Sharp and Peter Holmes (eds) *Strategies for new technology* Peter Allan, 1989.

One critic complained at the end of the 1980s that the Thatcher government's hands-off policies "seem to have been little if at all more successful than earlier interventionist approaches at stimulating British industry out of its lethargy towards new technologies". According to this view, there was no strategy or vision in the government's approach. The problem was made worse by rivalry between the research councils, and by the failure to make use of the buying power of the Departments of Health, Agriculture and Energy, all of which had an interest in genetic engineering applications. The government's policies had left British biotechnology "like a rudderless ship, launched but carried with the tide and lacking any positive sense of direction".¹⁰²

With the benefit of hindsight, this judgement seems wide of the mark. The Conservative governments' market-driven approach between the early 1980s and their departure from office in 1997 generated a sizeable British biotechnology industry. The new Labour government saw no reason to abandon the Thatcherite approach, but chose to build on it. The government increased its support for biomedical research and maintained the DTI's sponsorship role in biotechnology, without any significant increase in funding. Today a Biotechnology Mentoring and Incubator scheme provides grants of up to £50,000 for consultants to provide specialist advice for biotechnology start-ups, and a Biotechnology Exploitation Platforms scheme gives advice to scientific institutions on how best to exploit their intellectual property.

The government also sought to promote the development of biotechnology clusters around universities. The value of clusters had been emphasised by Michael Porter, the Harvard economist, and his work influenced the Labour government's thinking. In 1999 a government-industry team led by Lord Sainsbury, the Science Minister, examined biotechnology clusters in Britain and, as a result of its recommendations, the Department of the Environment issued new guidance to local planning bodies, to ensure that planning system would be more responsive to the land-use implications of clusters.¹⁰³

Some commentators questioned the value of the clustering policy, suggesting that it could lead to wasteful duplication as each region sought to foster its own cluster.¹⁰⁴ In general, however, the biotechnology industry had few complaints about government policy. A group of high-technology entrepreneurs, including Chris Evans, wrote a letter to the Financial Times in 2001 claiming that Labour had produced a "remarkable change" in science-based enterprise in Britain.¹⁰⁵ "The University Challenge Fund", the letter said, "has given science entrepreneurs the early funding they often lack. The Science Enterprise Centres are teaching science students the business skills they need. Incentives for technology transfer and the promotion of venture capital have helped the start-up of new companies".

It is true that this letter was written in the middle of an election campaign and that several of the signatories were known Labour supporters; many of the improvements they were praising had been set in train by Conservative governments. Nevertheless, the letter reflected a degree of confidence among biotechnology firms in the attractions of the UK as base for developing their businesses.

At the end of 2002 the UK had nearly 500 biotechnology companies (of which 47 were publicly quoted), employing some 26,000 people. The industry had 225 drugs in clinical development or awaiting approval, more than twice as many as the German industry, its nearest European competitor.¹⁰⁶ Comparisons with the US, however, were much less favourable, and there was concern that, as in electronics and information technology, too many of the British biotechnology firms were too small to be viable in the long term. The Cambridge biotechnology cluster looked impressive in European terms, but its Boston counterpart employed a third more people and had much higher rates of successful commercialisation.¹⁰⁷ There was no sign that any of the British firms were about to leap out of the pack in the way that Amgen and others had done in the US.

Some commentators argued that, despite the improvements that had been made since the 1980s, there were still deficiencies in the financial markets. According to this view, the financial backers of US companies start fewer companies than their European counterparts but fund them more generously, not only at the outset but all the way through their development life cycle.¹⁰⁸

These fears were echoed in a report produced by leading biotechnology executives, together with venture capitalists and academics. They urged the government to ease the industry's financial problems through changes in taxation to improve biotechnology firms' cash flow, through a new scheme of 'bioscience innovation awards' for later-stage firms, and through changes in the treatment of stock options. The report also called for changes in the Stock Exchange's rules on pre-emption rights. These rules oblige companies, when they issue new shares exceeding 5 per cent of the equity, to offer them to existing investors. This was said to restrict the ability of biotechnology firms to raise capital from new sources and put British firms at a disadvantage vis-à-vis their US counterparts.¹⁰⁹

