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OCCASIONAL
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Enhancing the benefits from biomedical and health research spillovers between public, private and charitable sectors in the UK

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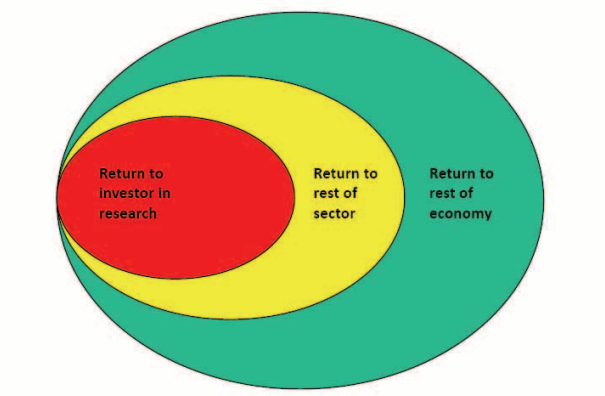
Introduction

There is widespread agreement that £1 spent on biomedical and health research will yield a large and positive rate of return, much of which will not be captured within the outputs of the organization that spent that £1 (Jaffe et al., 2000; Breschi and Lissoni, 2001; HERG et al., 2008). For example, research at a university laboratory into the mechanics of a disease process may lead to numerous benefits beyond the better understanding of that particular question, including new treatments developed by private companies or other organisations, or providing insights which aid research into other diseases, or generating spin-offs into other areas of activity altogether, perhaps due to advances in non-medical computer software which were prompted by the needs of the original, medical, research.

It is well established that knowledge spillovers can exist, whereby investments in knowledge creation by one party produces external benefits by facilitating innovation for other parties (Jaffe et al. 2000; Breschi and Lissoni 2001). Of particular interest in this paper is the idea that investment in biomedical and health research can yield a large and positive rate of return, much of which will not accrue to the organization making the investment. Questions remain, however, about the extent of spillovers and their mechanisms of action (Macilwain, 2010).

The spread of the societal and economic benefits of research funding outside the organisation directly involved is known as 'spillover' (Figure 1) and can occur between any of the sectors involved in biomedical and health research – public, charitable and private. Spillover effects are becoming increasingly important to research funders wishing to justify their funding of research beyond direct research outputs and to recognise the broader benefits their research could make possible (Buxton and Hanney, 1996; Wooding et al., 2004; HERG et al., 2004).

Figure 1: Spillovers



The diagram shows that spillovers can be expected throughout the economy, as distinct from consumer and producer surpluses. It is important to note that spillovers do not diffuse evenly throughout the economy. Some organisations are systematically better placed to benefit from spillovers than others (Teece et al., 1997). This is related to organisations' absorptive capacity[1] (Cohen and Levinthal, 1990) and is critical to appreciating that specific strategic and policy measures are needed to realise potential spillovers.

Enhancing the value of scientific research is likely to be central to UK government policy, particularly in light of current constraints on public, charitable and private research funding. The biotechnology, pharmaceutical and healthcare sectors are extremely research-intensive, and opportunities for spillover effects there are correspondingly great. Finding ways to enhance spillovers to realise the full value of research spending in these areas is vital, both in terms of targeting high-spillover projects and increasing the rewards from existing beneficial spillovers.

This document highlights key points from a high-level Forum organised and facilitated by the Office of Health Economics and RAND Europe which met in Cambridge on 11 May 2010 to discuss the nature of spillover effects from biomedical and health research and how to realise their benefits. The Forum was chaired jointly by Professor Dame Sally Davies (Director of the National Institute for Health Research (NIHR) and interim Chief Medical Officer at the Department of Health) and Dr Jane Osbourn (Vice President of Research, MedImmune) and was co-sponsored by the NIHR and MedImmune. Other participants were drawn from senior levels of industry, venture capital, research charities, academia and the public sector. A full list of participants is provided in the appendix.

The objectives of the Forum were:

- to find ways to increase the benefit to the UK from biomedical and health research; and
- to advance thinking on how to exploit spillover effects more effectively.

