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ESRC Genomics Scenarios Project:

4. CRIC Report on Genomics and Social Science

A Project for the
Economic & Social Research Council



4. CRIC Report on Genomics and Social Science: Using the ESRC Thematic Priorities for Scoping the Genomics Scenarios Task

By the Centre for Research on Innovation and Competition
January 2002

Contents

Preamble	3
General Issues	4
Thematic Priority 1: Economic Performance	6
1.1 Genomic Industries and the GDP.....	7
1.2 The Geography of Economic Growth.....	8
1.3 Industrial Structure.....	8
1.4 Capital Markets	9
1.5 Risk Assessment.....	9
Thematic Priority 2: Environment and Human Behaviour	9
2.1 Human Role in Evolution.....	10
2.2 Eco-Sustainability.....	11
2.3 Environmental Protocols	11
2.4 Consumer Products	11
2.5 Agriculture.....	12
2.6 Environmental Risk	12
Thematic Priority 3: Governance and Citizenship	13
3.1 Geographical Scales of Governance.....	13
3.2 Globalisation	14
3.3. Personal Identity and Choice	14
3.4 Privacy	15
3.5 Public Understanding and Accountability	15
3.6 Military Utilisation	16
Thematic Priority 4: Knowledge, Communication and Learning.....	16
4.1 Popular Science & Its Communication	17
4.2 Multiple Perceptions of Risk.....	17
4.3 Learning and Memory	18
4.4 Ownership of Knowledge about Living Entities	18
4.5 Inter and Intra-Organizational Processes.....	18
4.6 “Redisciplining “ of Many Fields	19
Thematic Priority 5: Lifecourse, Lifestyles and Health	19
5.1 Ageing.....	20
5.2 Extended Longevity.....	20
5.3 Data Integration.....	20
5.4 Health Care.....	20
5.5 The Role of Food	21
5.6 Human Choice	21
Thematic Priority 6: Social Stability and Exclusion.....	21
6.1 Opportunities for New Interventions.....	22
6.2 DNA and Proteomic Based Discrimination.....	23

6.3 Enhanced Longevity and Paid Work	23
Thematic Priority 7: Work and Organisations	24
7.1 The Geographies of Knowledge and Resources.....	24
7.2 Business Models.....	24
7.3 Customer Focus and Firm Performance	25
7.4 Appropriate Levels of State Funding.....	25
7.5 Regulatory Approaches and Outcomes	26
7.6 New Industrial Society.....	26
7.7 Change in the Workplace and Workforce.....	26

Preamble

A huge range of social issues and research fields are related to developments in genomics, with greater or lesser degrees of intimacy. More connections are becoming apparent as genomics research and its applications continue to evolve. This range of issues does not just call for interaction between natural and social scientists: there is also need for the sharing of knowledge and perspectives across diverse fields of social science. In order to help inform future research priorities, we need to move beyond the perspectives of single disciplines, and make sure that we do not simply emphasise those areas where social scientists have already been actively engaged. A more comprehensive and multidisciplinary approach is proposed for this exercise.

Here we use the ESRC's **Thematic Priorities** as a framing device. These seven thematic priorities cover a broad spectrum of social research topics and issues, grouping them into a workable set of fields where knowledge is required. The themes are ones seen by the ESRC as particularly important for UK social research to continue to make progress. The scenario exercise can thus benefit from its conclusions being related to established lines of effort.

The current list of thematic priorities is:

- 1. Economic Performance and Development**
- 2. Environment and Human Behaviour**
- 3. Governance and Citizenship**
- 4. Knowledge, Communication and Learning**
- 5. Lifecourse, Lifestyles and Health**
- 6. Social Stability and Exclusion**
- 7. Work and Organisation**

Each, of course, contains several sub-areas highlighted as particularly important and promising. Some of the areas are clearly important ones for cross-Research Council work – in addition to the BBSRC being naturally relevant to work concerning genomics across the themes, but also NERC for environmental issues, MRC for health issues, etc.

This paper presents an initial appraisal of future issues that may confront the social science research agendas in the context of the development of genomic science and technology. It is a “visioning exercise”, in which the ESRC thematic priorities have been taken as a framework for exploring the different dimensions of these future agendas.

