The R&D, knowledge, innovation triangle: education and economic performance

Derek Bosworth

Institute for Employment Research, University of Warwick

January 2009

1. Introduction

While the Lisbon Strategy states that the EU should

> "… become the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion"

there is considerable concern at both national and European levels that, currently, innovation is too slow and insufficiently pervasive. In the UK there have been a series of reviews that have outlined the need for greater and more effective investments in science and technology to promote the country's innovative capability (eg the Sainsbury Review, 2007).

The present paper argues that such concerns are well founded within an increasingly competitive global economy. It argues that while issues remain about highly qualified individuals and relatively high technology organisations, the net has to be spread much wider to make creativity relevant to a much greater proportion of the economy, and to make human capital improvements amongst a much wider percentage of the population. Section 2 begins by outlining the main elements of the most widely recognised formal R&D, education and innovation triangle, before broadening these elements to other parts of the economic system. Section 3 then provides the main rationale as to why this triangle is so important to the future economic performance of the UK. Section 4 briefly reviews current evidence concerning UK performance with respect to the various elements that comprise the R&D, education and innovation triangle, indicating where improvements are necessary or where more evidence is required. Section 5 outlines the evidence that the market mechanism is either imperfect or failing with regard to performance in these areas. Finally, Section 6 provides the main conclusions.

Keywords: population, knowledge, innovation, society, education, economics, technology

2. Elements of the R&D, knowledge, innovation triangle

As a first step to establishing the nature and significance of the R&D, knowledge, innovation triangle, this section outlines some definitions of key formal elements of the triangle, before extending the discussion to more informal, but, probably, equally important components.

Elements of the formal triangle

Research and experimental development (R&D) are formally defined as "... creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications." (OECD, 2002, p.30) The general feeling, however, is that this definition is very narrow and of little relevance to the inventive activities of most small firms or many parts of the service sector (Gallaher et al, 2006), as well as failing to capture all the creative investments of large organisations.

The United States Patent Office states that an invention includes "... any art or process (way of doing or making things), machine, manufacture, design, or composition of matter, or any new and useful improvement thereof".[1] European patents are granted for "... inventions that are new, involve an inventive step, and are susceptible of industrial application."[2]

The EC (2005a, p31) define innovation as "Technological product and process (TPP) innovations comprise implemented technologically new products and processes and significant technological improvements in products and processes." CRIC (2005, p. 5) defines innovation as "…the successful exploitation of new ideas. That is, the development and commercial exploitation of a new idea for a product or process that contributes to wealth creation and profitability."

Elements of the informal triangle

The formal triangle is well defined, largely for tax and legal purposes (eg R&D tax breaks and protection of intellectual property), but this makes it much narrower than is ideal for the purposes of the present discussion. The concept needs to be widened to attempt to include all aspects of creativity amongst the management and workforce that is reflected in creative products and new ways of doing things.

The so-called "creative sectors" themselves, which span 13 different industries (DCMS, 2002, Annex A), give some indication of areas of creative activity that lie in the service rather than the manufacturing sector, some of which have no significant link with technology *per se* or traditional forms of R&D. Examples of such industries include advertising, architecture, music and the visual and performing arts, and computer games, software and electronic publishing. Few of such activities would be linked with patenting, but are associated with other forms of intellectual property rights such as copyrights and trademarks. As the Work Foundation's (2007, p16) report indicates

> "The creation of ideas, images, symbols, design and cultural expression on this scale would alone be enough for the sector to warrant attention; such vitality needs to be honoured and nurtured."

However, creativity is far from limited to the creative industries, it can happen in any sector of the economy and at any point in the production, distribution and use of goods and services. Individual workers may have ideas for improving the production process, ideas may move up and down the supply chain, final consumers may find new uses for an existing product. The sum of the often incremental improvements may nevertheless prove significant.

[1] http://www.uspto.gov/main/glossary/index.html (accessed Sept. 3, 2008).

[2] European Patent Office http://www.epo.org/patents/Grant-procedure/About-patents.html (accessed Sept. 3, 2008).

3. The central role of the R&D, knowledge, innovation triangle

The centrality of R&D and knowledge creation and use is set out clearly by Romer,

> "Ultimately, all increases in standards of living can be traced to discoveries of more valuable arrangements for the things in the earth's crust and atmosphere … No amount of savings and investment, no policy of macroeconomic fine-tuning, no set of tax and spending incentives can generate sustained economic growth unless it is accompanied by the countless large and small discoveries that are required to create more value from a fixed set of natural resources." (Romer, 1993, p345).