The government pointed out in its response that some of these proposals were contrary to established tax policy or would run foul of the EU rules on state aids.¹¹⁰ On the issue of financial support for later-stage companies, it reminded the industry that the government "does not support the picking of industrial or sectoral winners for specific, unconditional financial support; rather it seeks to identify market failures in order to address the causative factors across the board". The government did accept the need for a fresh look at pre-emption rights, and a subsequent report commissioned from Paul Myners recommended several changes to make the rules more flexible.¹¹¹

A broader point stressed in the industry's report was the absence in Europe of a single public equity exchange with the critical mass in bioscience of NASDAQ. Most of the 22 European exchanges had only a handful of bioscience companies – "they lack liquidity and the necessary foundation of specialised analysts and fund managers that would encourage new capital to enter the sector, and help insulate the sector from the failures of individual companies and products". More mergers among European stock exchanges might help to solve this problem. Meanwhile London, and AIM in particular, was emerging as the preferred European market for biotechnology flotations. In 2004, 18 such firms were listed in London, and the City had about 25 analysts focusing on the sector.

How valid was the industry's concern about finance? Peter Fellner, one of the most experienced UK biotechnology managers – he had been chief executive of Celltech and later chairman of Vernalis, which had absorbed British Biotechnology – accepted that one of the difficulties faced by British firms was that they were under-capitalised compared to their American counterparts. But they were under-capitalised, in his view, because their business models were not attractive to investors. They needed to get away from the traditional model of always having to go back to shareholders for more money, and progress more rapidly to the point where they could become financially self-sufficient.¹¹²

One way of strengthening the industry's finances – and attracting greater interest from investors – was through consolidation. When Oxford Asymmetry, a platform technology company, was taken over by Evotec of Germany in 2000, it had a market capitalisation of £230m against Evotec's £600m "Size was part of our concern" said Oxford Asymmetry's chairman, "We all know that you have to have a market capitalisation of at least £400m to get institutional investors on board".¹¹³

If there was to be consolidation in the industry, the obvious leader was Celltech, which had the highest market capitalisation of British-owned biotechnology firms. In 2003 it paid £140m for Oxford GlycoSciences, defeating a rival bid from Cambridge Antibody Technology. In the following year, however, Celltech itself was bought by a Belgian chemical group, UCB, for £1.53bn; it was an agreed deal, and the price paid was at a 28 per cent premium to Celltech's market price before the bid.

¹⁰² Sharp *Biotechnology in Britain and France* p.156.

¹⁰³ *Biotechnology clusters, report of a team led by Lord Sainsbury, Minister of Science* Department of Trade and Industry, HMSO, August 1999.

¹⁰⁴ Ron Martin and Peter Sunley *Deconstructing clusters: chaotic concept or policy panacea?* Journal of Economic Geography, Vol 3 No 2, 2003.

¹⁰⁵ Financial Times May 24 2001

¹⁰⁶ Critical I *Limited Report on the biotechnology industry to the Department of Trade and Industry* 2004.

¹⁰⁷ Casper and Murray *Examining the marketplace for ideas*.

¹⁰⁸ Critical I *Report on the biotechnology industry*

¹⁰⁹ *Bioscience 2015, a report to government by the Bioscience Innovation and Growth Team* Department of Trade and Industry, 2003.

¹¹⁰ *The government's response to 'Bioscience 2015'* Department of Trade and Industry, May 2004.

¹¹¹ Financial Times, November 4, 2004.

¹¹² Sunday Telegraph, September 12, 2004.

¹¹³ Financial Times August 1, 2000.

The chief executive of Celltech insisted that the merger was good for the UK and Europe. "The key is to have viable European businesses that have a sustainable long-term presence". Yet the deal raised once again the familiar issue of the UK's dependence on foreign companies: did it matter if what had seemed to a promising knowledge-based industry passed largely into foreign control? One observer feared that "we could end up with the UK performing the role of the research division of US multinationals".¹¹⁴ Another suggested that, while the UCB deal was not the death knell for the sector, "it is hard to see us ever progressing to become a US-style industry".