Insofar as the exercise may contribute to the framing of issues for the new Genomics Centre, it should be borne in mind that such a centre is unlikely to adopt the framework of the seven thematic priorities as its own method of organising a research agenda. Indeed, the call for proposals to establish the centre indicated a rather different set of themes (including technology, health, etc.), which map imprecisely onto the thematic priorities. The aim here, however, is to provide an open-ended spectrum of issues and a broad contextualisation, which can assist the ESRC and hopefully the centre in the further development of work in this extremely important field.

This “visioning exercise”, a background input for the scenario workshop, deals in turn with each thematic priority area. It outlines some starting points for thinking about how the area relates to genomics developments in our time period. It does so by:

- identifying what some of the **key research questions** might be, and
- providing some **specific “forecasts”** combining social and technological developments. These are not **predictions** of what will happen, but suggestions as to possible futures, hopefully of sufficient plausibility to illustrate the scope for genomics developments impinging upon social research issues.

The aim is to help stimulate and focus the discussions in the scenario workshop, which will be the opportunity for a wide range of expertise to be brought to bear on these issues. Thus, the accounts below are neither exhaustive nor comprehensive. They are intended to **illustrate the range of themes** that the workshop might need to consider – to add to (or subtract from), to elaborate or reinterpret, to prioritise.

Before we move to the thematic priorities, a few general points should be considered. Some apply across all or most priority areas, and we also need to explain how we are using the term “genomics”.

General Issues

One of the general issues running through all of the thematic priorities concerns the need for enhancement of the interactions between social and natural sciences. This is not a new problem arising from genomics as a natural science. The Foresight Programme, for example, has highlighted the needs for such interactions across practically all of the areas of technological change that it examined.

But living in a post-genomic world (see the end of this section for a discussion of terminology) undoubtedly challenges us to develop improved mutual

understanding between natural and social sciences in new ways. Social scientific understanding of the issues raised by genomics may be required in ethical analysis, in evidence-based social policymaking, or in economic analysis of genomic technologies, for example. Such social scientific understanding requires a high level of lay-knowledge of genomics, if it is to support informed judgements and analyses. For example, understanding of the specificity of single nuclear polymorphisms (SNPS) is important for social scientific understanding of potential gene or drug therapies in many fields. To take another example, an understanding of the nature of biodiversity is important for establishing risks of genetic “pollution” arising from different agrifood genomic innovations. The process is a two-way one, however. It can also be argued that the decision making and informed debate about the major implications of genomics research and innovation for social and economic life would also benefit from an equivalently high level of lay-knowledge of social science of genomics amongst natural scientists and technologists involved in genomics science and innovation.

Thus, one major issue, beyond and above the seven specific thematic priorities, concerns the future relation between social sciences and the natural sciences engaged in genomics, and the degree of public learning related to these fields. In this respect, it is possible to envision various futures, ranging from divergence, non-communication and mutual hostility through to collaborative research programmes with shared technological goals. We can envision different attitudes to the role of social science on the part of natural scientists and engineers, and of those charged with policymaking in these fields. It is possible to envision quite different scenarios for the future of social research.¹ For example,

- social science might be regarded as being an irrelevance or even a nuisance in the future, by a wide range of significant decision makers and public opinion;
- or it might be seen mainly as a way to improve the communication of knowledge and decisions about genomics to the public at large, and experience demands to evolve its studies in this direction;
- or it could be seen as having a major role to play helping to foster dialogue about genomics and its wider social implications, and so on. Scenarios of this sort can prompt us to think about what factors might push the balance between these different viewpoints one way or another.

