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Science in the economy and the economics of science

ESRC Science in Society Programme

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science in society

Contents

Preface

The science-society relationship is recognised as no longer being one in which the needs of the public are dictated by those in authority. But what is it to become? How can those in government, science and the private sector manage the science-society relationship more effectively? How can the public in all its diversity become more engaged in the production of science and its role in society?

The goal of the ESRC's Science in Society Programme is to explore and help develop the rapidly changing relations between science (including engineering and technology) and the wider society. These brochures are intended not only to bring together the findings of research projects in the Programme, but also to draw on wider insights into the relationship of science and society.

To that end, although these brochures provide an overview of academic research, they hope to prompt questions that go beyond the academic to the role of science and technology in real lives, in all their diversity.

"The relationship between science and the economy is never one-way"

Foreword

It is a widely held belief, particularly among politicians and scientists, that there is a strong causal relationship between the capacity that a country or region has for scientific and technological innovation and its economic development. Yet history suggests that any such relationship is far from simple. Britain in the 1960s was a hotbed of new scientific ideas that never made their way into UK production. Japan, in the same period, built massive economic growth by, initially at least, reverse engineering technology that originated elsewhere.

Over the past decade, there has been much concern in the UK about a perceived shortage of homegrown scientific talent. But how much does this really matter in an era of international scientific labour markets? Furthermore, the relationship between science and the economy is never one-way. How do the incentives of changing intellectual property regimes influence the challenges that scientists select for research and the kinds of solutions that they seek to problems, such as disease eradication?

Under the theme of *Science in the economy and the economics of science*, the ESRC Science in Society Programme sought to open these kinds of questions up to social science scrutiny. The projects described in this brochure are only a beginning. But they have clearly established the importance of the topic and demonstrated the value that social science research can add to public understanding of the science-economy relationship as well as to the formation of public policy and private investment in this important area.

Steve Rayner
Director

Executive Summary

Science and technology are now widely claimed to be the drivers of innovation in the global economy. Governments are ploughing significant resources into scientific initiatives, keen to capitalise on the next wave of knowledge-based growth. Innovative firms in cutting-edge areas such as information technology and pharmaceuticals are emerging in countries such as China and India, challenging the dominance of those in industrialised countries. Skilled workers are able to move to take up the best jobs wherever they find them around the world.

These developments pose some difficult questions for those who are involved in science policy:

- Is the brain drain happening, and if so what effects is it having on the economies of both sending and receiving countries?
- How effective are the different forms of collaboration between universities and firms?
- What does 'excellence' mean in science, especially in relation to other goals such as social relevance?
- Is it possible to pursue scientific excellence, for example in clusters, at the same time as supporting regional development?

The links between science, technology and innovation are still unclear. Analysts have long challenged the neat linear logic that investments in science will inevitably produce economic benefits in the form of new technologies and innovations. Yet causative links are difficult to discern; technological advance sometimes runs in front of scientific understanding, while economic development also sometimes seems to trigger technical innovation rather than the other way round. And there are many other intervening factors, such as the capacities and capabilities within local firms to engage with, and make the most of, the new insights that are emerging from science.

So in recent decades, governments have put in place a range of policies aimed at encouraging collaboration between universities and other players, particularly industry, in the expectation that this will lead to economic benefits. But what really helps to create beneficial outcomes? How do formal types of collaboration compare with informal links? Do knowledge workers in different sectors still face such different incentive and reward structures that collaboration remains the exception rather than the norm?

In such a complex and fast-paced area it is easy for a range of easy myths and assumptions to emerge, and this brochure starts by challenging the assumptions that:

- investments in science and technology will automatically result in economic and social benefit

“Science and technology are now widely claimed to be the drivers of innovation in the global economy”

- the best method of knowledge transfer comes when a talented researcher moves out of the university and into business, or vice versa
- the most effective way for less industrialised countries to acquire technology is to start by assembling technologies from Europe, the US and Japan
- the ‘brain drain’ always has damaging effects on countries such as the UK.

The discussion of these assumptions reveals a range of tensions around the economic aims of science policy, and these tensions emerge throughout the discussion. In addition, two main themes emerge from the research:

Theme 1: International Science and Science in the Regions: The Spatial Dimension

In the UK, science policy has traditionally been handled at the national level, but that is now changing. Organisations at all levels are keen to harness science and technology. Now, a more fluid set of relationships is emerging between international, national and regional actors. Perhaps the highest-profile public debate on this aspect of science relates to the idea of the brain drain. How can countries cope with the loss of skilled people, and ensure that even if not all of their scientists return, they can benefit from their skills and experience?

Theme 2: The Changing Role of Universities and Academics

Recent changes within science policy, and also the greater economic and social expectations that are being placed on science, are having significant consequences for scientific personnel and research and development (R&D) institutions. What influences Indian scientists to return to India? Is there unequal involvement in science, engineering and technology among different social groups, and what can be done about it? How are highly innovative Chinese firms collaborating with universities? How can scientists develop both the breadth and depth of skills required for the knowledge economy?

These themes are explored through the lens of a range of research projects conducted within the Science in Society Research Programme, leading to 12 key insights:

- The impact of the brain drain can be overstated; it is not an inevitably one-way process. Out-migration of highly trained people can be stemmed and even reversed.
- In addition, large numbers of scientific personnel who stay abroad are collaborating with partners in their home country, transferring knowledge and skills and helping to set up new scientific initiatives and firms.
- Nevertheless, the brain drain phenomenon poses significant challenges for both sending and receiving countries. Sending countries need to invest in science over the long-term and modernise their scientific institutions in order to allow skilled people to re-integrate effectively.
- The large number of short and long stays abroad by scientists demonstrates the potential for return. Encouraging shorter stays and research-related travel in both directions would increase the potential for knowledge transfer and co-operation.
- Receiving countries also need to be careful that their good fortune does not mask structural weaknesses. Countries such as the UK have failed to attract enough of their own young people into science.
- The research challenges the idea that there is a simple linear relationship between scientific capabilities and economic development; technical capacity in places like India often seems to *follow* economic development rather than lead it.
- There are some serious tensions within European science policy. The European Union’s commitment to freedom of mobility and the development of science in clusters of excellence challenge the viability of achieving balanced growth and regional equality.
- There are also continuing tensions around the widely held goal of encouraging collaboration between scientists in universities and players in other sectors. Reward systems differ widely, making it difficult to reconcile people’s incentives to engage.
- Similarly, academic ideas of excellence – measured through the output of academic publications – often have little direct link with the wider value that science is producing for society. Yet excellence and local relevance need not be mutually exclusive.
- Allocating science funds according to regional criteria is undesirable; excellence requires open competition. Additional effort does need to be invested in building capacity across regions to ensure a more balanced distribution of excellence.
- Policymakers also need to bring together their policy objectives on science and innovation, higher education and regional development. Cross-departmental thinking is needed on how science funding structures, university policy, the devolution agenda and regional economic development initiatives can be knitted together.
- Science policy in the UK involves players at regional, national and international levels, yet there are no well-developed arenas or mechanisms for these players to develop science policy jointly. In such a system, the capacity of the English regions to truly develop science regions or cities is limited.

Introduction

It is widely acknowledged that science plays an increasingly significant role in the economy. Scientific funding is a major way in which governments at all levels – regional, local, national and international – attempt to support economic development and local quality of life. It is often argued or simply assumed that science is a key component of economic prosperity in this, the age of the knowledge economy.

Recently, longstanding scholarly questioning about the appropriate relationship between science and the wider society has become recognised as a vital topic for public policy. For example, the European Union's Lisbon agreement from 2004 set the goal for the Union to become the most competitive and dynamic knowledge-based economy in the world by 2010 and put research at the heart of achieving this goal, seeing it as a key factor in business competitiveness, employment and quality of life.

Should scientific investments always go to existing centres of excellence, or can investments in science also be used as means to achieve other goals – such as the desire to balance the relative prosperity of different countries, or regions within countries? How should we measure excellence in science given the existence of a range of demands now being made of scientists and the institutions in which they work? The Lisbon agenda opens a host of such questions about the relationship between science and the economy.

At the same time, heated public debate over questions such as stem-cell research, nuclear power, food risks and biotechnologies all demonstrate that people are willing to question the science-society relationship, even if the vast bulk of scientific activity remains uncontroversial.

"It is often argued or simply assumed that science is a key component of economic prosperity in this, the age of the knowledge economy"

One of the features of science is its international character. Scientists are highly mobile relative to those in most other professions. Scientists communicate with their peers around the world – indeed, they invented email and the internet to help them achieve this. But what are the economic implications of this mobility? Is there a brain drain, and if so, who benefits and who pays? Does the brain drain ever go into reverse? How does scientific mobility play out in particular places, and how does it affect specific groups?

Improving the skills of scientists and engineers is partly a question of training and experience in cutting-edge technologies. However, increasingly it is recognised that the key is establishing a diversity of skills amongst the scientific labour force. For example, combining technical and managerial acumen, savvy entrepreneurs, the ability to estimate risk and the existence of individuals who can act as knowledge brokers between different communities of practice. The ability and willingness not just to support scientific research but also to find ways to develop this diversity of skills will be important for both developed and emerging economies in their attempts to take advantage of their science and technology infrastructure.

These are just some of the aspects of the Science in Society Programme's aim to explore the rapidly changing relations between science, engineering, technology and wider society, and thereby to facilitate debate and policy development. Other brochures in this series have addressed a range of closely related topics: science and globalisation, and the challenge of re-thinking science communication. The Programme has aimed to evaluate the role of scientific institutions and to explore alternative models for their design in the light of public goals and social aspirations.

This has involved understanding the economic incentives for scientific research as well as for the development and deployment of new ideas, products, and services derived from that research. It has also meant questioning the design of R&D institutions in the private, public, and academic sectors, as well as the relationships among these sectors.

The research projects discussed in this brochure begin to examine such questions. We start by challenging a range of common assumptions about the relationship between science and the economy and then go on to identify two themes that emerge from the research: the spatial dimensions of science policy; and the challenges for scientific institutional and personnel raised by recent changes in the science-society relationship.

Challenging Common Assumptions

People are central to science, which is an inherently international activity. As mobility between countries becomes easier within continents such as Europe and more broadly, scientists are becoming more mobile, moving to take up opportunities wherever they appear. While this is commonly discussed under the banner of the irresistible phrase 'the brain drain', the realities of scientific mobility are much less linear than implied by the phrase.