The Forum discussed a number of aspects of spillovers and identified the top priorities for policy research that could help bring spillover effects more explicitly into policy decisions. Below, we describe the background to spillover conceptions and present the main points raised and discussed by the Forum, in particular the mechanisms behind spillovers and the research agenda to take the issue forward. Finally, we identify the two highest priority research projects in the view of the Forum, for which scoping studies are urgently needed.

[1] Absorptive capacity refers to a firm's 'ability to recognize the value of new information, assimilate it, and apply it to commercial ends' (Cohen and Levinthal 1990, p128).

Part 1: Background
What are research spillovers and how important are they?

Returns from investments in biomedical and health research in the public, private and charitable sectors include improved health and quality of healthcare, as well as possible cost savings in the provision of healthcare. They also include a return on the investment to the investing organisation captured via royalties, licence payments or revenues from selling products developed from research. Research can also generate benefits to third parties outside the originating organisation and can extend beyond the originating sector to the rest of the economy. These are termed spillovers. Research by one organisation spills over into increased output for other organisations operating in the same or quite different sectors of the economy, e.g. by lowering barriers to entering new modes of research or by reducing production costs. The existence of these effects from research has been observed empirically for a few sectors of the economy and a few countries (Griliches 1963) but not well documented for biomedical and health research in the UK. Many theories are available in the literature about how research spillovers might occur, but what happens in practice remains in many respects a 'black box' (Mansfield, 1986). Spillovers are not captured and sold by one organisation or individual to another, but rather are the unpriced ideas/knowledge/know-how that contribute to R&D and improved output.

The 'social' or total return to investment includes both direct and indirect returns. The contribution of indirect returns to the total return is likely to be significantly higher than that of direct returns. A small number of studies (Access Economics, 2003, 2008; Funding First, 2000; Murphy and Topel, 2003) have shown that public and charity funded research yields high rates of indirect social return in the US and Australia. Spillover effects in the biopharmaceutical sector have been described by a number of authors (Cockburn and Henderson, 1996, 1998, 2000; Toole, 2007; Ward and Dranove, 1995; and others).

Work done by the Brunel University Health Economics Research Group (HERG), Office of Health Economics and RAND Europe argues, based on US analyses, that a £1 increase in public spending on biomedical and health research can be expected to increase private pharmaceutical industry R&D spending by £2.20 to £5.10 in the UK (HERG et al., 2008). This additional private R&D in turn is expected, based on a range of studies, to yield a total social rate of return of approximately 50% to the national economy as a whole (HERG et al. 2008), meaning that the £1 invested in private R&D now can be expected to yield a stream of future benefits to the economy as a whole that are equivalent to £0.50 per year in perpetuity. But the published empirical literature on the social rate of return to research relates to sectors

other than biomedical and health research. On the assumption that a similar social return would be observed to biomedical and health research in the UK, then for every extra £1 spent on public R&D plus the extra £2.20 to £5.10 consequently spent by the private sector, the national economy earns respectively a return equivalent to an extra £1.10 to £2.50 per annum of GDP thereafter. Thus the social rate of return to the total (public + private) investment stimulated by the initial £1 of public/charitable investment is in the range 26%-34%, i.e. of the order of 30%.

Economic spillovers have long been recognised. Economist Alfred Marshall in his seminal work *Principles of Economics* (first published in 1890) outlined the advantages in companies being located close to each other when he stated that 'the mysteries of the trade become no mysteries; but are as it were in the air...if one man starts a new idea, it is taken up by others and combined with suggestions of their own; and thus it becomes the source of further new ideas.'

Despite the name, spillovers should not be viewed as accidental. They can be a deliberate policy objective for public research spending; for instance through 'cluster' policies, which explicitly encourage spillovers by encouraging the co-location of public and private research organisations, or researcher networking programmes, which encourage sabbaticals and visiting fellowships. Current fiscal constraints increase the need for demonstrable returns and for highlighting the spillovers effects that should be taken into account.

A number of initiatives in the UK have explicitly addressed the issue of spillovers from biomedical and health research, whether publicly, charitably or privately funded. In 2007 the Department of Health published "Best Research for Best Health: A New National Health Research Strategy". One of the key dimensions highlighted by this Strategy was the need for the NHS to work alongside partners including the private sector.