The points made above are liable to apply to many other fields of scientific and technological advance. While the precise issues that arise are liable to be quite different, the general questions as to the roles of social science are likely to be posed on a widening front. Examples that immediately spring to mind include Information and Communications Technology (e.g. issues

¹ We here use scenarios in the sense of images of possible courses or outcomes of future developments, which we can use to think through alternative possibilities and their underlying assumptions and dynamics. They are not forecasts of what is likely to happen – the future is liable to be some combination of elements of the different scenarios. They are certainly not predictions.

surrounding artificial intelligence, the legal status of intelligent agents, new challenges to established intellectual property right (IPR) regimes, e-governance, etc.) and nanotechnology (just moving over the horizon, with many environmental and health applications and question marks associated with new materials, nanomachines, etc.) One implication of this is that the social research issues related to the emergence and further development of genomics may be also shaped by developments in other areas of scientific and technological knowledge.

As a final comment, before moving to the thematic priorities, in the text below we refer to “genomics”, the “genomic era” and so on. This is strictly speaking quite inaccurate. In many ways, we could be said to be already in, or rapidly entering, the post-genomic era – in the sense that a completed rough draft of the gene sequencing of the human genome has been prepared. The term “post-genomics” is now commonly being used to refer to the scientific and technological activity taking place on the back of this gene sequencing – to functional genomics, proteomics, metabolomics, and so on. Many researchers consider that the big challenge is post-genomics, in this sense of the development of new layers of knowledge on the base laid down by genomics (rather than something that happens 'after' sequencing). In terms of social and social science implications, the most significant developments in the years ahead will involve applications of the knowledge established from mapping the genome and from the subsequent understanding of gene and protein function, as they are used in health care, agriculture and other fields – and enter into our cultural frames of reference. For this ESRC project we will be using "genomics" to include the applications in this "post genomics" era, for reasons of simplicity and familiarity. We leave the question open as to whether an effort should be made to move our terminology on more widely.

We now present illustrative examples of developments involving genomics that may emerge in relation to topics covered by the individual thematic priorities, and indicate some of the major research issues that might be raised in this context. We outline some “forecasts” of possible developments, which are presented as isolated events or trends, rather than full-blown scenarios. It is likely that many of the individual forecasts are contradictory of each other. Many of them are extremely speculative – the aim is to open our minds, rather than to provide a coherent view of a plausible future. (No doubt we will learn that some of these speculations turn out to be already mundane, that our imagination lags behind reality. Apologies in advance!) Finally, we must stress again that this account is intended as a starting point for discussion, not as an effort to pre-empt it.

Thematic Priority 1: Economic Performance

The development of genomics over the next 15 years is liable to have significant effects on economic performance in a number of respects. These include the potential for economic growth, the distribution of economic growth, sectoral restructuring, and productivity. There may well also be implications for the relationship between public policy and economic growth.

Developments in each of these areas present specific challenges to social science and policy. The emergence of biotechnology, for example, may raise questions about the impact of a new technology platform on GDP growth of a similar order to those arising from the 'productivity paradox' associated from ICT.

Contemporary analyses of economic growth and stability place considerable emphasis on technological change and the capacity to generate and appropriate value from innovations. Genomics is liable to be at the core of many product and process innovations, so questions arise concerning the way and speed with which these innovations are generated, and converted into economic productivity and growth. The returns to R&D and other innovation-oriented investment are part of this story; related to this is the ways in which such investments are valued in stock markets and by venture capital. Within empirical economic systems, how far are geographic proximity and other types of network linkages important for "clusters" to take off around the new technologies enabled by genomics, and what is the role of linkages between the public science base and industry? What is the scope for start-ups and spin-offs, and for the creation and survival of genomics-based small firms? How does the globalisation of research and innovation impinge upon the capacities of firms and regions to establish their own footholds in new (genomics) technology-based fields?

Key questions relating to these could include the following (each would present particular issues of measurement and appropriate indicators):

1.1 Genomic Industries and the GDP

What will be the contribution to global GDP of biotechnology and genome-based industries in the year 2015? Major social, scientific, theoretical and methodological challenges arise from this question: in terms of identifying the specific contributions of genome-based technologies to economic growth, or more generally concerning the contribution of scientific/technological revolutions to economic growth, and whether there are distinctive features about this scientific revolution in terms of its growth implications. Do statistical measures need to be modified to cope with changing structures and relationships?