The Celltech sale coincided with the take-over of Amersham, a diagnostics company with close links to the biotechnology sector, by General Electric of the US. This was a much bigger deal – GE paid £5.7bn for the business – and was designed to strengthen the American company's position in healthcare. Sir William Castell, who had been mainly responsible for Amersham's growth over the preceding decade, was appointed head of GE's health care division, which would transfer its headquarters to the UK.

After the Celltech acquisition, the remaining British publicly quoted biotechnology firms were relatively small; only two, Acambis and Cambridge Antibody Technology, were ranked among the top 30 most highly valued biotechnology companies (Table 2). At the end of 2004 AstraZeneca, one of the big British-owned pharmaceutical firms, acquired a 10 per cent stake in Cambridge Antibody as part of a wide-ranging technical collaboration in antibody-based drugs.

Table 2 Some leading biotechnology companies by market capitalisation (figures in \$bn November 2004)

1.	Amgen (US)	71.91
2.	Genentech (US)	47.79
3.	Biogen Idec (US)	19.68
4.	Gilead Sciences (US)	14.91
5.	Genzyme (US)	11.96
6.	Serono (Switzerland)	7.23
16.	Actelion (Switzerland)	2.66
27.	Acambis (UK)	0.51
28.	Cambridge Antibody (UK)	0.50

Source: *Financial Times*, November 10, 2004

As the table shows, the gap between the two most highly valued British companies and the US leaders is extremely wide. Size of company is not the only measure of an industry's performance and, in the case of biotechnology, perhaps not the most useful. Most biotechnology firms will continue to rely on partnerships with established pharmaceutical companies, and their value will lie in early-stage research where economies of scale are relatively small. While the financial fragility of some parts of the British biotechnology industry is a matter of concern, the solution lies mainly in the hands of the companies themselves – the quality of their research, and their ability to develop business strategies that will ensure their financial viability. The focus of public policy should be to create a favourable environment for biomedical research – support for the science base, promoting collaboration between academia, industry and the National Health Service in clinical research, and ensuring that the regulatory system provides appropriate incentives for the development of innovative drugs.

6 CONCLUSION

Entrepreneurial success in high-technology industries depends on a supportive domestic environment and on a supply of entrepreneurs and managers capable of exploiting technological and market opportunities. Over the last twenty years successive British governments have tried to make progress on both these fronts, in the hope of matching the entrepreneurial dynamism of the US. How much have they achieved?

The US benefits from four institutional advantages: a large and competitive domestic market; a highly developed financial system which ensures that entrepreneurs with sound projects have access to capital; generous government support for basic science; and a well-financed university sector responsive to the needs of industry.

On the first two of these, substantial progress has been made in the UK. The pro-market policies introduced by the Thatcher government in the 1980s included privatisation and de-regulation, which reduced the power of incumbents in such industries as telecommunications and widened opportunities for new entrants. Rules against anti-competitive practices were tightened, and this has been taken further by the current Labour government. The competition policy regime is now quite similar to that of the US.

The disadvantage of a relatively small home market has been partially offset by the removal of trade barriers within the European Union. Although Europe is not yet as integrated a market as the US, most of the distortions arising from government intervention have been removed, and the ability of firms to operate on a European scale is far greater than it was twenty years ago. There is still more to be done on public procurement, particularly in relation to small and medium-sized firms which are often at a disadvantage in competing for orders from government agencies; there are useful lessons to be learned from the US in this area.

On access to finance, a series of measures has increased the flow of funds into venture capital and early-stage finance, and entrepreneurial activity is no longer seriously impeded by lack of access to capital. If there has been a weakness in public policy, it may have been an excessive emphasis on support for start-up firms. As an American commentator on small firms policy has observed, providing generous amounts of capital to all comers is likely to lead to a misallocation of resources. "Meagre funding forces entrepreneurs to conduct low-cost experiments that help resolve market and technological uncertainties and prepare the ground for subsequent large-scale investment".¹¹⁵ There is no way of predicting in advance which experiment is going to succeed, but weaklings are more likely to be winnowed out if their access to finance is subjected to a market test.