International mobility is often not forever, with migrants often returning home more skilled and experienced than when they left. Skilled people are influenced by a complex and dynamic set of factors that call for empirical analysis rather than easy rhetoric. Here, we discuss a set of common assumptions that have been challenged by research.

It is often assumed, especially in government circles at national and regional levels, that investments in science and technology will automatically result in economic and social benefit. This is often fuelled by an exclusive focus on the idea of excellence, which can lead to an uncritical worship of science as economic saviour. Yet as Beth Perry and colleagues found in their research reported here, scientific measures of excellence – such as the scientific quality and quantity of publications produced by researchers – may not be the best way to assess the types of knowledge that address society's problems in a relevant, timely and accessible way. Conversely, too narrow an emphasis on relevance can engender an inward looking parochialism that measures the value of research solely according to spin-offs produced. There is an urgent need to discard this either/or approach and begin to look for the elusive win-win, requiring a delicate balancing act between excessive reverence of science on the one hand and short-term instrumentalism on the other.

"People are central to science, which is an inherently international activity"

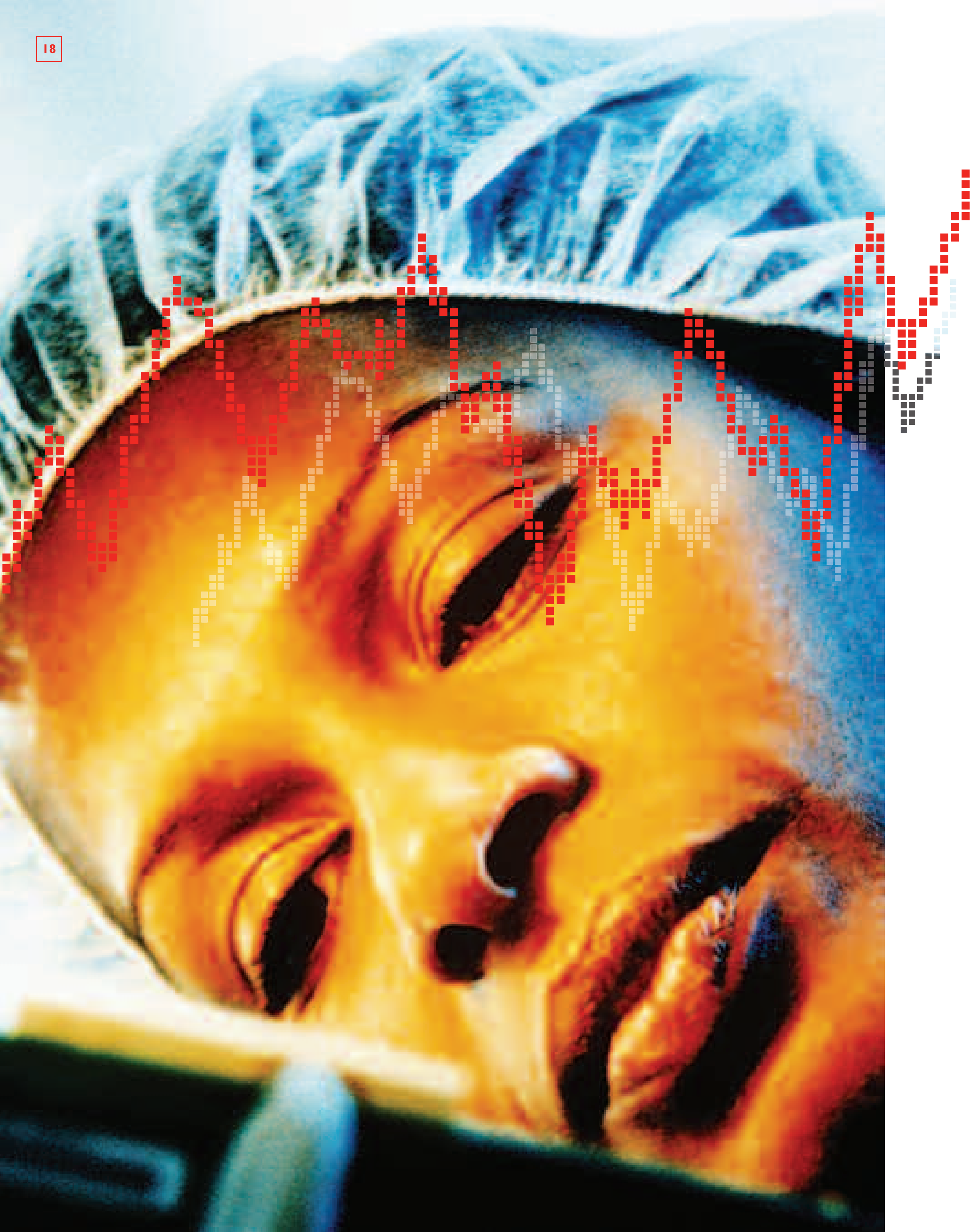
Another commonly held assumption that is challenged by research relates to the mechanisms for how to promote effective collaboration between universities and the private sector. This has been an important topic of science policy through the past decade. It has become widely assumed that the best method of knowledge transfer comes when a talented researcher moves out of the university and into business, or vice versa. This now-orthodox view was notably promoted in the recent Lambert review (Lambert 2003). But, as Professor Alice Lam has found in her research reported here, although career moves constitute an effective mechanism for knowledge transfer, they represent only one of the channels of knowledge flow across organisations. Where such orthodox views remain unchallenged by evidence, other forms of collaboration such as joint ventures and more informal mechanisms such as networking and advice can be overlooked.

Economic development is, of course, a key concern for less industrialised countries where it is often assumed that the best way that they can acquire technology is to start by assembling technologies that have been developed in Europe, the US and Japan. This assumption has stemmed from discussions about development and the theories that have become central to many of these discussions. Here, it is often assumed that under the economic theory of comparative advantage, this strategy plays to the main strength of developing countries such as China, namely cheap labour. Only much later, it is assumed, can such countries reach a point where they can come up with indigenous designs and other innovations.

Yet as Mathias Ramirez found in his research, leading ICT firms in China – such as Lenova, Founder and Huawei – have challenged these assumptions by becoming highly innovative entities from early on. Several questions arise. Firstly, what we can learn from such cases – can they be explained by peculiar institutional arrangements in China, where Chinese ICT firms have access to the technological resources of the state? Secondly, does the business model in China's high technology districts create the basis for an innovative economy? Important challenges are posed, primarily to the institutions presiding over education, training and the governance of economic activity.

Another common assumption is that the brain drain always has damaging effects on countries such as the UK, which is typically assumed to lose out to US. But is there a brain drain – does scientific mobility always imply net losses to sending regions and net gains to those receiving scientific personnel? Research such as that reported here by Professor Louise Ackers and colleagues shows that the brain drain is not a one-way process, that the UK is a recipient of scientific personnel from other countries such as Italy, and that less competitive regions in the EU that export high numbers of scientists do not necessarily lose out to the UK and Germany. The research shows that the relationship between mobility and knowledge transfer is highly complex; movement is often like a pendulum or shuttle – implying a level of circulation – and that knowledge flows in other ways via networks and connections.

Although serious problems exist in the scientific development of the *sending* regions of the EU, it is overly simplistic to attribute causation; brain drain, if it exists, is the effect but not the cause of scientific under-development, and scientific mobility offers many benefits to these regions. By contrast, a reliance on foreign scientists to meet skills shortages in the receiving countries, especially the UK, also raises serious questions about the sustainability of scientific development and labour markets. Debates such as this benefit from a longer-term vision generated by research into the trends and evidence.



Cross-Cutting Themes

There is now an emerging set of tensions around the objectives of science policy. These tensions will appear repeatedly throughout our discussion, and demand attention from those involved in science policy. There are tensions between science policy objectives at the national, international and regional levels, and there are tensions between the different policy goals being imposed on science. For example, the desire to develop and support centres of excellence is in tension with other policy aims around addressing inequality and regeneration.

As discussed in the brochure on governance in this series, competing levels of governance are now shaping national and regional science policy, for example when leading English regions battle to be the home for the latest scientific laboratory, in the belief that this will bring economic benefits. As we shall see, the traditional, centralised model of science policy in the UK and elsewhere is being challenged by a diffuse set of aims being pursued by actors at many levels – regional, national and international.

In addition to adding detail about the tensions within science policy, this section identifies and elaborates on two cross-cutting themes that emerge from the research.

Theme 1: International Science and Science in the Regions: The Spatial Dimension

In the UK, science policy has traditionally been handled at the national level, but that is now changing rapidly. Now, in the knowledge economy, organisations at all levels have been looking to science and technology as a key source of growth, jobs and wealth creation. National states remain important, but a more subtle, fluid and dynamic set of relationships are emerging between international, national and regional actors.

Perhaps the highest-profile public debate on this aspect of science relates to the idea of the brain drain. How can countries cope with the loss of skilled people, and turn brain drain into brain circulation? Analysts such as Professor Louise Ackers and colleagues are now turning away from using the term brain drain as its one-way connotations tend to conceal the more complex realities involved. What opportunities and challenges are associated with scientific mobility?

Even in federal countries, where some aspects of science policy have been handled at regional level, change is afoot. Regions and cities in England and elsewhere are increasingly devoting attention to how science and technology can be harnessed for economic and social gain. This might involve redirecting resources to the science base, creating new science policy institutions or seeking to attract or retain academic and specialised talent.

In recent years, European governments, such as that of the UK, have sought to devolve some types of decision-making towards citizens – for example through the creation of regional assemblies in England and national administrations in Scotland and Wales. At the same time, science policy has been pulled in the opposite direction, through the development of European-level initiatives on science and technology.

This international level of science policy has taken the form of the European Research Area (ERA), which was created to improve the conditions for research in Europe, combining an area of free movement of knowledge, researchers and technology, better co-ordination of national research activities and policies and the development of a European research policy. The ERA initiative aims to increase national expenditure on R&D by 2010 as a means to improve competition with the US and Japan and to co-ordinate between member states' science and research policies.

This spatial dimension to science policy creates further tensions and dynamics that are explored in the light of research within this theme.

Theme 2: The Changing Role of Universities and Academics

The second theme highlighted here examines the consequences of recent changes within science and science policy such as those just outlined, and also the greater economic and social expectations that are being placed on science. The analysis dwells particularly on the consequences of these changes for scientific personnel and R&D institutions.

For example, while science has traditionally been a highly mobile and international career, Professor David Wield and colleagues' research into scientific personnel returning to India has found that a range of factors influences the mobility of scientifically trained people and their decisions to return home. In another international study, Mathias Ramirez has examined the case of highly innovative ICT firms in China and their relationships with universities.