Forecasts: We present below, as a set of forecasts for the coming decades, some developments that are intended more to suggest the sorts of context in which we could be conducting social research:

- 1.1.1** Genomics-based technologies and activities approaching parity with the performance of ICT activities, according to SIC and related national accounts data.
- 1.1.2** Public sector investment in genomics overtakes that going to NASA, in the US.
- 1.1.3** Chemical-based industries demonstrate a tendency to contract in terms of GDP contribution and employment.

- 1.1.4 Increased agricultural yields are maintained, but alongside lower levels of input of chemical pesticides and fertilisers.
- 1.1.5 Individual medical profiling (targeting drugs to genomically relevant individuals) together with new methods of drug delivery and reduction of drug introduction lead times, results in lowered demand for most individual drugs², together with a reduction in the overall costs of drug production.

1.2 The Geography of Economic Growth

What are the possible impacts of genomic-based industrial activity on the geographical distribution of economic growth? Indeed, what is the appropriate macro-economic unit of analysis? Questions arise here for social science in relation to the factors that lie behind geographical shifts. For example, how do regulatory structures at different levels (global, regional, national) affect the formation of markets? How does demand (and anticipations of demand) affect investment decisions in R&D in genomics-related areas, and does this challenge current social science understanding of the role of demand in innovation?

Forecasts for 2015 -- Here are some possible developments that might raise these questions, and present challenges to social research

- 1.2.1 Globally, the development and use of genetically modified crops are concentrated in such regions as the USA and China.
- 1.2.2 Major markets exist in highly developed countries for arresting senescence through gene therapy or other genomics-based processes.
- 1.2.3 There has been a concentration of drug discovery in US, while clinical trial work has become even more globally dispersed.

1.3 Industrial Structure

How will industrial sectors be restructured as a consequence of development in genomics? Will adequately addressing this involve a re-examination of SICs and other classifications mainly derived from (mid-) 20th century industrial structure? Social science institutions – the primary collection of official statistical series – may well confront category problems as a result of major industrial restructuring. “Systems” approaches in social science, likewise, will need to address questions of whether (or how) a sector/technology can be seen to constitute a system, and the issues of complexity and boundary definition that are associated with the conceptual issues raised here.

Forecasts: Again we can suggest potential future developments that would break existing moulds and pose such research questions starkly:

- 1.3.1 Delivery of a wider range of anticholesterol and other drugs through staple foods such as bread and rice (“nutriceuticals”).

² Perhaps more accurately: lower levels of use of specific pharmaceutical entities through the life cycles of these pharmaceuticals, relative to the size of the population being treated.

- 1.3.2 Integration of biomining with bioremediation.
- 1.3.3 Replacement of fossil fuels with biosynthesised renewable resources in a wide range of applications.

1.4 Capital Markets

How will capital markets be restructured to meet the challenge of long lead-times in genomic technologies? The social science concept of risk may well require further elaboration, in light of the new combinations of different orders of risk that are involved in developments of new markets and new technologies with significantly different risk time horizons. This presents issues of immediate practical significance – e.g., for management science, of risk management within companies, investment banks, and capital markets. How do you calculate the value of genomics-based R&D, and the economic returns to R&D investment?

Forecasts:

- 1.4.1 Relative importance of venture capital markets shrinks from current low base.
- 1.4.2 Collaborative joint projects are regularly used by major players to share pre-competitive risks in development of genomics-based products.

1.5 Risk Assessment

How is economic and financial risk assessed in relation to genomics-related externalities, such as environmental degradation, public opinion, biodiversity, and human health? Some major social science issues arise both in relation to assessing risk beyond current human knowledge, the private or public assumption of obligations in relation to externality-based risk, and the effects on economic performance of risk-related institutions (insurance, public regulation).

Forecasts can include:

- 1.5.1 Research programmes undertaken with a mixture of private and public funding – for example from insurance companies, the DTI, Research Councils – establish a set of software-based decision aids which are widely used by companies and policymakers to estimate risks associated with genomics applications.
- 1.5.2 New professional groupings and specialisms arise in activities such as accountancy and insurance to deal with genomics-related risks.