Several high-level working groups with representatives from the private sector and the UK government have been created with the purpose, among others, to show the benefits generated for the UK by private R&D in the biomedical and health sector (PICTF[2] for pharmaceuticals, BIGT[3] for bioscience and HITF[4] for medical devices).

The latest piece of UK policy that focuses on the gains from public-private collaboration and how they might be maximised, can be found in the Office for Life Sciences (OLS) Blueprint (OLS, 2009; 2010). In 2009 the UK prime minister set up the OLS with global industry leaders. The objective was to identify a range of policy options that would ensure that the UK maintained its position as a world leader in life sciences (OLS, 2009; 2010). Underpinning this initiative was the desire to improve collaboration between industry and academia and to strengthen the partnership between industry and the NHS. One of the recommendations was a commitment to develop a UK Life Sciences 'Super Cluster' in order to boost collaboration and leadership in translational research by harnessing UK capabilities in areas of clinical need.

However, even though the importance of spillovers is recognised and efforts are being made to encourage them, the conceptual and empirical evidence base for spillover effects and the mechanisms that produce them is limited, making it difficult to ensure that all potential

[2] More information on PICTF can be found at: http://www.dh.gov.uk/ab/Archive/PICTF/DH_090491

[3] More information on BIGT can be found at: http://www.bioindustry.org/bigtreport/

[4] More information on HITF can be found at: http://www.dh.gov.uk/ab/HITF/index.htm

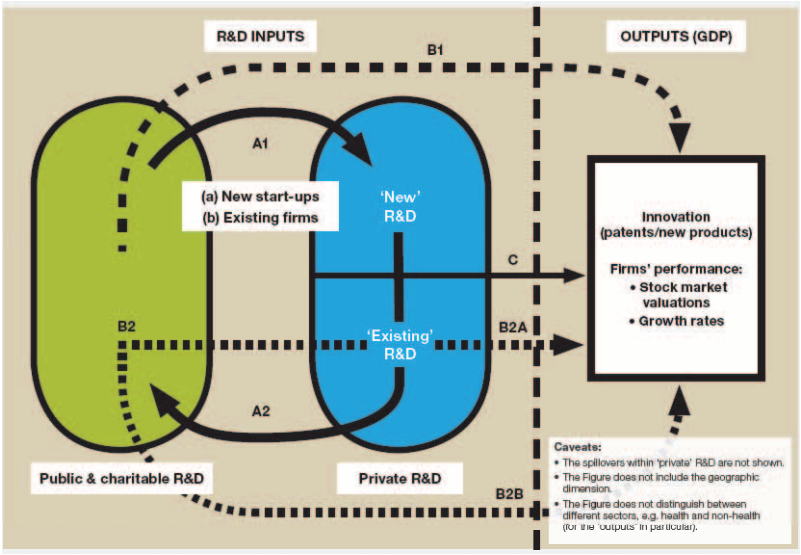
benefits of spillovers are captured through policies designed to encourage them.

Part 2: Opening the black box. How do spillovers happen and how can we make the most of them?

The Forum participants were unanimous that spillovers are substantial and agreed the importance of finding ways to exploit them. In addition they offered many insights from their experience into how the benefits of biomedical and health research are realised. In the following section these insights are related to the views of others as revealed from the published literature.

As a starting point, Figure 2 illustrates a framework for understanding the total return to biomedical and health research, and demonstrates that the public, charitable and private sectors all play major roles in the realisation of social benefits. There was strong agreement that research spillovers do not simply proceed in a linear fashion from public/charitable lab to private company to end users, for example, but entail numerous feedback loops – including from private to public sectors – and dead ends. The point was made that much of the benefit of flows of knowledge and ideas may be in stopping or redirecting research that is likely to prove unproductive, that is to say in avoiding what would turn out to be waste, and not just in prompting avenues of enquiry.

Figure 2: Sources of spillovers: public and charitable R&D and its interaction with private R&D



Source: HERG et al., 2008

The simplified conceptual framework in Figure 2 indicates a number of different routes by which spillover effects can be realised, and suggests that there may be a number of mechanisms at work driving those effects. Primary among these are the movements of skilled labour, the norms and values of institutions, and the rules and regulations put forward by policy development.