There are also elements of inequality of opportunity and involvement in science, engineering and technology. Research by Professor Pooran Wynarcyk reported here indicates that women and people from ethnic minorities participate less in science, engineering and technology than average – how can this be explained and what measures might there be to address it?

More broadly, how can scientists develop both the breadth and depth of skills required for the knowledge economy? As Professor Alice Lam asks in her research reported here, do organisations and institutions actively foment, recognise and reward skills that straddle the scientific and business environment and the individuals who specialise in building links and networks at the frontiers, rather than at the core of the organisation?

International Science and Science in the Regions: The Spatial Dimension

Decades of UK regional policy under both Conservative and Labour governments have done little to reverse persistent imbalances in regional economic development. In the UK, cities and city-regions outside London have a key role to play in driving regional and national development. Players at many levels are now pinning their hopes on science, technology and innovation as a new remedy for an old ailment (Perry 2006).

Science policy has a spatial bias that has traditionally been largely ignored in national policy. This results from favouring existing excellence via a concentration of research funds in traditional centres of research. In the UK, this concentration is largely in the South East of England (Charles and Benneworth 2001).

For its part, the European Research Area Strategy emphasises the importance of clustering and the concentration of scientific expertise in Centres of Excellence as the basis for competitiveness. This emphasis can clash directly with other policy goals aimed at using investments in science to help regenerate poorer areas and bring about greater equality of opportunity across Europe (Ackers 2005).

The success of science-based economic development will require changes in regional governance (Cooke and Piccaluga 2006) and in the role of universities and the ways they produce knowledge. In federal countries such as the US, Canada, Germany and Australia a number of linked policy areas have long been governed jointly: science and innovation policy, economic development and higher education funding and regulation. This joint governance leads to complex inter-governmental negotiation and bargaining, overlapping competencies and the potential exploitation of ambiguities for national or local advantage. In previously centralised countries, the governance of science policy is also highly contested in the context of debates over political devolution, economic growth and competitiveness (Perry and May 2007).

This multi-level perspective again raises the possibility of tensions between concentration and distribution of resources, between competition and equality. Indeed, given that the principles of equality between states may also be constitutionally enshrined, such as in Germany, tensions are perhaps even more likely to emerge. National and regional frameworks for action and inter-governmental relations can both constrain and enable efforts to build science regions and cities, as do entrenched policy discourses, values and views on science, economic development, space and scale (Perry 2006). There can be no one-size-fits-all solution; context matters.

"Science policy has a spatial bias that has traditionally been largely ignored in national policy"

Research reported here, and also research under the Programme's theme of *Science in governance and the governance of science*, reported in another brochure in this series, has examined fundamental questions relating to the issues of participation, representation and interests in science and science policy. In this section of *Science in the economy and the economics of science*, we focus specifically on the regional economic dimensions: how regional needs (economic, social and scientific) relate to science and technology, calling into question the authority of those who traditionally speak on behalf of science.

Scientific development raises questions not only about the distribution of physical resources but critically also about the spatial dimension – where the skilled people end up. Scientific mobility plays a significant role in matching scientific infrastructure with optimal human capital in order to maximise productivity.

In March 2000, the Lisbon European Council established the strategic goal of the European Union "becoming the most competitive and dynamic knowledge-based economy in the world capable of sustainable economic growth". The increasing emphasis on the development of the 'knowledge economy' focuses attention on the role of international mobility as the basis for the optimal generation and transfer of knowledge and scientific expertise. The development of the European Research Area (ERA) lies at the heart of the European Commission's strategy to achieve the Lisbon objectives.

The Communication *Towards a European Research Area* speaks of the need to develop "essential critical mass in the major areas of progress in knowledge, in particular to achieve economies of scale, to allocate resources better overall, and to reduce negative externalities due to insufficient mobility" (European Commission 2001). In another document, the Commission alludes directly to the imperative of encouraging labour mobility in response to, "skills mismatches [which] are often a major cause of imbalances in the supply and demand for labour across sectors and regions" (European Commission 2002). Mobility plays a critical role in the ERA strategy in:

- raising the scientific excellence of *individual researchers* and furthering the creation of internationally renowned centres of excellence attractive to researchers from all over the world

- improving the quantity and quality of research training, by offering the best available opportunities *regardless of where this expertise is situated* (European Commission 2001).

Recognition of the potential tension between the desire to promote scientific specialisation (and its corollary circulation) and concerns to ensure balanced growth have begun to surface on the political agenda. The report expresses concern at "the insufficient link between policies promoting balanced regional development and policies promoting geographic and occupational mobility". The ERA strategy explicitly acknowledges the need to protect new Member States from the negative consequences of "increased competition for highly qualified researchers" and concludes that, "special attention should be paid to prevent new forms of brain drain from countries with less developed research capacity".

Two linked pieces of research within the Science in Society Programme – the first a pilot project – investigated these tensions and the relationship between highly skilled, scientific migration and the transfer of knowledge within the European Union. The pilot study focussed on Italian scientific mobility and the follow-up study addressed the movement of scientists between two 'receiving' locations (the UK and Germany) and two 'sending' locations (Bulgaria and Poland)[1].

Project: Scientific Mobility: Flows Between Italy and the UK

Every year, Italy exports 30,000 scholars and scientists and imports only about 3,000. Resources at a regional level within countries such as Italy are being invested in the training of scholars yet these people are not being retained in the regional system.

The Italian academic infrastructure has a strong – and largely negative – influence in determining whether Italian scientists decide to return. In cases where scholars did decide to return, the research found that the management of universities and other scientific institutions creates a range of problems in re-integrating these scholars (Gill 2005).

Cases of nepotism, corruption and bureaucracy in the academic system have made the structure inefficient and impenetrable. The recruitment system is not transparent, and there is an almost feudal structure in many research groups, such that one senior academic can dominate decision-making. For these reasons, career progression, even for the best scientists, is often sluggish.

These problems add to the overall unattractive package offered to scholars who remain at home. Furthermore, a chronic lack of public and private investments means that the academic infrastructure offers little chance of growth, either regionally or individually.

[1] The second study was co-financed by the Anglo-German Foundation (project 1468).

A further set of barriers, the research found, result from the attitude of Italian politicians towards scientific research. The Italian government displays an ambiguous attitude towards science and is characterised by chronic discontinuity in its policies – making it difficult to plan and execute research programmes, which typically require several years of stable support (Morano Foadi 2005).

There is much that countries like Italy can do themselves to address these problems. Increasing the priority attached to scientific research, partly by increasing funding, is one obvious candidate. They could also introduce more transparent and merit-based approaches to recruitment and progression in order to both improve the working of the science system as a whole and encourage Italian scientists to return. These changes would also enable foreign nationals to penetrate the Italian system, thereby increasing internationalisation in a virtuous circle of investment and in-flow of skills.

Project

Scientific Mobility: Flows Between Italy and the UK

Professor Louise Ackers, University of Liverpool

The desire to create centres of excellence clashes with other aims of science policy – such as that of developing capabilities in less well-favoured regions. This research looked at the UK and Italy; Italy is a key donor of scientific expertise and workers, whereas the UK can be seen as a key recipient.

The research was based on the observation that a political focus in the UK on brain drain to the US ignores the fact that the UK is a recipient of scientists from other countries.

The research asks:

- How does the phenomenon of Italian researchers moving to and working in the UK affect each country?
- What is the relationship between scientific mobility and knowledge transfer?

http://www.sci-soc.net/SciSoc/Projects/Economics/Mobility+and+excellence+in+scientific+labour+markets.htm

Project: Moving People and Knowledge

Mobility increases individuals' exposure to new skills, ideas and ways of working and, as such, forms a critical means of facilitating the transfer of knowledge. There is a significant 'expectation of mobility' within science, and international experience is often important to career progression in scientific research. For this reason, scientists are sometimes argued to be knowledge migrants rather than economic migrants.

However, this characterisation can be misleading as, particularly in the context of countries like Bulgaria and Poland, scientists are generally more pushed than pulled. To the extent that selectivity exists it is as much about the willingness of individuals to tolerate repeated moves and uncertainty than innate human capital or ability.

In practical terms this manifests itself in the pulling-power of resource-rich centres of excellence, which contain both the know-how and, critically, the know-who that enhance scientific productivity and individual career progression. Some scientists develop a conscious strategy for building up their human and social capital through mobility in order to increase their scientific productivity and long-term employability security.

Mobility is rarely, if ever, the result of a single decision but rather an on-going response to a wide range of shifting stimuli. Some are simply not able to practise as a scientist in their home country and are forced to work in another sector, becoming de-skilled in the process. Mobility is often seen as the only way to access the physical resources needed for research or to achieve a wage that will sustain an adequate basic living standard. However, although many do make planned decisions, it is important to recognise that serendipity and chance also influence moves and careers (Guth 2007).

The research supported the idea that there is an increase in the level of short-term scientific mobility both prior to longer mobility episodes and following returns. Most respondents who had returned to their home country were achieving a work-life balance and sustaining their scientific productivity through repeated short stays abroad. Even the most apparently settled respondents in host countries often spent repeated short stays in their home country. The fact that such circulation is taking place indicates a strong potential for return and associated knowledge transfer should the conditions exist to support the effective re-integration and retention of scientists.

"Networks play significant roles in scientific mobility"

The findings emphasise the impact that relationships and obligations have on migration behaviour. Personal relationships both generate resistance to the pull of economic considerations and, in other contexts, lubricate mobility. Although single young people tend to be more mobile, most of the respondents in this research had a partner even at an early career stage. The majority of these couples will both be pursuing careers, often both in scientific research (Ackers 2004, Ackers and Stalford 2007).

Networks play significant roles in scientific mobility. Connections with fellow nationals whilst abroad can bring benefits when settling and in personal lives. However, networks based on scientific, rather than national ties are perceived as both more legitimate and effective. Connections with scientists at home play a critical role in shaping migration, reverse knowledge transfer and the propensity to return. Without established and carefully nurtured anchors with scientists in the sending regions, academic labour markets can become more or less impenetrable to potential returnees.

Seniority also has an influence. Connections through supervisors and mentors are particularly influential. Although losses of more senior and established scientists, on the face of it, might be predicted to have a more serious impact, the potential for reverse knowledge transfer in such cases is much higher. Early career scientists generally have fewer or less effective networks so their migration may imply a more permanent, unilateral loss of expertise.