It is now widely accepted that the creation, dissemination, and application of knowledge have become a major engine of economic expansion (Shapiro et al, 2007, p15). Innovation drives economic growth because,

> "Through innovation processes leading to the creation of new knowledge and its application in new or better products, services, processes, and modes of organisation, or application of existing knowledge and/or technologies to new contexts." (*ibid*., p10)

Innovation, knowledge, and technology are such powerful drivers of economic growth because unlike capital and labour, they do not suffer from diminishing returns (*ibid*., p11). In other words, the creation of knowledge and technological innovation can actually increase the return to further knowledge and innovation, thus creating a powerful growth mechanism (this is discussed in detail in Section 5 below). Innovative efforts are on the rise as a share of economic activity (OECD, 2007, p6). Investment in knowledge has grown more rapidly than investment in machinery and equipment since the mid-1990s in most OECD countries, and has surpassed the latter in a few countries such as Finland and the United States. Most sectors and industries are currently experiencing what the OECD calls a "Schumpeterian renaissance", in which innovation is the crucial source of effective competition, of economic growth, and of the transformation of society (Shapiro et al, p15).
The creative industries themselves are hugely important, playing an increasingly significant role in economic life. In the UK, this set of industries account for 7.3% of the economy's output, which is comparable in magnitude to the financial services sector (Work Foundation, 2007, p16). The thirteen creative industries directly employ a total of 1 million individuals, although around another 800,000 work in creative occupations, and

> "The livelihood of a growing proportion of British citizens will depend upon the sector maintaining its trajectory of growth." (*ibid*.)

Higher level, technological innovations

Formal, more radical innovation relies heavily on the creation of basic knowledge, through both education and science (OECD, 2007, p18). Scientific progress has become a direct driver of the innovation process, for instance

> "Technical progress has accelerated in areas where innovation is directly rooted in science (eg biotechnology, information technology, new materials) and firms' demand for links to the science base has increased." (OECD, 2000, p4)

There is also "... a strong relationship between expenditures in R&D and innovation output measured by US patents granted". (Bosch et al, 2005, p19)
Creating, developing and diffusing new products and processes requires strong science and technology (S&T) skills as well as many non-research soft and entrepreneurial skills (OECD, 2007). There is an increasing emphasis on policy issues related to the availability of highly skilled labour, in particular highly skilled human resources in S&T. Strong S&T skills facilitate the uptake and use of new technologies which drives innovation throughout the economy (Bosworth, 1996). This places a premium on both the "quantity" as well as the quality of highly skilled labour in the economy.

Lower level innovation and diffusion

It is too easy to focus on higher level at the expense of lower level innovation. Popper and Wagner (2002, p7) argue that "… relatively small innovations and developments of new technology may lead to results almost beyond our imagining, as we have witnessed only in the last decade with the advent of the internet and the world-wide web. Relatively small investments in knowledge creation may lead to large dividends in more familiar form such as enhanced productivity, more sustainable economic activity, and richer, healthier, and more fulfilling lives." (*op cit.,* pp7-8)

It has long been recognised that lower level innovation and the adoption of new technologies already in use elsewhere are more crucially dependent on the skills and competencies of the workforce (eg Solo, 1966; Amsden, 1989). In the context of economic development, Solo (1966) argues that the presence of formally educated scientific and technical elites is a necessary but not sufficient condition for development, which can only begin when the skills of the middle mass of "mechanics and technicians" reaches a sufficient threshold. Similarly, in the case of Korea, Amsden (1989, p9) argues that, while "Salaried engineers are a key figure in late industrialization because they are the gate keepers of foreign technology transfers", nevertheless "... Korea was a successful learner partly because it invested heavily in education" (*ibid*., p23).

This link between education, innovation and diffusion has been taken up extensively in the literature. OECD (2007, p18) argues that a well-performing and broadly accessible education system facilitates the adoption and diffusion of innovation and that human capital is a key factor in the adoption of new technologies and the introduction of innovative practices.

Evidence for this argument lies scattered throughout the international comparative case study work of the NIESR. For example, Mason and Wagner (2002, p93) argue that the greater skills of the German workforce – particularly intermediate skills – help to keep production moving smoothly and this frees up time for strategic incremental process improvements. The NIESR case studies provide many other instances of the role played by skills, particularly intermediate skills.