The 'clustering' effect of researchers and companies seeking to locate where knowledge is 'in the air' is well known. The Forum agreed that geographical proximity is still, even in a world of high-quality electronic communication, a key factor in creating and mediating spillovers. Evidence suggests that clustering, agglomeration and the strategic decisions of where to locate new start-ups and other small and medium-sized enterprises (SMEs) and the research facilities of large firms are linked to the presence of universities and other public research organisations, but the formal research evidence of this is largely from outside the UK. There are also instances of clusters developing around so-called 'anchor tenants', large commercial concerns that serve to attract other companies, from the same and other sectors, to locate nearby. The important point was made during the Forum's discussion that clusters may not easily be grown from scratch without incurring significant expense: i.e. public policy can more easily foster the conditions in which research clusters form and grow but it is much harder and more expensive to directly manufacture them.

There may be endogenous growth and transaction cost benefits to clustering, such as collegiality and trust. There may be infrastructure benefits of clustering too, such as lower transportation costs and product complementarity with other industries and sectors. However, separating the role of knowledge spillovers from these other drivers of geographical concentration remains a key empirical knowledge gap. Furthermore, it is unclear to what extent different clusters and networks are more or less successful in producing beneficial spillovers: the Forum identified a need to measure not only the existence of clusters but also their respective impacts. The basis for strategic locational decision making remains unclear and lacking in empirical evidence (Breschi and Lissoni, 2001). There are few developed economies and sectors where this shortage is more acute than for the UK life sciences.

Spillovers were recognised by the Forum to also have far reaching benefits that cannot be captured only by analysing clusters. Evolution of business models in the private sector, for instance the move by big pharmaceutical companies away from in-house R&D, indicates that there is an ongoing need to be innovative and develop new collaborative models as the research and commercial environment changes. New business models may make factors other than clustering more important for successful spillovers.

Spillover effects, and associated economic growth, reflect the transfer of knowledge in its widest sense. An important mechanism for productive knowledge transfer centres on the movements of highly skilled people, because tacit knowledge embodied in people is often economically more useful than widely available information (Hayek, 1945). Universities and other public laboratories are recognised as generators and repositories of public knowledge (Geuna et al., 2003), but they also facilitate the transmission of knowledge via their output of talented graduates and pool of expert researchers and their interactions with peers in other organisations. This is in addition to the obvious roles that universities play in generating ideas and knowledge, and providing high-quality training, research facilities and libraries, as well as publications and other dissemination routes (meetings, seminars and so on).

Encouraging, facilitating and promoting contact and exchange between staff across academia, the NHS, charities and the private

sector is a key mechanism in promoting spillover effects from biomedical and health research funding. Cockburn and Henderson's (1996, 1998, 2000) econometric studies of pharmaceutical R&D demonstrated that productivity of commercial drug discovery is positively associated with proxies for inter-firm and intra-firm knowledge output outside the research programme, firm-level 'pro-publication' norms and incentives, collaboration with not-for-profit science (co-authorships) and co-location with public science.

Both formal and informal methods of exchange play a role, the former including, for instance, technology transfer programmes, such as licensing from universities to firms, and the latter operating through networking and social interactions. It is important to recognise that knowledge flows in this context are not linear, indeed they have been likened to a whirlpool rather than a waterfall. Studies on collaboration in the life sciences sector (Powell et al, 2005) demonstrate that inter-organisational networks are highly complex and multi-dimensional, as do studies on social capital and the role of individuals (Owen-Smith and Powell 2005).

The discussion at the Forum emphasised the importance of the culture of the people and organisations undertaking the research. An example was cited where an open and pro-publication culture (including sharing data from 'failed' research) instilled by the founders and characterised as a greater interest in the science than in financial gain, led to the creation, sustained growth, and eventual commercial success, of a UK biotechnology company located near Cambridge and its university research laboratories. Interest in the science for its own sake, sharing the objectives and enjoying the company of particular colleagues, can all motivate, and perhaps more so than financial incentives.