Continuing outflows of scientists are a *symptom* of the decline of science in countries like Italy, Poland and Bulgaria not the sole *cause* of the problems. The research suggests various ways to improve reverse circulation. Increasing the funding for expatriate scientists to spend time in their home countries on research visits and conferences – and for scientists in countries with underdeveloped scientific bases to travel – would improve opportunities for networking and knowledge transfer without significant increases in investment.

Research raises serious concerns about the attractiveness of research careers in receiving countries. The continued ability to recruit high-quality, experienced, researchers from abroad reduces the urgency to respond to these fundamental concerns threatening the sustainability of science. Where reliance on international recruitment reaches the levels seen in the UK, it is important to begin to plan more strategically for a sustainable workforce (Hatakenaka 2004).

Project

Moving People and Knowledge

Professor Louise Ackers, University of Liverpool

The MOBEX projects examined the relationship between highly skilled, scientific migration and the transfer of knowledge within the European Union.

The research asked:

- Who is moving (what are the characteristics of migrants)?
- Why are they moving (what motivates and shapes mobility)?
- How are they moving (how long are they staying; how frequently are they moving; are they returning)?
- What relationship exists between these forms of human mobility and the distribution of scientific knowledge and expertise (can highly skilled mobility generate forms of disembodied knowledge transfer)?
- What would happen if they did not move (would scientists continue to work productively in scientific research in the sending countries and would receiving countries suffer as a result)?

http://www.sci-soc.net/SciSoc/Projects/Economics/The+Impact+of+enlargement+on+scientific+labour+markets.htm

However, recent evidence suggests that in certain countries, the brain drain is now reversing or has at least been changing into what might be termed brain circulation, as talented engineers or scientists who have studied or worked abroad return to their home countries to pursue promising opportunities.

In particular, there is evidence to suggest that mobility of foreign-educated experts or scientists has played a crucial role in the development of capabilities in South Korean and Taiwanese firms. In these countries, talented immigrants who have studied and worked in the US increasingly reversed the brain drain, which proved critical in shifting these countries from a peripheral source of cheap labour to a global leader in IT production. In extensive analysis of the *Asian miracle*, the World Bank emphasises that return of foreign-educated nationals has provided significant transfer of best practices and state of the art knowledge to South Korean and Taiwanese semi-conductor firms (World Bank 1993).

A team at the Open University has examined this international migration of labour, focusing on the example of the Indian pharmaceuticals and IT sectors. They found that the brain circulation trend is now a significant force among Indian scientists in these sectors. Here, the emergence of industrial success stories, such as the IT and pharmaceutical industries, has changed the perceptions of the Indian scientific diaspora towards India and has resulted in the gradual movement of non-resident Indians back home. According to the Nasscom report, nearly 35,000 IT professionals (a little under ten per cent of the total Indian IT workforce in the US) have returned since 2001 (Nasscom 2003).

Project: Diffusion of Knowledge Through Migration of Scientific Labour in India

Research by Professor David Wield and colleagues looked at Indian pharmaceutical firms and their realisation that reversing the brain drain and bringing in scientists is not enough to assure that they make productive and profitable contributions to the firm; the knowledge, skills and experience that these scientists bring back must also be assimilated and made useful. This involves complex challenges, such as how to insert senior scientists into established routines, and the role of return incentives and their impact on other employees. These issues shape and affect the relationship between newly hired experts and firms, and in most cases influence the outcome of such partnership. The study showed that factors specific to the industry sector, along with personal and cultural motives, are shaping the industry's evolution.

Return migration is happening at two levels, both the senior scientist and post-doctorate level. This two-level migration has implications for firm strategy as each group has different requirements and expectations from firms. The research shows that cultural and career considerations impact variably on the migration decisions of these two groups of scientists. At the post-doctorate level, a scientist is mainly concerned about learning new skills and finds it comparatively easy to become assimilated into a firm. A move back to India tends to offer these younger people opportunities in middle management, whereas such opportunities were virtually non-existent in the US.

At the senior scientist level, concerns were focussed on the long-term future of the firm and the role a scientist can play in creating that future. This group places much more value on good social infrastructure, suggesting an important role for government policy in providing and establishing adequate physical and social infrastructure.

In the software industry, people can work remotely and management can be more hands off. People can work by travelling between India and the US. Many Indians working in Silicon Valley contributed to the growth and knowledge of the Indian software industry by setting up units in India whilst working in the US. They were based in the US but could utilise Indian skill sets and thus contribute towards the development of Indian industry.

This is not really possible in the case of pharmaceutical R&D. Drug discovery requires scientists to work in laboratories and to integrate different knowledge bases through intensive interaction between biology and chemistry. This limits hands-off approaches, so the nature of the technology and work requires relocation.

Another dimension of the findings is that many Indian firms are still new to innovative pharmaceutical R&D. Thus they require scientists who have knowledge in all pharmaceutical R&D areas whereas returning scientists are mainly specialists. Thus a mismatch between the requirements of firms and scientists' skills has emerged as a major issue in effective diffusion of knowledge in Indian firms.

Diffusion of Knowledge Through Migration of Scientific Labour in India

Professor David Wield, Open University

The main objectives of the research were to explore relationships between human mobility and diffusion of knowledge in firms from developing countries. The study also identified key issues and policies that facilitated or restricted knowledge diffusion within scientific research through human mobility. Furthermore, it aimed to describe and understand implications of issues related to management policies in facilitating or restricting the migration of scientific labour.

The research found:

- Scientists at each end of the career spectrum are returning to India to work. This generational difference presents different challenges and tensions between the skills obtained outside and the perceived skill needs inside Indian firms.

- Differences in working culture in the Indian firms and western firms have emerged as an important issue in effective diffusion of knowledge specifically in the case of senior scientists returning to work in India.

http://www.sci-soc.net/SciSoc/Projects/Economics/Diffusion+of+knowledge+through+migration+of+scientific+labour+in+India.htm

Regions and cities are now looking to science, technology and innovation (STI) to transform sub-national identities and fortunes inspired by, for example, Cambridge-MIT and Silicon Valley (Hodson and Marvin 2006).

Since 2001, all English regional development agencies have established Science and Industry Councils and have spent up to 15 per cent of annual budgets on STI. Bristol, Birmingham, Nottingham, Newcastle, York and Manchester were designated as 'Science Cities' by the government in 2005.

The aspirations for these initiatives go far beyond marketing and spin. They are underpinned by a real desire for economic, and to a lesser extent, social development. The Science Cities are held to be at the vanguard of the campaign to make science and technology the engine of economic growth in the UK. The reasons for this are compelling.

First, innovation has been identified as one of the key drivers of productivity (HM Treasury 2004). In a global knowledge-based economy, the UK can no longer compete on the basis of land or labour, but rather through its skills, creativity and innovation. The vision is of internationally excellent science leading to new innovations that are then transferred into industry to improve global competitiveness.

Second, delivering this agenda requires local work. Knowledge transfer between universities, industry and governments needs both international networking and local connections.

"Science was appropriated for economic and political reasons by multiple actors at national and regional levels"

Spaces and places matter in building an innovative environment, in which knowledge can be produced, transferred and used.

Third, decades of regional policy have done little to reverse persistent imbalances in regional economic development. Cities and city-regions outside of London have a key role to play in driving regional and national development. Hopes are now pinned on science and technology as a new remedy for an old ailment.

Within this context, the decision to locate the next-generation Synchrotron in the south of England rather than on the existing site in the north west provided a good case study of the tensions between the international, national and regional expectations being placed on investments in science.

Project: Making Science History: The Regionalisation of Science Policy?

In March 2000 the UK Government decided to locate the next generation 'Diamond' Synchrotron Radiation Source (SRS) at the Rutherford Appleton Laboratory (RAL) in Didcot, Oxfordshire, instead of at the home of the existing SRS at the Daresbury Laboratory in the north west of England. The announcement was decried as devastating for the scientific capacity of the north west, in both the public and private sectors.

Many involved saw the decision as emblematic of the tension between a science policy oriented around national priorities and new regional policies aimed at decreasing regional disparities and promoting economic development in the English regions.

The potential significance of the Diamond decision was two-fold. For the first time, national science policy was seemingly challenged by demands for a regionalised science policy by the English regions, while developments in the region's science base since the Diamond decision were hailed as making science history (NWDA 2001). This research provided the first independent analysis of the implications of the Diamond decision in re-shaping national and developing regional science policies in the English context.

The Diamond debate was popularly portrayed as international excellence challenged by regional needs. On the one hand, the Government claimed that greater scientific synergies were available through co-location at RAL. On the other hand, an angry north west coalition stressed the prime importance of the Daresbury Laboratory to the regional economy and nascent innovation system. The research found both claims to be flawed. Science was appropriated for economic and political reasons by multiple actors at national and regional levels.

The link between science and economic development meant that the siting decision had no clear national ownership. The positions of the Ministers for science and economics were particularly ambiguous, with their respective and seemingly contradictory public sector agreement targets on scientific excellence and regional disparities. Ministers' views were inconsistent, leading to false hopes, opaque decision-making, disaggregated interests and fragmented policy. The eventual siting of Diamond cannot be understood as a scientific decision made according to allegedly universal standards of international excellence. The decision set a precedent that criteria for funding science cannot be divorced from the wider objectives of government.

The Diamond debate was catalytic in opening up gaps in national state control over science policy and sowing the seeds for a *minimal* system of multi-level governance in science policy in England (Perry 2007). Centralised control has been undermined by sub-national actors who have mobilised their own resources to exploit cracks in policy processes. In 2001 the North West Science Council was established to advise the regional development agency on science-related matters. Regional Science and Industry Councils now exist in all of the English regions. Similarly, the north west was the first to introduce a regional science strategy to better link science and wealth creation, a trend mirrored in the English regions. Limited influence can be exerted over national policy through substantial sub-national mobilisation, representation and institutional creation, and complementary policy functions have emerged.

Yet such changes represent the *potential* for re-shaping science policy from below, rather than the *reality* of what occurs in practice. The challenge to national science policy initially mounted in the north west has not led to a re-orientation of capacities or devolution to the English regions. Mobilisation and influence have increased without genuine empowerment; indeed sub-national actors have been largely co-opted into support of a nationally driven paradigm for science and wealth creation. No real arenas exist for the co-production or negotiation of policy, with tiers of governance largely parallel rather than strategically joined-up. National reactions to the involvement of regional development agencies in science policy have been hesitant and reluctant; patterns of interaction are varied across the English regions and responses are ad hoc.