4. Areas where improvement is necessary

Overall skills position

The UK uses five levels to measure literacy and numeracy skills, Level 1 literacy and Entry Level 3 numeracy are the standards necessary to function at work and society in general. In 2003, 16% of the working-age population in England (over five million people) lacked Level 1 literacy skills and 21% (6.8 million people) lacked Entry Level 3 numeracy skills (OECD 2005). International surveys have found the UK lies in the bottom half of the OECD in terms of the number of people that lack these basic skills.

The proportion of adults in the UK with low skills has decreased slightly in recent years from 35% of the adult population in 2003 to 33% in 2005 (OECD, 2005). However, UK adults with low skills still form a relatively large percentage of the population by international standards. Out of thirty countries compared by the OECD in 2005, sixteen countries had a lower proportion of adults with low skills than the UK. The top performing countries, such as the USA, Canada, Japan and Germany had less than half the proportion of adults with low skills compared to the UK.

The UK saw little change in the percentage of adults holding intermediate skills between 2003 and 2005 – forming 27% of the total. The proportion of adults in the UK with intermediate skills, however, remains relatively low, and below the average for the thirty OECD countries.

The amount of adults possessing high skills in the UK increased from 28% of the adult population in 2003 to 30% in 2005. The UK has a larger proportion of adults with high skills than nineteen of the OECD countries, but lies considerably behind the top performing countries such as the USA, Japan and Canada, with at least 40% of their adults possessing high skills.

The skills level of UK workers can be measured by looking at the national qualifications framework (NQF), which distinguishes six levels of qualification obtained, ranging from no qualifications, through NQF1 to NQF5, where NQF5 is the highest level of qualification. In the UK there is a major difference in the qualifications of those people living in the least and most deprived areas of the country. For instance, nearly 10.6% of the employed population in the least deprived areas has obtained a qualification of NQF5, whereas just 3.4% of employed workers in the most deprived areas have obtained this qualification. The proportion of those with NQF4 falls from 32.3% in the least deprived areas to just 16.1% in the most deprived areas. The proportion of employed workers with NQF3 also falls with the level of deprivation. There are compensating increases in amongst those with no qualifications (from 3.7% to 14.6%), NQF1 (from 14.1% to 23.1) and NQF2 (from 19.3% to 24.4%).

The supply of top-level managers in the UK argued to be very competitive, as evidenced by the high international ratings of UK management schools and the quality of the students they attract (Porter and Ketels, 2003). The UK has relatively high levels of professional management (as opposed to the majority of owner-managers) and attracts the best managers from around the world. Modern executive compensation techniques are used more widely in the UK than elsewhere, except in the USA. It is generally believed that problems in managerial skills are mainly concentrated at lower and middle management levels.

Overview of the UK's innovation position

The UK's relative performance in innovation can be assessed by looking at the following factors: strength of the science and engineering base (the number of publications and citations per head of population); business enterprise R&D (BERD) and gross expenditure on R&D (GERD), both as a percentage of GDP; intellectual property (eg the number of patents and trademarks granted); networks and collaborations (eg percentage of innovation-active firms reporting research cooperation with other organizations); and innovative products (eg share of firms' turnover attributed to new or significantly improved products) (DTI, 2006, p20).

The UK has a strong science and engineering base. The UK leads its competitors (eg France, Germany and the US) both in terms of the number of papers and the number of citations per head (*ibid*., p23). Only the US leads the UK in terms of its overall share of world citations (*ibid*., p23). The UK research base performs relatively strongly right across the subject spectrum, with some variation. The UK is strong in clinical, preclinical health-related, environmental and biological sciences, but not quite so good in mathematics, engineering and physical sciences (*ibid*., p23).

The UK lags behind its competitors on R&D spending. In 2004, the UK's BERD/GDP was about 1.2%, compared to 1.9% for the US, 1.8% for Germany and 1.4% for France (*ibid*., p26). The UK also performs less well in terms of GERD/GDP, which was below the EU25 average in 2003 (EC, 2005b, pp21-22), at about 1.9% in 2003, while that of France was 2.2%, Germany 2.5% and the US 2.7% (DTI, 2006, p26).