Industry participants at the Forum noted the importance of a 'revolving door' to enable public and private sector researchers to gain first-hand experience of each other's work. There is scope, for example, for collaboration to develop and promote more opportunities for academic researchers to spend time with their counterparts in commercial research.

While some commercial research staff would welcome the opportunity to move freely from the private sector to the public, this is hindered in practice because university recruitment policies require senior candidates to demonstrate academic publication records of a scale not generally achievable by those working in commercial organisations. This is an unintended consequence of university funding mechanisms focusing on past publications by faculty members as an indicator of the current and future research excellence of an institution, and could be seen as a barrier to spillovers that could be mediated through movement of people between employers.

The Forum discussed the importance of introducing incentives to encourage staff mobility from the private sector to the public/academic sector. This could be achieved, for instance, by providing ring-fenced time for private sector scientists to collaborate with academic researchers. The potential rewards for the private-sector scientists would be increased reputation – rather than additional financial rewards.

The spillover pathways indicated in Figure 2 can be influenced by policy measures, affecting the transmission of ideas as well as the movement of people. For instance, tightening intellectual property or fiscal regulations has had adverse effects. Forum participants raised anecdotal evidence that policies implemented to encourage universities to be more 'commercial' in their approach to working with the private sector may have 'overshot' and been limited by, for example, inflexibility in the scale or nature of payments required.

The Forum agreed that the presence – or absence – of spillovers from private to public research, although included in the conceptual

model, have not yet been adequately explored or quantified. The notion that private sector R&D activity can stimulate more productive public and/or charitable research is widely accepted in principle, but its scale has not been measured. Nor has there been much investigation of factors that would either stimulate, inhibit or distort private-to-public spillovers. For instance, we do not know whether the size of private companies affects spillovers.

Part 3: Research agenda and priorities

Based on the initial discussion of the nature and mechanisms of spillovers, and how they might be stimulated or discouraged by different factors, the Forum then went on to identify, discuss and prioritise what it saw as the main elements of a research agenda to improve exploitation of the benefits of spillovers from biomedical and health research. The Forum agreed on three important gaps in knowledge that hinder private and public funders of UK research enhancing beneficial spillovers from biomedical and health research:

- Lack of UK data on spillovers from biomedical and health research – the available empirical evidence is either derived from US datasets of public and private biomedical and health research and/or is drawn largely from (mostly quite old) studies of total social returns to research in the agriculture sector;
- Lack of evidence on private to public spillovers – most of the literature focuses on spillovers from the public sector to the private sector, or between two private sector organisations. There is little empirical work on spillovers from the private sector to the public sector; and
- Lack of knowledge about the mechanisms of spillovers – particularly the relative importance of the different means by which spillovers may be transmitted.

UK data on the presence and extent of spillover effects is severely lacking in coverage, consistency, quality and relevance. Methodologies that have been used in the US may be suitable for investigating the magnitude of spillovers from biomedical and health research in the UK (see HERG et al., 2008; and Toole, 2007). They might also be used to test whether different therapeutic areas or proximity to application in biomedical and health research generate spillovers at different rates, and perhaps whether the marginal rate of spillovers per research pound spent is increasing, constant or diminishing over time. In addition to direct estimates of the magnitude of spillovers from research in the UK, it would be possible to collect indirect indicators of spillover effects including patent registrations, company start-ups, numbers and values of public/private R&D collaborations, and so on.

There is currently little research on how spillovers have enabled organisations to redirect, or terminate, research that was likely to be relatively unfruitful. Nor is there enough information on collaborations that did not work, although these could provide useful lessons for future collaborative efforts. In other words, the Forum identified a need to focus not only on research which is successful in producing health-improving ultimate outcomes but also on research which generates benefit by identifying dead-ends sooner.

As discussed above, the extent of spillover effects from private to public research have not been explored or quantified, leaving a large gap in our understanding of spillover effects. Any research into how spillovers are mediated should therefore include explicit consideration of public/private spillovers in both directions.