For the English regions, such an analysis may seem bleak. However, the terrain is inherently shifting. The permeability and porosity of boundaries leaves the possibility of change open. Efforts to aggregate interests and to join thinking up across regions, such as in the Northern Way initiative, can only increase the persuasive influence of the English regions and cities. As they are taken more seriously as having not only wealth to offer, but knowledge and expertise, the possibility for re-shaping science policy from within policy processes increases.

Project

Making Science History: The Regionalisation of Science Policy?

Professor Simon Marvin, Professor Tim May and Ms Beth Perry, Centre for Sustainable Urban and Regional Futures (SURF), University of Salford

The aim of this project was to understand the nature of the interaction between existing scientific practice and regional needs through a case study of contemporary developments in the science base of the north west of England.

The research:

- assessed the changing power relations between competing levels of governance in re-shaping national and developing regional science policy
- analysed the process through which different actors were mobilised, involved and engaged in the design and implementation of regional science policy
- explored the implications of regional needs in terms of the content and outcome of science policy.

http://www.sci-soc.net/SciSoc/Projects/Economics/Making+science+history.htm

http://www.surf.salford.ac.uk/BuildingScienceRegions/BSR_FirstPhaseProject.htm

A focus on the relevance of science and technology to particular local and regional problems has traditionally been held as contradictory to the aims of world-class excellence in science. There is a dominant view that funding science according to any criteria other than excellence will result in a slippery slope to mediocrity. This tension between local relevance and international excellence is another example of an emerging tension within science policy, this time with a regional, spatial dimension.

As Beth Perry and colleagues found in the research reported next, the growth of a regional dimension to science policy has led to fears of second-rate science and a backlash from the scientific establishment. Excellence is becoming a game in its own right, with universities and policymakers alike apparently forming a consensus that what matters in science is a university's position in international league tables (as measured mainly by publications output, but also sometimes by teaching quality or funds raised). Other powerful symbols of excellence include new emblematic science investments such as new laboratories.

The role of universities is key here. Since measures of excellence are often so closely tied to academic publication, and this process of publishing is a largely international or national affair, a university's excellence may have little or no connection with the social and economic needs in its local area. Universities may be *in* but not *of* their localities. In this context, if teaching and research are the first two missions of universities, the third mission of producing benefits for the economy, policy and the quality of life – particularly locally – can easily become the last choice for those universities outside the upper echelons of the global hierarchy. While top universities may command the resources to be able to invest in some third mission activities, others mainly find themselves in a struggle to conform to the narrow measures of excellence that hold so much power (Perry and May 2006).

"The dynamics of the global knowledge economy are filtered through diverse national and regional systems"

Project: Building Science Regions in the European Research Area

This research developed a comparative analysis of approaches for building science regions in different national and regional contexts: north west and north east of England, Alsace (France), North Rhine Westphalia (Germany) and Catalonia (Spain).

The debate on science and regions is international in nature. The dynamics of the global knowledge economy are filtered through diverse national and regional systems and the regional debate is unfolding in different ways in different countries. A common trend towards the multi-level governance of science policy can be seen. Rather than positioning the replacement of the nation state by sub-national actors, a more subtle, fluid and ambiguous picture of inter-governmental relations is suggested.

In all cases an increasing passive or active regional dimension is evident. In one view, regions may be seen as stages for or implementers of national policy, within centrally defined frameworks. Alternatively, they may be partners in the joint construction of new frameworks for action at different scales. They can also be independent policymakers, developing new policy tools and interventions or setting up new institutions. This is more common in countries with less well-established structures for regional governance, such as England. Yet multi-level governance is more appropriate for *certain* regions, rather than *all* regions.

Context matters: a diversity of factors – political, institutional, historical, geographical and cultural – influence attempts to build science regions. The case studies demonstrated the differential position of regions to engage with the 'new' science paradigm linking knowledge to wealth creation. The capacity of regional actors in the north east and north west of England to achieve their aspirations lags behind those elsewhere, such as in Catalonia where full regional competencies over higher education, science and innovation policy afford greater potential to meet European and global ambitions.

At the same time, there is no automatic correlation between officially devolved responsibilities and regional action. The Regional Council in Alsace has clear responsibilities for economic development, of which science is a part, yet there have so far been insurmountable difficulties in establishing a regional science and industry council or expressing priorities for science. The non-elected English regional development agencies are doing as much, if not more, than their central European counterparts.

Yet we also see a similarity in approach: regional interventions in science policy are best understood as physical, symbolic or additive – with transformation expected to occur automatically as a result. Science is largely conceived as an asset, an emblem or a magnet and assumed to have benefits for regional and local economies without due consideration of how these effects will be realised. The emphasis on university mergers, such as Manchester-UMIST, the European University of Strasbourg or Duisberg-Essen, are emblematic in this respect.

Regions are becoming more involved than ever before in science policy, devoting significant proportions of their own resources towards the funding of the science base, in the expectation that this will lead to economic development. Yet this is accompanied by a disconnection between efforts to direct and steer research within policies aimed at bringing about clusters of excellence, and the orientation of the science base towards international competition. There is a gap between policy aspirations and the realities of implementation.

The growth of a more active regionalism in science policy – aimed at resource distribution and regional development – introduces new tensions into policy processes. These tensions are mitigated to a greater or lesser extent in different national systems relating to forms of capitalism as much as historical factors. Thus, regional disparities are seen as anathema to the principles underpinning forms of social democracy in the French and German states, with new forms of state intervention emerging precisely to balance the tension between competition and equality.

In these cases, regional imbalance or tensions between national and regional actors are seen as problems to be managed out, as potentially avoidable through better co-ordination and joined-up thinking. This contrasts with a more neo-liberal approach in the English case, where concentration and increasing inequality are seen as both unavoidable and an acceptable price to pay for competitiveness and flexibility as pre-conditions for global success.

A certain homogenising logic to the dictates of the global knowledge economy is apparent. A continued trend to the concentration of resources can be seen in which only certain regions can succeed in the global race to become science regions. Indeed, it is not certain that the regions have been the beneficiaries of these shifts in governance, both in terms of the emergence of new territorial configurations and multi-scalar alliances and the effects on policy outcomes.

Project

Building Science Regions in the European Research Area

Ms Beth Perry, Professor Tim May and Professor David Charles, Centre for Sustainable Urban and Regional Futures, University of Salford

This project aimed to develop a comparative analysis of different approaches for building science regions in the European Research Area in order to understand the dynamic interaction between forms of governance, economic development and scientific practices.

The objectives related to three deficits in our current knowledge:

- There is a gap in our understanding of the dynamics and drivers of shifts in the governance of science policy.
- A better understanding of approaches to building science regions in different national contexts is needed.
- Effective public policy interventions, at different levels of scale, require better articulation of the assumptions upon which interventions are currently based.

http://www.sci-soc.net/SciSoc/Projects/Economics/Building+science+regions+in+the+ERA.htm

http://www.surf.salford.ac.uk/BuildingScienceRegions/home.htm

The Changing Role of Universities and Academics

The role of universities and academics is widely seen to be changing. With governments and other players investing significant sums in research and tertiary education, this brings great implications for the redesign of research and development institutions. Universities, often argued by scientists themselves to be institutions that should primarily be aimed at hosting free enquiry and the pursuit of knowledge, or spaces of reflection, have increasingly been looked to as some of the main sources of innovation and inputs into wealth creation – they are now 'places of expectation'.

Universities are essential to delivering the regional agenda (Charles 2006). The key here is to better understand universities and the challenges they face. They have frequently been dubbed the knowledge factories of the new millennium and are expected to deliver on 'third mission' objectives, in addition to the traditional areas of research and teaching (Harding et al. 2007).

Yet universities have multiple allegiances: to their students, the international reputation of their staff and/or the pursuit of knowledge. Not all universities are the same, nor are they monolithic organisations that are naturally oriented to single goals. The challenge, then, is to recognise the strengths and limitations of the university as an actor in local and regional growth coalitions. The university has a duty towards society, but this is served as much through providing a place for the unrushed and objective pursuit of curiosity-driven knowledge in the super-speed world, as through meeting performance targets and counting licensing and patents.

There is a 'missing middle' in current expectations for science, technology and innovation: that is, the capacity of different institutions to deliver. Many investments are being thrown at science, innovation or knowledge transfer activities in the absence of a clear evidence base. This has left a vacuum that has been temporarily populated by unjustified assumptions.

People are one of the key ingredients to success in science. Yet when we look closely, there are many varied and sometimes mundane influences on the ability and motivation of people to participate in science. Policies that seem completely unrelated to science – such as European enlargement, for example – can dramatically affect the ability of scientists to move between countries and work together. Careers and labour markets can significantly influence the nature of the relationship between science and industrial innovation. Similarly, gender and ethnicity seem to have a considerable influence on people's ability to take part in science.

"The majority engaged in industrial ventures to obtain funding and other knowledge resources to support and expand their scientific research"

As a result of these developments, the roles of academics, universities and other scientific organisations are changing, challenging deeply held and institutionalised assumptions about their flexibility and mobility, about gender roles and about what these changes mean for universities as key sites of knowledge production. The relationships between universities, academics and decision-makers and organisations in other sectors are also shifting, not least because universities are becoming 'business-like' as they take on more students and as it becomes more expensive to attract and maintain world-class expertise and facilities. In this context, the experiences of those academics who span the worlds of the university and business provide useful evidence, as discussed next.

Project: Work Roles and Careers of Academic Scientists in University-Industry Collaboration

This research looked at the human resource connections between universities and industries. It examined how closer ties between the two sectors transformed the nature of work roles and professional orientations of university scientists in the UK. In particular, it looked at a growing category of academic scientists referred to as linked scientists. These people engage in the practices of both science and business, and develop knowledge networks and career patterns that straddle the two sectors.

University-industry links and the collaboration of scientists across the two sectors have long been shown to be problematic. This is particularly because of the difficulty of reconciling the divergent work norms and career interests of scientists with the needs of the two different kinds of institutions. The study aimed to explore how the development of linked scientists might offer a potential solution. It examined the entrepreneurial dynamics as well as the tensions inherent in the hybrid space that supports joint knowledge production between the two sectors.

The research sample consisted of academic scientists based at five universities. It covered biosciences, medicine, computer science, electrical engineering, mathematics and physics. Data were collected by 60 in-depth individual interviews and analysis of 730 on-line questionnaire surveys received (the survey was sent to 3,000 scientists, a response rate of 25 per cent).