Data from the US Patent and Trademark Office (USPTO) shows that Germany and the US have a significantly greater number of patents per million of population than the UK, while the UK and France have a similar number of patents per head (*ibid*., p29). The large difference with the USA might, in principle, be due to the fact that US firms are more likely to register this with the USPTO than non-US firms. Nevertheless, USPTO data are broadly consistent with other measures of patenting performance, such as triadic patents (ie patents for the same invention registered in the US, EU and Japan), which correct for this bias.

It has been argued that a greater percentage of UK innovation-active firms use alternative methods of protection to patenting than other European firms (consistent with the importance of the "creative sectors" in the UK, where forms of IP other than patents were important – see Section 2 above). UK firms are more likely to use trademarks (UK firms dominate the top 10 in the UK Trade Mark scoreboard according to HM Treasury et al, 2005), lead-time advantage, secrecy, complexity of design, and registration of design patterns and copyright. The Report suggests that these differences are partly the result of differences in industrial structure across countries.

They suggest that UK firms achieve improvements in their market position through means that are under-recorded in traditional innovation indicators. If true, these assertions raise questions about why the UK is going a different route than its main competitors and, if not true, the evidence suggests that the UK is considerably under-performing vis-a-vis its main competitors.

The share of turnover in UK businesses accounted for by new or significantly improved products was second only to German firms in the EU15 (Lucking, 2004, p15). The UK leads all the countries covered by the CIS in terms of the proportion of turnover that is due to new or improved products amongst product innovators. Of UK product innovators, 41% of their turnover appears to be generated from new or improved products. These results seem somewhat out of line with the other innovation evidence reported above.

5. Market imperfections and government intervention

Historically, support for government intervention in education, training and R&D came from the fact that taxes on earnings drive a wedge between the private and social returns. As the individual only receives earnings net of taxes, they under-invest in education from society's viewpoint. The same argument can be applied to training, whether this raises the individual's wage or the firm's profits, and to R&D, which raises the firm's future profits. Both wages and profits are taxed, which leads to a private under-investment from society's point of view.

More recently, the justification for government intervention has shifted, based upon growing evidence that there may be increasing returns to investments in knowledge at the macro level. This occurs because the knowledge generated by one firm can be recombined with other knowledge by other firms (Smith, 2002). As each firm does not take into account the benefits to other firms, the level of private investment in knowledge is less than the socially optimal level.

R&D spillovers

The R&D literature has widely explored the existence of spillover effects in which any one firm may benefit from the R&D carried out by other firms, for example, in the same sector (Bosworth, 2006, pp194-197). Of course, defining the relevant pool of R&D from which a particular firm benefits is an empirical question, which has been extensively tested using either R&D or patent measures of the pool based upon the technological distance of one firm from that of others. Technological distance can be based on similarities or differences in the international patent classes within which firms operate. The pool exists because each firm is unable to appropriate all of the benefits arising from their R&D and innovation activities. Some of the scientific and technological information cannot be protected through secrecy or intellectual property rights, leaks out and is of value to other firms. Griliches (1992, ppS30-31) notes that

> "The more difficult to measure and the possibly more interesting and pervasive aspect of R&D externalities is the impact of the discovered ideas or compounds on the productivity of the research of others." (Griliches, 1992, ppS30-31).

Even in the case of strong patents, appropriation is incomplete. For one thing, "disclosure" of information is part of the "price" the inventor must pay to obtain patent monopoly rights over the idea.

The result is that the return to the stock of R&D knowledge is higher at the aggregate than the individual firm level (Griliches, 1992). This implies that firms that take decisions based upon their own private calculus invest in R&D at a level below that which is socially optimum. In other words, the firm only invests up to the point where the private return to the next £1 of R&D is also £1. This calculation does not account for the fact that the firm would benefit from a greater industry- or economy-wide investment in R&D – according to the spillover hypothesis, if there is an overall expansion in R&D, all firms benefit.

The associated empirical literature links firm performance (eg total factor productivity or market value) to own-R&D and some measure of the R&D pool that the firm benefits from. The results thereby provide information about both the private and the social rates of return to R&D. According to Griliches (1992, ppS43-44)

> "… there has been a significant number of reasonably well done studies all pointing in the same direction: R&D spillovers are present, their magnitude may be quite large, and social rates of return remain significantly above private rates. ... R&D

> returns account for half of the growth in output per man and about three quarters of the measured TFP growth, most of the explanatory power coming from the spillover component ... ".