Studying the mechanisms behind spillover effects through examining the structure and extent of people flows and interactions (informal as well as formal) and their contributions is not straightforward but is essential if appropriate policies are to be developed to enhance the benefit from research expenditure. The use of familiar proxies, such as bibliometric information (e.g. citation and co-authorship patterns), and network analysis, need to be supplemented by more direct research into the interactions between people, especially when they are in different organisations, and what, if any, identifiable outcomes result from these interactions – including the kind of valuable 'negative' outcomes referred to above.

Spillovers may also be limited by clustering in the publication process, where valuable information tends to be published in a handful of journals in a limited number of languages. At the same time, current bibliometric studies that may be used to try and trace spillover pathways also focus on publication in particular types and tiers of journals, and do not capture valuable information that might be published elsewhere, particularly online, including in registries such as www.clinicaltrials.gov.

Cultural attitudes within public and private institutions, which have different objectives and responsibilities towards taxpayers and investors/shareholders respectively, may affect the strength and speed of spillovers permeating into the wider economy - for instance towards alliances or open sharing of knowledge. The level of social trust, and the extent to which it is realistic for that to be enhanced, may need to be considered along with ease of movement and interaction of people working in biomedical and health research.

The role of geographical clustering, and hence of policies aimed at encouraging it, in facilitating spillover-enhancing interactions should be an important element of the research into 'people flows and interactions'. Clustering and geographical considerations, and their effects on the exchange of ideas and knowledge, may be more important at different stages in the research and spillover cycle.

Part 4: Conclusions and next steps

In summary, the Forum participants concluded that spillovers are indeed an important part of the benefits of medical research and that too little is understood about their magnitude in specific circumstances and how to enhance them. Much work could be envisaged that would help to rectify that lack of understanding. But from among the many options, the Forum participants agreed that:

- The first priority is to create a UK evidence base for the spillovers from biomedical and health research to ensure that current understanding, which is largely based on non-UK (indeed non-EU) data, is appropriate and sound. A quantitative analysis of the impact of biomedical and health research spending for example comparable to Toole (2007) for the US should be applied to UK data, and followed through to identify and quantify the extent of spillover effects accruing to biomedical and health research here.
- The second priority is to gain a better understanding of the mechanisms that generate spillover effects and the barriers that hinder them. In particular, research is needed into how these effects are channelled through individuals and their formal and informal interactions, including, but not limited to, research collaborations and the labour market.
- An essential first step to tackling these priorities would be a scoping study to determine the feasibility and cost of this research.

References

Access Economics, *Exceptional Returns: The Value of Investing in Health R&D in Australia*, Canberra: Access Economics, 2003. (Available online at http://www.accesseconomics.com.au/publicationsreports/showreport.php?id=33&searchfor=2004&searchby=yearearlier.)

Access Economics, *Exceptional Returns: The value of Investing in Health R&D in Australia II*, Canberra: Access Economics, 2008. (Available online at http://www.accesseconomics.com.au/publicationsreports/showreport.php?id=165.)

Breschi, S. and F. Lissoni, 'Knowledge Spillovers and Local Innovation Systems', *Industrial And Corporate Change*, Vol. 10, No. 4, pp.975–1005, 2001.

Buxton, M. and S. Hanney, 'How can Payback from Health Services Research be Assessed?', *Journal of Health Services Research and Policy*, Vol. 1, No. 1, pp.35–43, 1996.

Cockburn I. and R. Henderson, 'Public–private Interaction in Pharmaceutical Research', *Proceedings of the National Academy of Sciences USA*, Vol. 93, pp.725–30, 1996. (This paper was presented at a colloquium entitled 'Science, Technology, and the Economy,' organized by Ariel Pakes and Kenneth L. Sokoloff, held 20–22 October 1995, at the National Academy of Sciences in Irvine, CA)

Cockburn I. and R. Henderson, 'Absorptive Capacity, Coauthoring Behaviour and the Organization of Research in Drug Discovery', *The Journal of Industrial Economics*, Vol. 66, No. 2, pp.157–82, 1998.

Cockburn I and Henderson R (2000) Publicly funded science and the productivity of the pharmaceutical industry, NBER conference on science and public policy

Cohen, W. and D. Levinthal, 'Absorptive Capacity: A New Perspective on Learning and Innovation, *Administrative Science Quarterly*, Vol. 35, pp.128-152, 1990.