The analysis identified a great deal of variation in scientists' attitudes towards closer university industry ties. The most complex responses were found among those in hybrid positions who combined the characteristics of both the old-school ivory-tower traditionalists and the new-school scientist-entrepreneurs. They comprised a significant proportion (43 per cent) of the responses. These people may experience work role tensions but, at the same time, provide crucial bridges between the old and the new.

These hybrids occupy an intermediate and somewhat ambiguous position between the two polar types at the opposite ends of the spectrum. This provides a free space for experimenting with new practices without undermining the established academic norms. Indeed, the study shows that many academic scientists embarked on new, entrepreneurial roles within a relatively stable value framework and academic identity. Further, those who displayed a stronger entrepreneurial orientation were more likely to believe that scientific values are resilient in the face of commercial gains. This suggests that the growth of an entrepreneurial academic paradigm is taking place alongside a strong continuity of the traditional academic ethos.

The engagement of the linked scientists in boundary-crossing knowledge networks provides a powerful mechanism for bridging the apparently contradictory cognitive frameworks and institutional logics of the two sectors. Many of them were able to use their scientific reputation and expertise to negotiate the blurred boundaries between science and business, and used old academic norms to legitimate *new* work practices. For example, the academics directly engaged in commercial and company formation activities stressed the scientific and public good benefits of their ventures such as testing new ideas, generating research resources, and social obligations.

The study shows that it is primarily career-related motives that drive academic scientists to build links with industry. The majority engaged in industrial ventures to obtain funding and other knowledge resources to support and expand their scientific research. Many of them would engage in industrial ventures only if they perceived a connection between these activities and scientific career rewards. Thus academics' perception of career and research-related rewards appears to be a critical factor in inducing entrepreneurial behaviour.

In contrast to the growing concern by some about the potential negative impact of closer business ties on academic research and the conflicts of commitment that might occur, this study shows that scientists generally perceived a positive impact of industrial links on their research and careers/reputation. Only a small minority felt that industrial links had harmed their research and academic careers. However, there was some evidence that scientists at smaller and less experienced institutions, and junior academics were more likely to experience negative impact. The analysis also shows that increased workload was a problem experienced by many, especially among those who engaged in commercial activities many of whom worked excessively long hours.

For the young researchers in temporary employment, joint projects between the two sectors can create opportunities for developing new competences and alternative career options. However, the difficulties in reconciling the different reward systems of the two sectors and the intermittent nature of industrial projects mean that the career paths for those engaged in hybrid roles could be fragile and uncertain. Young scientists are more likely to benefit from the traditional mode of collaborative projects than direct engagement in commercial activities.

The study shows an overall indifferent attitude among the scientists towards their universities' incentive policies on science-business links. Some criticisms were directed towards the technology transfer offices, which were seen as lacking the necessary competences, and creating a bureaucratic layer that could stifle bottom-up science-business networking activities.

An important message for policymakers is that institutions cannot easily engineer entrepreneurship. The university is a complex organisation with different departments and disciplines characterised by diverse attitudes and research orientations. Fostering entrepreneurship from the top may be less effective than working at the departmental level. More crucially, the research suggests that policies focusing on human capital formation, novel arrangements for dual appointments and appropriate design of career reward structures might be more effective means for promoting continuous knowledge flows between science and business than the conventional preoccupation with technology transfer and commercialisation.

Project

Work Roles and Careers of Academic Scientists in University-Industry Collaboration

Professor Alice Lam, School of Management, Royal Holloway University of London

This project examined the nature of work roles and careers of academic scientists in university-industry collaborative ventures.

It explored:

- The difficulty of reconciling the divergent work norms and career interests of scientists with the needs of the two different kinds of institutions.
- How hybrid work roles and careers shape the cognitive abilities and competencies of academic scientists who engage in industrial collaborative ventures.
- The motivations and incentives behind scientists' engagement in industrial links and how they reconcile the tensions and career risks inherent in hybrid work roles.
- The organisational frameworks that support co-operative behaviour, and examined whether joint projects and research centres influence the training of young scientists and their career expectations and prospects.

http://www.sci-soc.net/SciSoc/Projects/Economics/Work+roles+and+careers+of+academic+scientists+in+University-Industry+collaboration.htm

The expectations of universities and scientists are not only shifting in developed countries; great changes are also taking place in the less-industrialised countries. For example, China's notable economic development has been accompanied by the growth of a strong, internationally competitive information and communication technology sector, which was the focus of research in the Science in Society Programme. A recent survey (August 2004) by the All-China Federation of Industry and Commerce ranked Lenova, a PC manufacturer, as the country's number one privately managed company by sales revenue. This project focussed on the composition of labour market institutions for knowledge workers, including the mobility of knowledge between academic and business institutions and its influence on the ability of companies to innovate in the IT sector.

The research suggests that Chinese society is evolving quickly, leaving certain assumptions about China's economy and business open to question. Specifically, the umbilical link that was long assumed to exist between Universities and businesses appears no longer to be so strong. Furthermore, standard ideas about the differences between State and non-State owned enterprises do not reflect the hybrid nature of the Chinese economy. For example, many co-operative enterprises that drive the Chinese economy have minority State ownership of shares but autonomous management structures.

"Why might certain networking activities impact performance more than others?"

Project: Labour Markets and Knowledge Flows in the Chinese National System of Innovation

In the past 20 years, a number of Chinese information and communication technology (ICT) firms have developed into internationally competitive players. To reach this position, they have innovated new products that are competitive on the world market. This achievement is particularly significant since China remains poor in per-capita income terms, and other developing countries have failed to make similar breakthroughs.

This research looked at the basis for Chinese innovation in the ICT sector and how it compares to the Western (US/UK) model. What are the patterns of mobility between research organisations and firms in the Chinese labour market? Is innovation linked to state resources/institutions? How do the labour market institutions resemble the US/UK?

The investigation focussed on three principal aspects:

- The degree of 'openness' of labour markets in terms of mobility and the extent to which diverse careers and specialisation are rewarded in the Chinese labour market of high-technology employees.
- The networks and networking activities knowledge workers are engaged in and the role these play in learning and diffusing knowledge.
- University-industry relationships.

The research mainly involved interviews with managers and employees of research and development (R&D) departments located in the Zhonguanccun science park in Beijing, China's largest high-technology district.

Analysis of the surveys suggests that broadly defined external knowledge plays a key role as a source of new knowledge for firms. In particular, tacit knowledge through new recruits and conference participation were thought to be important. These results suggest that many of the institutional features that characterise the labour market for scientific and technical employees in the State-controlled planned economy era have given way to a highly fluid labour market. The labour market in China also differs significantly from its Japanese equivalent, which is defined by strong internal labour markets in the high-skilled sector.

To further investigate the nature of networks, three types of networking activities undertaken by knowledge workers were differentiated. These were characterised by differences in the governance of these networks and type of knowledge transfer. After controlling for various factors, it was found that only those networking activities undertaken by employees that avoided formal collaboration – what the research team termed 'searching and scanning' activity – attracted an earnings surplus for knowledge workers.

Similarly, searching and scanning was the only networking variable to make a positive impact on the performance of specific innovation projects that these people worked on. By contrast, two other forms of networking activity by employees had no significant impact on earnings or on performance of projects: those that involved formal collaboration between firms over R&D projects or the use, by R&D employees, of personal networks to gain useful knowledge.

Why might certain networking activities impact performance more than others? A resource-based approach would suggest that, while organisations will be reluctant to engage in detailed inter-firm collaboration to share their core competence, knowledge and awareness of the outside environment and the ability to understand and react to changes is essential for dynamic capabilities. Other possible explanations are that Chinese firms are not yet undertaking the type of complex innovation projects that forces them into inter-firm collaboration. Lack of flexibility in the HR system may also be impeding new incentives for R&D employees to develop more sophisticated networking skills.

The research also examined the links between universities and firms. In particular, the research asked whether the success of Chinese ICT firms is linked to their privileged access to academic institutions and the special networks created by employees and academics. Overall, universities and research institutes are seen as important institutions to be associated with, although this appears to be for reputational reasons rather than to support innovation projects directly.

No compelling evidence was found that the university is central to innovation activity. This may reflect the different stages the Chinese innovation system has gone through. Thus, while at an earlier stage in China's industrialisation, the establishment of large firms with technological capabilities was prioritised; today the development of managerial capability in firms is seen as paramount. By contrast, the Chinese State more recently appears to have discouraged universities from directly engaging in commercial activities that may compromise their position as provider of education and basic research, as opposed to applied research.

Project

Labour Markets and Knowledge Flows in the Chinese National System of Innovation

Matias Ramirez, Brunel Business School

This research examined the emergence of China as a producer of successful and competitive ICT companies, despite its relatively modest per-capita income. The research team studied ICT firms and looked more specifically at inter/intra firm mobility of knowledge workers, work organisation and the nature of teams, qualifications and labour market typology.

The research explored:

- the new labour market institutions that have emerged to mediate the knowledge flows of Chinese workers between research institutions and firms and between firms
- the nature of the networks that exist between State institutions and indigenous innovative corporations.

http://www.sci-soc.net/SciSoc/Projects/Economics/Labour+markets+and+knowledge+flows+in+the+Chinese+national+system+of+innovation.htm

Traditional gender differences in patterns of employment have continued to persist in the past two decades. Women are still less well represented than men in science, engineering and technology (SET), which for centuries have been regarded as a male career path. Women are more likely to be employed in the service related sectors such as health, social work, education and public administration. In the UK as a whole, women account for less than 25 per cent of the workforce in some SET related industry sectors compared to 80 per cent in health and social work, and 45 per cent for all sectors.

Concerns about the under-representation of women in SET have been raised and expressed by researchers, policymakers and practitioners since the 1970s, resulting in numerous policy initiatives, reports and consultations, particularly at the national level. However, even with the slight improvement in female participation in the scientific labour market in recent years, the number of women reaching high positions in science is still much lower in the UK compared to the USA and many other European countries, and only a small proportion of women eventually emerge to make successful careers in science.

This is the context for research by Professor Pooran Wynarczyk on the participation of women and those from ethnic minorities in science, engineering and technology (SET) sectors in the north east of England.

Project: The Impact of Gender Innovation on Regional Technology, Economy and Society

The problem of low participation in science and innovation among women and those from ethnic minorities appears to be particularly strong in the less favoured regions of the UK such as the north east. This is partly due to the low level of scientific activities such as research and development (R&D) in these regions, combined with their lower than average level of economic activity and a number of other social and economic failings (Wynarczyk 2006).