Education and human capital spillovers

Similarly, a reason for government intervention in education is the existence of externalities and spillovers, even if these are much more difficult to quantify than in the case of R&D. The argument that there are externalities from education – human capital spillovers – has a long history, which dates back at least to Marshall (1890). The work by Blaug (1968, p243), for example, outlines nine different types of economic and non-economic spillovers that arise because of improvements in education. Indeed, there is a significant literature on positive educational spillovers on social activities (Wolfe and Zuvekas, 2000).

In the main, attempts to isolate human capital spillovers have largely focussed on the effects of the average level of education in different locations on the earnings of otherwise similar individuals in those locations (eg Rauch, 1993; Acemoglu and Angrist, 2000; Ciccone and Peri, 2006; Moretti, 2004a). Some of these locational studies are quite sophisticated. Moretti (2004b), for example, uses longitudinal, plant level data (which help to eliminate some of the issues of selectivity and endogeneity). In addition, this paper explores the role of "economic distance" in determining the strength of spillovers, showing that

> "... spillovers decline with economic distance ... aggregate human capital in the high-tech sector of the city matters more for high-tech plants than aggregate human capital in the low-tech sector of the city; and aggregate human capital in the low-tech sector matters more for low-tech plants than aggregate human capital in high-tech plants." (*ibid*., p657)

The local area spillover effects outlined above are somewhat different from those envisaged by Battu et al (2004). Here the productivity increasing "employment related" spillovers (Blaug, 1968, p244) occur from the more to the less educated amongst employees in the same workplace. Based on a statistical analysis of the Workplace Employment Relations Survey, Battu et al (2004) report the existence of substantial and significant educational spillovers in the workplace, which are largely independent of the individual worker's own educational level.

Endogenous growth – the "new growth theories"

Most goods and services, such as capital and labour are characterised by:

- rivalry – that only one person can make use of them at a given point in time;
- excludability – that one person (eg the owner) can prevent other individuals using them.

Knowledge is a non-rival good and, insofar as it is not wholly appropriable – in other words, insofar as there are knowledge spillovers – it is also non-excludable.
The result is that, while there may be diminishing returns to investing in knowledge at the individual level (eg each additional unit of knowledge adds less to income than the previous unit of knowledge), there can be increasing returns to investment in knowledge at national level (as not only the individual making the investment benefits, but so do other individuals and groups within the economy).
Thus, according to Cortright (2001, p4),

> "The centerpiece of New Growth Theory is the role knowledge plays in making growth possible. Knowledge includes everything we know about the world, from the basic laws of physics, to the blueprint for a microprocessor, to how to sew a shirt or paint a portrait. Our definition should be very broad including not just the high tech, but also the seemingly routine."

Free markets fail to produce adequate amounts of knowledge. In essence, there is a "free rider" problem. If there is no way to exclude others from benefitting from the knowledge an individual produces, there is no effective way of making them contribute towards paying for its production. To put it slightly differently, there is no way the producer of knowledge can capture revenues that reflect all of the benefits other individuals receive from knowledge and, as a consequence, they under-invest in knowledge from a societal perspective.

6. Implications for education and training

The UK's future economic performance is dependent on the generation and exploitation of new ideas that will provide a lead over competitors (Bosworth, 2008). This requires, at the very least, the successful combination of:

- people with the skills to recognise, produce and exploit ideas (e.g. management, leadership, entrepreneurship, technical know-how, a creative and innovative population)
- an infrastructure capable of supplying the skills and knowledge to generate new ideas and support their exploitation (eg education and training systems, R&D capacity), and,
- a system capable of making appropriate connections between the supply of and demand for ideas (such as establishing mutually beneficial partnerships between industry and the further/higher education sectors, support for entrepreneurs and new businesses).

The literature highlights several important links between education, R&D and innovation. These include the need for high level science and technology skills, necessary for the more high profile forms of R&D and innovation. However, they also include the skills of the general workforce, which both free management time for innovation and allow innovation to take place. Increases in education and skills allow more innovation options – not just cost reducing, but also quality increasing. In addition, increases in education and skills lower the degree of risk in activities such as R&D and the introduction of new products and processes.

Historically, the skills focus in the context of innovation has largely been on graduate level jobs in management, engineering, and science. In England, for example, the Lambert Review (2003) concentrates on the university sector and the extent to which it can and should act as a catalyst for change in industry and the Sainsbury Review (2007) looks at the role of science in enabling British companies to move away from low-cost and towards high-value goods, services and industries. While these top level skills are crucial to future success, they are not, in themselves, enough. They are necessary but not sufficient.