Funding First, *Exceptional Returns: The Economic Value of America's Investment in Medical Research*, 2000. (Available online at http://www.laskerfoundation.org/advocacy/pdf/exceptional.pdf)

Geuna, A., A. Salter and W. Steinmueller, eds, *Science and Innovation: Rethinking the Rationales for Funding and Governance*, Cheltenham, UK: Edward Elgar, 2003.

Griliches, Z., 'The Sources of Measured Productivity Growth: 1940–60', *Journal of Political Economy*, pp.331–346, 1963.

Hayek, F. A., 'The Use of Knowledge in Society', *The American Economic Review*, Vol. 35, No. 4, pp.519–530, 1945.

Health Economics Research Group, Office of Health Economics, RAND Europe, *Medical Research: What's it worth? Estimating the Economic Benefits from Medical Research in the UK*, UK Evaluation Forum (Academy of Medical Sciences, Medical Research Council, Wellcome Trust): London, 2008.

Jaffe, A., M. Trajtenberg and M. Fogarty, 'Knowledge Spillovers and Patent Citations: Evidence from a Survey of Inventors', *American Economic Association*, Vol. 90, No. 2, pp.215–218, 2000.

Macilwain, C., 'What Science is Really Worth', *Nature*, Vol. 465, pp.682–684, 2010.

Mansfield, E., 'Patents and Innovation: An Empirical Study', *Management Science*, Vol. 32, No. 2, p.173, 1986.

Marshall, A., *Principles Of Economics*, New York: Prometheus Books, 1997.

Murphy, K. and R. Topel eds, *Measuring the Gains from Medical Research: An Economic Approach*, Chicago: University of Chicago Press, 2003.

Office for Life Sciences, *Life Sciences Blueprint*, (London: Office for Life Sciences) 2009.

Office for Life Sciences, *Life Sciences 2010: Delivering the Blueprint*, (London: Office for Life Sciences?)2010.

Owen-Smith, J. and W. Powell, 'Knowledge Networks as Channels and Conduits: The Effects of Spillovers in the Boston Biotechnology Community Organization', *Science*, Vol. 15, No. 1, pp.5–21, 2005.

Powell W. et al. 'Network Dynamics and Field Evolution: The Growth of Inter-Organizational Collaboration in the Life Sciences', *American Journal of Sociology*, Vol. 110, No. 4, pp.1132–205, 2005.

Teece, D., G. Pisano G and A. Shuen, 'Dynamic Capabilities and Strategic Management', *Journal of Strategic Management*, pp.509–533, 1997.

Toole, A., 'Does Public Scientific Research Complement Private Investment in Research and Development in the Pharmaceutical Industry?', *Journal of Law and Economics*, Vol. 50, pp.81–104, 2007.

Ward, M.R., and D. Dranove, 'The Vertical Chain of Research and Development in the Pharmaceutical Industry', *Economic Inquiry*, Vol. XXXIII, pp.70–8, 1995.

Wooding, S., S. Hanney, M. Buxton and J. Grant, *The Returns from Arthritis Research. Volume 1: Approach, Analysis and Recommendations*, Cambridge, UK: RAND Europe, 2004.

Appendix: Forum participants

Dr Virginia Acha – Director of Public Affairs Strategy and Analysis, Pfizer Pharmaceuticals

Dr Hannah Chaplin – UK Trade and Investment

Professor Joanna Chataway – Director of Innovation and Technology Policy, RAND Europe

Professor Iain Cockburn – Professor of Finance and Economics, Boston University and National Bureau of Economic Research

Professor Dame Sally Davies – Director General for R&D, Department of Health

Dr Iain Foulkes – Executive Director of Strategy and Planning, Cancer Research UK

Dr Jonathan Grant – President, RAND Europe

Dr David Halpern – Director of Research, Institute for Government

Mr A. Michael Hoffman – Chairman, Palamon Capital Partners

Dr Jackie Hunter – Director, Pharmivation

Dr Jeff Kipling – Director of EU/UK External Engagement, GlaxoSmithKline Drug Discovery Operations

Dr Jorge Mestre-Ferrandiz – Senior Economist, Office of Health Economics

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