This research aimed to identify the social, economic and institutional factors in the workplace in the north east of England that inhibit participation by women in innovation activities in science, engineering and technology, as well as examples of good practice. The study aimed to:

- identify appropriate means of measuring innovation activities amongst men and women in order to address current gender disparities
- recommend policy measures to overcome both capability stereotypes and the economic vulnerability of women in the scientific labour market.

There are two commonly used measures of innovation: R&D and patenting. The Department of Trade and Industry's R&D Scoreboard provides a breakdown of annual R&D expenditure and employment of the UK by regions. Furthermore, the UK Patent Office publishes annual data on UK regional activities aimed at protecting intellectual property rights (IPRs – patents, designs and trade marks). However, at the present time there is no gender breakdown of R&D, patent and commercialisation of IPR (eg university spinouts) in the UK let alone at regional levels. Therefore, the degree to which women occupy positions directly connected to scientific activities and discoveries (eg invention, the innovation process, industrial R&D and patenting) is left largely to conjecture. So while we know the proportion of women in the SET sector as a whole, it is not easy to discern the specific contributions they are making.

To measure the innovation activities amongst men and women in the north east, this research created and used a number of original databases. First, a survey of 60 science-based small and medium sized enterprises in the north east shows that women are hugely under-represented in Industrial R&D. Women hold only around two per cent of all R&D jobs.

In another survey of over 100 SET employees in the public and private sectors, a high proportion of women (70 per cent) stated that they had experienced personal and professional barriers to entry and progression in science. These barriers varied in theme, but by far the most significant related to: caring for dependent children; work-life balance; the need to live in geographical proximity to their partner; lack of

"Women are just as capable and creative as men when it comes to new ideas and innovation"

support from teachers at school and mentors; lack of resources and funding; being female and institutional sexism; and male-dominated informal networks. Lack of awareness of initiatives is clearly also a major problem, despite the wide range of programmes targeted at women in SET. Furthermore, those who worked in chemical R&D raised concerns about health and safety issues relating to handling unsafe chemicals and working in unacceptable laboratory conditions in case "unknown chemicals harm unborn babies".

In terms of measuring innovation and invention activities amongst men and women in the north east, this research analysed about 150 applications made to the North East Spirit of Innovation Awards over the period 2003 to 2006. This was the only available source of data on innovation activities in the north east; of the applications, 42 were by women and 107 were by men. The results generally demonstrate that the gender imbalance *headline* captured in current statistics masks an excellent contribution to innovation and invention by selected individuals. The results of the analysis of the participants in the awards show that women are just as capable and creative as men when it comes to new ideas and innovation but that there is a shortage of successful female role models and general lack of confidence to encourage greater participation.

Policy recommendations include establishing a platform in the north east, under the Science City Initiative, upon which successful female scientists can act as role models and mentors, offering more support and training as part of the drive to encourage greater participation of women in innovation, and helping to remove the obstacles to their success.

Project

The Impact of Gender Innovation on Regional Technology, Economy and Society

Professor Pooran Wynarczyk, Small Enterprise Research Unit, Newcastle University

The study investigated, compared and contrasted the level and nature of scientific activities and discoveries of women and men (including those with ethnic minority backgrounds) engaged in the scientific labour market and their impact and contribution to economy and society.

The research generated new data and analysis of the influence of gender and ethnic identity on participation in science, engineering and technology in the North East of England.

http://www.sci-soc.net/SciSoc/Projects/Economics/The+impact+of+gender+innovation+on+regional+technology+economy+and+society.htm

http://www.ncl.ac.uk/seru

Conclusions

Science is a highly international activity, and those involved in science tend to be highly mobile during their careers, using both shorter and longer stays abroad to gain experience and to broaden their skills and networks. Such mobility poses great challenges to countries that do not yet have well-developed scientific infrastructures and career paths, as both younger and more experienced scientists can be attracted to centres of excellence elsewhere that have great scientific facilities and attractive working conditions and pay.

However, the impact of the brain drain can be overstated, especially when informed by an assumption that it is inevitably a one-way process. Evidence from India and elsewhere discussed here shows that the out-migration of highly trained people can be stemmed and even reversed; thousands are now returning to take up opportunities in their home countries. In addition, large numbers of others, while staying abroad, are collaborating with partners in their home country, transferring knowledge and skills and helping to set up new scientific initiatives and firms.

The research evidence again challenges the notion that there is a simple linear relationship between scientific capabilities and economic development. The existence of highly innovative information and communication technology companies in China confounds the idea that less industrialised countries are doomed always to play catch up, relying on importing technology, knowledge and skills from more developed countries. While, on the other hand, the cases of international migration of scientific personnel point to a highly complex situation in which technical capacity may well *follow* economic development rather than lead it.

Nevertheless, the brain drain phenomenon poses significant challenges for both sending and receiving countries. Those countries such as Italy, Poland and Bulgaria that experience a net out-migration of scientific personnel need to send clear signals at the political level that they are going to invest in science over the long-term. They also have the opportunity to modernise their scientific institutions, challenging outdated practices, and providing for rapid career progression for those who deserve it.

The large number of skilled people who benefit from both longer and shorter stays abroad demonstrates the potential for greater mobility and return. Mechanisms could be *"the impact of the brain drain can be overstated, especially when informed by an assumption that it is inevitably a one-way process"*

found at European and national level to support more sustainable forms of mobility. Encouraging shorter stays and research-related travel in both directions would increase the potential for knowledge transfer and co-operation. Ultimately however, the onus rests on the sending regions to increase the priority they attach to scientific research through increased funding. They also need to open up their labour markets to enable both their own expatriates and other foreign nationals to access positions.

Those countries that have been on the receiving end of scientific mobility also need to be careful that this good fortune does not mask the development of structural weaknesses. In particular, countries such as the UK have failed to attract British young people into science, relying instead on recruiting many from abroad. If, as seems likely, other countries start to invest more in science, they will inevitably attract back some of the talent that a country such as the UK benefits from currently. The UK has long been a trading nation and is used to coping with permeable borders – and would be likely to continue to benefit from the networks generated with returnees. However, despite recent investment, its levels of investment in science still lag behind some international competitors.

The work on scientific mobility highlights the existence of key policy tensions implicit in European science policy such as the European Research Area (ERA). Two features of European policy comply with the European Union commitment to individual equity and neo-liberal markets: the promotion of individual freedom to move, and merit-based recruitment. However, these features also raise questions about the viability of achieving balanced growth and regional equality.

Any policy intervention aimed at restricting scientific mobility in the name of pursuing balanced growth risks undermining one of the fundamental freedoms associated with European Citizenship –the freedom to move between Member States. This would restrict the career progression and effectiveness of scientists working in less resource-rich regions. On the other hand, conceptualising these flows as an inherently positive dimension of internal migration within the wider EU fails to acknowledge the genuine concerns of scientists in those Member States who train many young citizens – and then see them leave the country.

The role of the EU in creating and supporting free movement, but also its policies that provide support for scientific centres of excellence, imply some direct responsibility to ensuring their resolution. It would be ironic if the impact of the ERA were to provoke an internal brain drain and unbalanced growth. Action solely at national level is unlikely to prove efficient and effective in dealing with a problem such as this, which spills over national boundaries. Policymakers will therefore have to grapple with the tensions that inevitably arise from using neo-liberal frameworks and market-based policies at the same time as setting strong social goals around inequality and regional development.

Moving from the idea of scientific mobility to that of collaboration between scientists in universities and players in other sectors such as the private sector, there are continuing tensions around this widely held goal. Reward systems in these sectors are different, leading to great difficulties in reconciling people's incentives to become involved in collaborative, 'third mission' work – those aspects of work in universities that go beyond teaching and research, such as entrepreneurial activity but also consulting, policy advice and media comment.

In addition, the intermittent nature of collaborative projects, for example with industrial partners, often means that the career paths for those engaged in hybrid roles can be fragile and uncertain. Technology-transfer offices come in for some criticism among university scientists; they are thought to lack competences and to create a bureaucratic layer that can stifle the informal networking that is so often crucial for forming the relationships on which collaborations are based.

Evidence from research in both the UK and China raises doubts about the effectiveness of the conventional preoccupation with formal activities aimed at technology transfer and commercialisation. These may be less effective for promoting continuous knowledge flows between science and business than a range of other mechanisms. Some changes can be highly effective, especially those that seek to embed rewards for these activities within career structures, for instance through novel dual appointments. The Chinese research also supported the idea that informal networking is probably more effective than any other form of more formal collaboration. Institutions cannot easily engineer entrepreneurship.

At the outset of the Science in Society Programme, the research agenda covered a broad range of topics within the theme of the economics of science. Inevitably in a competition-led initiative that relied on bids from research teams, although the research did shed light on many topics such as those discussed here, the Programme's research did not manage to cover all of the topics under this theme. Many avenues remain unexplored and even those topics where research has been conducted hold great promise for further development.

In particular, little research was conducted on the economic structures and incentives that favour specific lines of scientific inquiry and technological innovation, adoption and diffusion. What are the different incentives at play to invest in research into pain-relieving drugs as compared to acupressure technology, for example? Another theme that merits further investigation is the character of relationships between scientific and technological expertise, productivity, economic development and competitiveness.

Another cluster of conclusions relates to the idea of excellence, where the research challenges us to think through this attractive but nebulous idea. Excellence at many levels in science – the individual researcher, the research

"Government attitudes towards regional and local science-based initiatives are not uniformly positive"

team, the research project, and the institution – is predominantly measured through publications output. Unfortunately, this often has little direct link with the wider value that our investments in science are producing for society – for decision-makers, wealth creation and for our quality of life. Yet where investments are made with the aim of supporting these goals, those making the investments have every right to impose and expect other criteria of excellence.

Quality in science is rated most highly through publication in international scientific journals. Yet science policymakers should recognise that there is no zero-sum game between international excellence and local relevance – more of one does not have to mean less of the other. Policy discourses are beginning to change. The Science and Innovation Investment Framework (HM Treasury 2004) emphasised the role of science and industry in reducing regional disparities and the need for joint working between Research Councils and regional development agencies to explore how national funding systems can be better aligned to regional economic strategies. It committed the government to tackling the tension between regional policy and the pursuit of excellence; again we see the tension between the different policy goals that are being played out through science policy.

Government now faces several critical challenges in this respect. To start with, it is widely accepted that allocating science funds according to regional criteria is undesirable. The search for excellence requires open competition to find the best and the brightest brains anywhere in Britain. Furthermore, evidence from federal Germany would indicate that regionalised funding of science and higher education does not necessarily lead to more spatially sensitive policies.