Thematic Priority 2: Environment and Human Behaviour

This thematic priority involves research on the complex interactions between people and social institutions and the environment, on the social and economic causes and consequences of environmental change. Genomics is liable to have major significance for environmental issues – and for the political debates around these issues. Genetically Modified Organisms in agriculture have raised concerns about biodiversity and in particular

implications for existing species as interbreeding and competition for niches may develop, and there may even be gene transfer by other mechanisms. Equally, there are concerns about the ways in which pesticide use may be encouraged by the use of pesticide-resistant crops. There are also applications of genomics more directly aimed at environmental goals. Even pest-resistant GMOs give rise to concerns about their implications for ecosystems where the pests may play important roles (insects as food for birds). Biotechnology may be applied to environmental remediation – plants or bacteria extracting heavy metals or toxins from contaminated land for example. Applications of bioscience here (and in related areas like mining) have already been started without genetic manipulation: they may be accelerated through use of the new knowledge.

A wide range of genomic technologies has thus already posed a considerable number of radical possibilities in terms of interactions between human behaviour and the environment. Emergent social science issues raised by these possibilities range from the impacts of genomic technologies on the sustainability of life forms and ecosystems to the impact of genomic-related environmental change on consumption. Questions of whether humans are custodians or creators of their environments are given quite new dimensions by the possibilities afforded by genomics in agriculture, materials production, bioremediation, and resource extraction. Social science contributions towards re-conceptualisation of concepts of sustainability, conservation, preservation, will need to take account of genomically based conceptualisations of the same issues. What are the social rationalities for the preservation of existing species as against the creation of new organisms? Social science will be presented by new challenges around environmental policy issues, which are liable to require collaboration and better understanding between those engaged in genomic science and technology and the social sciences. Issues of sustainability, of environmental protection, and regulation of agricultural production also require an international perspective to policy and institutions in ways quite distinctive to genomics. The interaction between the geopolitics of genomics and the geopolitics of environmental management will become a key area of social scientific interest.

Among the major social science questions may be the following (again, illustrated where possible by “forecasts” of potential developments):

2.1 Human Role in Evolution

How can and will social understanding of the new forms of human interaction with the environment, that is likely to emerge with genomic technologies, be used to reconceptualise and even “re-engineer” the role of humans in the dynamics of biodiversity and evolutionary change?

Some example forecasts:

- 2.1.1** Numerous large new “biospheres” established in many countries, using knowledge and techniques derived from genomics, to create artificial environments for purposes beyond those of research and leisure
- 2.1.2** The revival of extinct species, and the creation of quite new life forms, leads to great debate about what role such creatures should and could

be allowed to play in agriculture, entertainment, and wilderness and park management.

2.2 Eco-Sustainability

Will the management of genomic technology innovations lead to eco-sustainable trajectories (bioremediation, crop production, materials/fuels, biomining) or eco-catastrophe (reduced biodiversity, severe disruption to ecosystems)? Is there a middle way? What would be the consequences of ecological disasters or eco-terrorism, involving genomics, for the development of the technology and for industrial society and geopolitics more generally? Some divergent forecasts here could be:

- 2.2.1** The use of genomics technologies is widely seen to be a major part of the reduction of unsustainable practices and of adaptation to the changes in climate or other environmental circumstances brought about by industrialism. Accordingly, it becomes a major element in national and international programmes to achieve greater sustainability.
- 2.2.2** A major disaster is referred to as an “ecological Chernobyl”, and a substantial amount of territory has to be subject to strict controls to prevent the spread of hazardous organisms, etc.
- 2.2.3** Considerable efforts are inaugurated to ensure that the sorts of human error and miscalculation that have permitted nuclear incidents and problems with other large technical systems are not replicated in this field. These require unprecedented levels of computerised surveillance of the workforce and special powers for rapid response by emergency services to threats of eco-terrorism.

2.3 Environmental Protocols

How will the social scientific understanding of the socio-economic impacts of genomic technologies assist in the development of environmental policy institutions and protocols at different geographical levels?

- 2.3.1** International agreements are reached on the national rights over local biodiversity (e.g. Brazil and the Amazon as an eco-system and genomic resource).