The third American advantage is the scale of government support for scientific research. There is no way in which the UK can match the amounts of government money that flow into defence-related and health-related research in the US. But within the constraints faced by a medium-sized country the British government has taken steps to strengthen the science base. In 2004 the government announced a new programme which would lift the government's core spending on science from £4.2bn in 2004-5 to £5.4bn in 2007-8; the aim was to raise British spending on research and development from 1.8 per cent of GDP to 2.5 per cent in 2014. At the same time – and again following the US example – the government has sought to boost private sector spending on research and development through an R & D tax credit, first for small firms and later extended to all companies.

The impact of these policies on innovation and on entrepreneurial activity will only be felt in the long term, and they will need to be complemented by better funding of the universities – a much bigger challenge which the government has barely begun to tackle. The UK has several universities which rank at or near the top in the quality of their science, but

¹¹⁴ *Financial Times*, May 22/23, 2004.

¹¹⁵ Amar V. Bhide *The origin and evolution of new businesses*

their ability to maintain this elevated position will depend on finding a solution to the funding problem. While the government's attempts to promote technology transfer are laudable, the overall health of the university sector is a far more important issue – and one in which the UK lags badly behind the US.

With these reservations, entrepreneurship policy as it has evolved over the past two decades has worked well. Institutions and policies have been aligned more closely to the US model. The big gap, as the last two sections have shown, is the absence of American-style 'big gorillas' – firms like Amgen and Cisco, which grow very fast over a sustained period to become major international enterprises. Part of the explanation has to do with the character of the industries concerned, and the difficulty of catching up with American first-movers, but it is sometimes argued that this problem has been compounded by a lack of dynamism or competence among British entrepreneurs.

A common accusation is that too many of them lack the will or the ability to make the transition into a higher league. Faced with the hassle and personal risk involved in building a big company, they prefer to stay small, or to sell out. It is true that a good many promising high-technology businesses have chosen to sell out at an early stage, often before they have gone public. But this may reflect an active British market in the buying and selling of companies (and an openness to inward investment) rather than a lack of ambition or energy. While a few cashed-out entrepreneurs retire to their yachts or their country mansions, others go off to start new ventures, or become business angels.

As for management competence, running a big business does demand special skills and motivation, and the founder-entrepreneur – a Clive Sinclair, perhaps, or an Alan Sugar – may not be well suited for the task. But this is not just a British phenomenon. Such men as Bill Hewlett and David Packard, who combine entrepreneurial and firm-building skills, are rare in any environment. More commonly, founders give way to professional managers – and the UK does have managers who are capable of running large, international companies in high-technology sectors. One example is Vodafone. Another is Glaxo (now GlaxoSmithKline), which, though not a start-up firm, was virtually a new entrant to the pharmaceutical industry after the war. Thanks to good management, excellent science and skilful marketing, it went from minnow to world leader within the space of some twenty years.

More technology-based companies of the size of Vodafone or Glaxo would be desirable. However 'global' such companies become, the locus of their headquarters does make a difference, since the home base normally contains the core of their marketing, engineering and product development expertise. Given the improvements that have taken place in the UK environment, the continuing flow of new entrants in high-technology sectors, and the availability of experienced managers, it is reasonable to expect that a few of them will 'make it' into a higher league, achieving a market capitalisation of, say, \$10bn rather than \$1bn, and employing several thousand rather than a few hundred; some may do so in collaboration with other European firms, both to widen their market and to gain access to technical skills which are lacking in the UK.

As for the role of public policy, there is no magic bullet available to government which will produce British versions of an Intel or a Hewlett-Packard – and no clear market failure which calls for government intervention. On the contrary, intervention is almost certain to make things worse. Admiration of the US model does not imply that British industry should be organised in the same way as its US counterpart, or that it should have strengths in the same industries. It was just such US envy that led to the disastrous 'national champions' policy of the 1960s and 1970s. The priority should be to continue the path that governments have been pursuing for the past twenty years – creating an environment that is conducive to the growth of entrepreneurial businesses and eliminating obstacles that stand in their way. The eventual industrial structure – the balance between small, medium-sized and large companies, and between national and foreign ownership – is outside the government's control.