Yet additional effort does need to be invested in building capacity across regions to ensure a more balanced distribution of excellence. This requires a shift of emphasis within existing national funding structures, rather than a regionalisation of science policy. This is important in levelling the playing field, as well as safeguarding the diversity of the research base, which has provided so many unpredictable and exciting innovations.

Policymakers could also make greater efforts to create shared objectives between policies on science and innovation, higher education and regional development. Government attitudes towards regional and local science-based initiatives are not uniformly positive. This is partly based on scepticism of what might be achieved and doubt as to whether regional investment in science is the best way to spend scarce resources for economic development. Yet without cross-departmental thinking on how science funding structures, university policy, the devolution agenda and regional economic development initiatives can be knitted together to create the capacity to deliver, the potential to build science regions and cities will be limited.

This relates to the finding that science policy is being governed by a more diverse set of actors than in previous decades, an idea developed in greater detail in the brochure on *Science in governance and the governance of science* in this series. Many organisations are now involved in trying to steer and harness science – the governance of science is no longer a centralised affair. This brings with it a number of significant tensions around the competing aims and agendas of those involved, and again can undermine any sense of a joined-up science policy.

In this emerging situation, organisations in the regions of England that have become involved in science policy have largely found themselves co-opted within the existing national strategy for science and wealth creation, leaving only limited possibilities to express and develop their own regional visions for how science might contribute. There are no well-developed arenas or mechanisms for national and regional players to develop science policy jointly, and national policymakers have been hesitant and reluctant to involve regional bodies. In such a minimal system of multi-level governance, the capacity of the English regions to truly develop science regions or cities is limited.

There is also a need to strike a balance between national co-ordination and regional diversity. The nature of international competition in science means that it is not possible for all regions to have world-class centres of excellence in genomics, nano- or bio-technology.

These suggestions, if implemented, would amount to a significant re-shaping of the governance of science policy. If the aims of national and regional policymakers for science-based economic growth are to be met, policymakers might do well to think about how the value attributed to science will be realised. There can be no one-size-fits-all solution. An open and transparent public debate about the value and purposes of science in society is a necessary part of this process of re-thinking and re-shaping.

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Research projects listed under topical themes

The Science in Society Programme is one of the ESRC's major investments and is a six year commitment running from 2002 to 2007. The Programme, originally conceived following a parliamentary report on science and technology, is both broad in scope and diverse in its research focus and has been host to 45 different research projects during its lifetime. The Programme is separated into six themes, each one acting as an umbrella for a variety of projects, all of which consider a different aspect of the science-society relationship.

Science in Governance and the Governance of Science

Social and Human Rights Impact Assessment and the Governance of Technology
Dr Andrew Barry, research undertaken at Goldsmiths College, London – now based at the University of Oxford
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Interdisciplinarity and Society: A Critical Comparative Study
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Using Public Environmental Knowledge in Industry
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Childhood Cancer Tissue Donations: A Gift Relationship?
Professor Mary Dixon-Woods, University of Leicester *md11@le.ac.uk*

Contesting Environmental Science: Business and Environmentalist NGOs
Dr Sally Eden, University of Hull *s.e.eden@hull.ac.uk*

Credibility Claims as Scientific Commodities
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Inside or Outside the Bio-science Tent? The Presentation of the Laboratory-self
Dr Lena Eriksson, research undertaken at Cardiff University – now at the University of York *le502@york.ac.uk*

Caught Between Science and Society: Foot and Mouth Disease
Dr Brigitte Nerlich, University of Nottingham *brigitte.nerlich@nottingham.ac.uk*

Public Perceptions of Risk, Science and Governance
Professor Nick Pidgeon, research undertaken at the University of East Anglia – now at Cardiff University *pidgeonn@cardiff.ac.uk*

Accountability and the Governance of Expertise: Anticipating Genetic Bioweapons
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Simulation Modelling of Contentious Scientific Knowledge Claims in Society
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Resolving Conflicts in Selecting a Programme of Fisheries Science Investigation
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Reproducing the Centre: Performing Innovation at Xerox PARC
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Governance and Accountability Relations in Mundane Techno-Scientific Solutions to Public Problems
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Re-modelling Science Communication

Deliberating the Environment: Scientists and the Socially Excluded in Dialogue
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Spinning Science: The Nanotech Industry and Financial News
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Public Involvement, Environment and Health: Evaluating GIS for Participation
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Communicating Science through Novel Exhibits and Exhibitions
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Experiments In Science Communication: A Pilot Study with a Digital TV Channel
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The New Zoos: Science, Media and Culture
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Consultation as Science Communication? The Case of Local Air Quality Management
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Divided we Stand: Bridging Differential Understanding of Environmental Risk
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What Does Social Change Mean in the Context of Engineering Education?
Dr Jane Pritchard, University of Glasgow *j.pritchard@udcf.gla.ac.uk*

Science in the Economy and the Economics of Science

Mobility and Excellence in Scientific Labour Markets: The Question of Balanced Growth
Professor Louise Ackers, University of Liverpool *lawhla@liverpool.ac.uk*

The Impact of Enlargement of Scientific Labour Markets
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Work Roles and Careers of Academic Scientists in University-Industry Collaboration
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Making Science History: The Regionalisation of Science Policy
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Building Science Regions in the ERA: Governance in the Territorial Agora
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Labour Markets and Knowledge Flows in the Chinese National System of Innovation
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Issues Involved in the Diffusion of Knowledge through Migration of Scientific Labour
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The Impact of Gender Innovation on Regional Technology, Economy and Society
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Science Technology and Globalisation

Institutional Impacts of North-South Partnerships in Agricultural Biotechnology
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Science, Technology and Water Scarcity: Investigating the 'Solutions'
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Childhood Vaccination: Science and Public Engagement in International Perspective
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The World Wide Web of Science: Emerging Global Sources of Expertise
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Databases, Naturalists and the Global Biodiversity Convention
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Science and Gender, Ethnicity and the Lifecycle

Boundary Work, Normal Ageing and Brain Pathology
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Public Perceptions of Gamete Donation in British South Asian Communities
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Gender Theories and Risk Perception: A Secondary Analysis
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Asbestos Diseases: Scientific Definitions and Gendered Identites
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Genomics and Society

Doing Embryo Ethics: Safety and Efficacy in Research and Practice
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Farmers' Understandings of Genetically Modified Crops within Local Communities
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Pharmacogenomics, Diagnostic Tests and Clinician Acceptance
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Science, Security and Regulation: How Effective are Export Controls?
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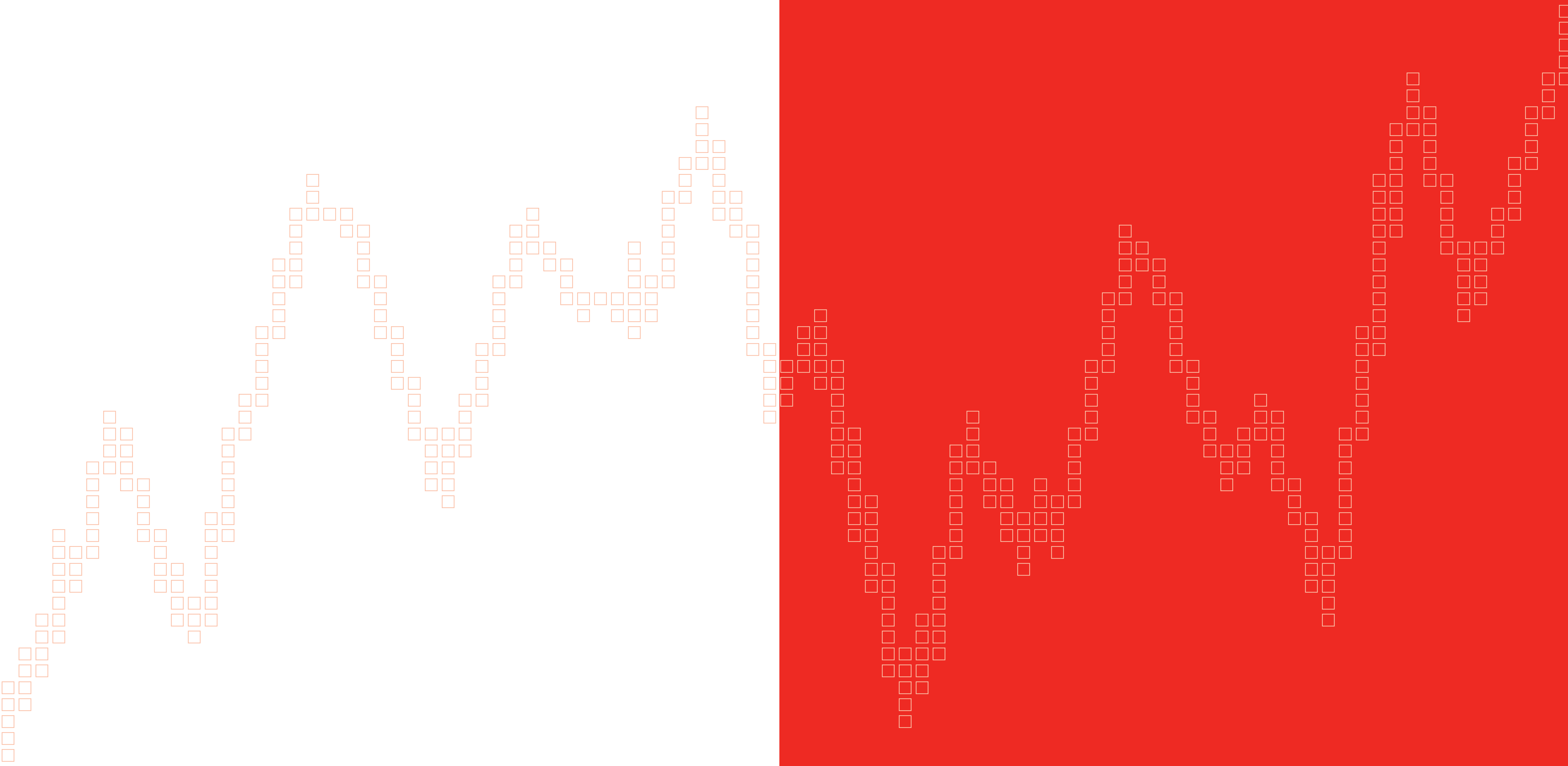

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