2.4 Consumer Products

Social scientific understanding of consumption in multiple spheres requires new understandings of aesthetics, convenience, novelty, well being, since these are possible outcomes of sustainable genomic-based production.

Some forecasts here are:

- 2.4.1** Housing projects are undertaken on a large scale in which renewable materials replace plastics used in construction.
- 2.4.2** Transport based on genetically modified ethanol production is introduced on a large scale in a number of developing and developed countries

- 2.4.3 Clothing using genetically modified cotton (or other fibres), replacing the need for chemical dyes and detergents, becomes widely available.
- 2.4.4 Novelty products are introduced – for example, unfamiliar GO fruits, blue (or other brightly coloured) bananas, with genetically controlled ripening in place of ethylene.
- 2.4.5 Aesthetics – “healthy” foods are engineered so that children in the industrial world find them more acceptable.

2.5 Agriculture

Possible trajectories in genomic-based agriculture in relation to land use, crop protection, and crop diversification lead to major global socio-economic changes requiring social scientific understanding of the impacts of technology on environmental change.

- 2.5.1 The Sahara becomes the breadbasket of Africa, radically changing the environment and consumption situation of the continent.
- 2.5.2 Disease resistant genetically modified crops replace agrochemicals.
- 2.5.3 Increased yields reduce the demand for land use, and allow for more preservation/restoration of ‘wilderness’ nature.

2.6 Environmental Risk

How will genomic knowledge change the way that environmental risk is understood, measured, assessed and managed? How will the potential impacts of genomic technologies on the environment (genetic pollution, reduction in biodiversity) change understanding of the nature of biological and environmental risk? (Here we would need to take into account the construction of risk as understood by different publics, expert groups, governments, political parties, social movements, and other social organisations.) How will social science conceptualise the newly emergent concepts of these risks?

- 2.6.1 Biosensors and information systems are created and widely used to monitor sustainability of different species and ecologies.
- 2.6.2 There is more debate about, and changing views concerning, the acceptable levels of (altered) biodiversity, influenced in part by new understanding of global genomic resources.
- 2.6.3 The precautionary principle becomes an object of continuous conceptual development.
- 2.6.4 A growing sense that environmental problems can be remediated or corrected by technological interventions leads to much greater acceptance of large-scale but supposedly short-term environmental damage.

Thematic Priority 3: Governance and Citizenship

Genomics has already been generating new ethical dilemmas, almost on a weekly basis. These have involved a wide range of regulatory bodies, communities of interest, and lobby groups, as well as alarming many state officials and individual citizens. This not only presents social science with new empirical objects of study, but at the same time creates a demand for a social science input into opinion shaping. The concentration of R&D, and the high levels of long-term investment by a few global public science institutes and transnational corporations, poses questions of global governance and accountability for the actions of states and companies in different regions of the world. Gene therapies, diagnostics, and care delivery systems may increasingly require resources available only to the most advanced economies, so accentuating issues that relate to the global availability of the gains of life sciences. Conversely, the geopolitics of agrifood genomic technologies may shift from the current centres of innovation and technology development, so posing new questions of global governance in relation to the exercise of influence by major economic powers.

Given the new powers of technological intervention arising from genomics, new and fundamental questions of individual citizen's rights emerge - in terms of screening, data protection, and assumption of risk (e.g. by the insurance industry). The possibilities afforded by genomic technologies also present individuals, groups, and governments with a new range of choice, and hence questions about the exercise of choice. The social science disciplines that deal most directly with human rights and international relations likewise are presented with major new empirical objects and policy domains arising from rights, choices, responsibilities, and accountabilities in relation to genomic technologies.

3.1 Geographical Scales of Governance

Governance and accountability issues of central significance to the social sciences arise at different geographical scales for different genomic technologies in different domains. For example:

- 3.1.1** Human reproductive technologies present the possibility of 'rogue' states where technologies unacceptable/illegal in some countries are available in others. Two types of question for social science arise, one relating to the nature and geography of the social organisation of codes of practice and legitimacy, the other to the activities themselves, where a new range of corporate 'crimes' is possible. Social policy issues will develop in relation to the construction and implementation of protocols.
- 3.1.2** A plethora of new regulatory organisations, at different geographic scales, are already emerging, concerning the testing and authorisation for commercial use of a range of genetically modified crops. Social science issues involve both the study of these organisations, and the distinctive nature of the object of regulation, with possibly major conflicts between different objectives: e.g. free trade and environmental protection.