As the report by CRIC (2005) argues, a much greater emphasis needs to be given to the skills of the overall workforce in order to ensure that a higher rate and greater pervasiveness of innovation materialises. In addition, it needs to be recognised that innovation is not just driven by large-scale investments in the production of new products and services or the introduction of new processes, which will largely be the results of decisions by senior staff within an organisation, but it will also be the result of more piecemeal, incremental changes suggested by other members of the workforce that nevertheless have a significant cumulative impact on performance.

The present paper has reported on the huge inequality in the distribution of education, knowledge and skills across individuals. This works its way into where individuals are located and the degree of deprivation they suffer, as well as the direct link between economic inactivity and the lack of skills. Education and training remain focussed on the younger members of society and are much less important amongst older individuals, even though society recognises the need for lifelong learning and is currently in the process of raising the retirement ages of both females and males. Smith (1776)[3] argues the point in the following way,

[3] Book Five, Chapter 1, Part 3, Article II.

> "In the progress of the division of labour, the employment of the far greater part of those who live by labour, that is, of the great body of the peoples, comes to be confined to a very few simple operations, frequently to one or two. But the understandings of the greater part of men are necessarily toned by their ordinary employments. The man whose whole life is spent in performing a few simple operations, of which the effects are perhaps always the same, or very nearly the same, has no occasion to exert his understanding or to exercise his invention in finding out expedients for removing difficulties which never occur. He naturally loses therefore, the habit of such exertion and generally becomes as stupid and ignorant as it is possible for a human creature to become. The torpor of his mind renders him not only incapable of relishing or bearing a part in any rational conversation, but of conceiving any generous, noble or tender sentiment, and consequently of forming any just judgement concerning many even of the ordinary duties of private life." … "His dexterity at his own particular trade seems, in this manner, to be acquired at the expense of his intellectual, social and martial virtues. But in every improved and civilised society this is the state into which the labouring poor, that is, the great body of the people, must necessarily fall unless government takes some pains to prevent it."

Policy has also tended to be supply side oriented with an emphasis on the role of publicly funded institutions. However, as DIUS (2007) has recently recognised that the policy remit needs to be broader and to give more prominence to the demand-side, in particular, to encourage investment in R&D in this country, improve the science base, support innovation within businesses, provide skills at all levels to make people more innovative (eg the establishment of National Academies at a sectoral level), encourage innovation in public services and use of public procurement to foster innovation, and assist locations become more innovative through the establishment of innovation partnerships.

While the HM Treasury (2000) report identifies a range of factors that result in poor productivity performance, including skills, these tend to be treated as being independent of one another. In practice, they are all inter-related and, in particular, the willingness to invest, adopt best practice, undertake R&D and to innovate are all dependent on the skills of management and employees. The assertion in HM Treasury (2005) that the UK is strong in areas of innovation that are not reflected in traditional technological indicators requires urgent further research. If this is wrong, some of the levels and trends (eg R&D/GDP) are very worrying; if it is correct, there is a need to know why the UK is different and what the implications are for the competitive position of the UK economy.

References

Acemoglu, D. and Angrist, J.D. (2000) *How Large are Human-capital Externalities? Evidence from Compulsory Schooling Laws*. NBER Macroeconomics Annual. Vol. 15. Cambridge, MIT Press, pp.9–59.

Battu, H., Belfield, C.R. and Sloane, P.J. (2004) Human Capital Spillovers in the Workplace: Evidence for the Service Sector in Britain. *International Journal of Manpower*, 25 (1), pp.123-138.

Blaug, M. (1968) *The Rate of Return on Investment in Education*. In: Blaug, M. (ed) *Economics of Education*. London, Penguin, pp.215-259. First published 1965.

Bosch, M., Lederman, D. and Maloney, W.F. (2005) *Patenting and Research and Development: a Global View*. World Bank Policy Research Working Paper 3739. Washington. October.

Bosworth, D.L. (1996) Determinants of the Use of Advanced Technologies. *International Journal of the Economics of Business*, 3 (3), pp.269-293.

CRIC (2005) *A Literature Review on Skills and Innovation. How Does Successful Innovation Impact on the Demand for Skills and How Do Skills Drive Innovation?* Report to the Department for Trade and Industry. Centre for Research on Innovation and Competition.

Ciccone, A. and Peri, G. (2006) Identifying Human Capital Externalities: Theory with an Application to US Cities. *Review of Economic Studies*. 73 (2), pp.381-412.

Cortright, J. (2001) New Growth Theory, Technology and Learning: a Practitioner's Guide. *Reviews of Economic Development Literature and Practice*, 4. US Economic Development Administration. Washington, US Department of Commerce.

DCMS (2002) *Creative Industries Fact File*. London, Department of Culture, Media and Sport.

DTI (2006) *UK Productivity and Competitiveness Indicators 2006*. DTI Economics Paper No 17.

EC (2005a) *Proposed guidelines for collecting and interpreting innovation data*. Oslo Manual. Brussels, European Commission.

EC (2005b) *Key Figures on Science, Technology and Innovation. Towards a European knowledge area*. Brussels, European Commission. Directorate-General for Research Communication Unit.

Gallaher, M.P., Link, A.N. and Petrusa, J.E. (2006). *Innovation in the US Service Sector*. London, Routledge.

HM Treasury (2000). *Pre-budget Report*. London, HM Treasury. Available from http://www.hm-treasury.gov.uk/pre_budget_report/pre_budget_report_2000/pbr_report/prebud_pbr00_repindx.cfm.

HM Treasury/DTI/DfES (2005) *The Ten-year Science & Innovation Investment Framework – Annual Report*. London, HM Treasury, Department for Trade and Industry and Department for Education and Science.

Lucking, B. (2004) *International Comparisons of the Third Community Innovation Survey (CIS3)*. London, Department of Trade and Industry. Technology, Economics, Statistics and Evaluation (TESE) Team. October.

Marshall, A. (1890) *Principles of Economics*. London, Macmillan (eighth edition, 1920).

Moretti, E. (2004) Estimating the Social Return to Higher Education: Evidence from Longitudinal and Repeated Cross-sectional Data. *Journal of Econometrics*, 121, pp.175–212.

Moretti, E. (2004b) Workers' Education, Spillovers, and Productivity: Evidence from Plant-Level Production Functions. *American Economic Review*, 94 (3), pp.656-690.

OECD (2000) *Science, Technology and Innovation in the New Economy*. Policy Brief. Paris, OECD Observer Organisation for Economic Cooperation and Development. September.

OECD (2002) *Proposed Standard Practice for Surveys on Research and Development*. Frascati Manual. Paris, Organisation for Economic Cooperation and Development.

OECD (2005) *Education at a Glance 2005*. Paris, Organisation for Economic Cooperation and Development.
OECD (2007) *Innovation and Growth Rationale for an Innovative Strategy*. Paris, Organisation for Economic Cooperation and Development.
Popper, S.W. and Wagner, C.S. (2002) *New Foundations for Growth: the US Innovation System Today and Tomorrow.* Rand Institute. MR-1388.0-OSTP. January.
Rauch, J.E. (1993) Productivity Gains from Geographic Concentration of Human Capital: Evidence from the Cities. *Journal of Urban Economics,* 34 (1), pp.380–400.
Romer, P.M. (1993) Implementing a National Technology Strategy with Self-Organizing Industry Investment Boards. *NBER Working Paper No. R1870*. Cambridge, Massachusetts.
Sainsbury Review (2007) *The Race to the Top: a Review of Government's Science and Innovation Policies*. London, HM Treasury.
Shapiro, H., Haahr, J.H. and Bayer, I. (2007) *Background Paper on Innovation and Education*. Danish Technological Institute and Technopolis. For the European Commission, DG Education & Culture. First version May 2000/revision August 2007
Smith, K. (2002) *What is the Knowledge Economy? Knowledge Intensity and Distributed Knowledge Bases*. Discussion Paper. United Nations University. Maastricht, Institute for New Technologies. Available from http://www.intech.unu.edu/publications/discussion-papers/2002-6.pdf.
Wolfe, B.L. and Zuvekas, S. (2000) Non-worker Outcomes of Schooling. *International Journal of Educational Research*, 27, pp.491-502.

Work Foundation (2007) *Staying Ahead: the Economic Performance of the UK's Creative Industries*. London, Department of Culture, Media and Sports.

This document has been commissioned as part of the UK Department for Children, Schools and Families' Beyond Current Horizons project, led by Futurelab. The views expressed do not represent the policy of any Government or organisation.