- 3.1.3** Issues of bio-piracy, where genomic resources of different locations are appropriated without sanction or recompense, assume levels of international agreement that as yet do not exist. Social science questions about the existence of, or need for, rights in this domain are likely to become more pressing for researchers involved with international relations, for example.

3.2 Globalisation

The issue of globalisation is already one that gives rise to considerable debate among researchers as well as activists. Genomics is likely to extend the number and range of questions about globalisation, relating to unequal distribution of resources, technological, therapeutic, and nutritional. These questions are likely to be posed in quite different ways across agrifood and pharmaceutical domains. Social research may be required to address, for example, the nature of the activities/strategies of transnational corporations, and the operation of regulation in this context. Consider some “forecasts”:

- 3.2.1** Transnational corporations create test-bed commercialisation of crops in low regulation countries in order to gain long-term entry into high regulation countries.
- 3.2.2** Gene therapies with little medical rationale become elective treatments for high-income groups in advanced countries.
- 3.2.3** The current high levels of investment in cardio-vascular and cancer genomics extend further the life-expectancy divergence between advanced economies and developing countries.
- 3.2.4** Commercial development of less-developed countries’ bio-resources through genomic technologies is undertaken for agropharmaceutical purposes – but the resulting disease preventative nutritional diets are available only for affluent consumers.
- 3.2.5** Improved methods of corporate accountability are developed, dealing with the consequences and externalities related to commercial exploitation of genomic technologies.

3.3. Personal Identity and Choice

Personal identity and choice issues relating to medical genomics open a wide range of new social science issues. Already the genomics of cloning, and the use of genetic screening for purposes such as the therapeutic use of sibling genetic resources, are posing new questions of personal identity and the nature of social being. Further research questions may be raised by such developments as:

- 3.3.1** Cloned human studies “solve” the nature-nurture debate in ways open to much greater scientific control than identical twin studies.
- 3.3.2** A cultural debate opens up concerning how far genomic identity can be equated to personal identity or social identity.
- 3.3.3** Legal battles over how far, and in what sense, individuals ‘own’ their DNA take place, and new strategies for using IPR tools in such battles

are adopted (extending, for instance, the moves towards copyrighting one's DNA that already have been made).

- 3.3.4** What is the nature of choice in various types of potential genomic technologies affecting reproduction, longevity, cosmetics, or any potential behavioural traits (e.g. will degree of athletic ability be preselected by parents)? We could envisage divergent scenarios in which these choices are largely exercised in market or non-market relationships.

3.4 Privacy

New social sciences issues related to privacy and data protection are raised by the developments of genomic therapies, screening, and research. Treating privacy as a social construction/institution, it can be assumed that genomic data on individuals will become the object of new institution building. Some "forecasts" that illustrate the sorts of research question that could be raised here are:

- 3.4.1** Rights to personal medical data (and their interpretation) are extended to DNA profiling of all individuals, as individuals carry their own DNA ID cards.
- 3.4.2** Data protection rules, and requirements for consent to use of DNA profiling data for research purposes, redefines the privacy of medical records.
- 3.4.3** companies require DNA screening for recruitment/promotion purposes.
- 3.4.4** Insurance companies offer substantial premium reductions for persons with "better" DNA profiles combined with the offer of genomic technology health insurance to fix genomic shortcomings
- 3.4.5** New ways of acquiring genetic data without permission or awareness of the individuals concerned proliferate; together with the formation of public and commercial DNA profile data banks, this demands the continuous development of data protection and privacy defining institutions.

3.5 Public Understanding and Accountability

Accountability and public understanding of science issues are also posed. The emergence of a major scientific revolution, with its subsequent developments in the form of technological innovation and the utilisation of these innovations with uneven distribution of costs and benefits, raises new questions here. These concern, for example, the accountability of science, both public and private sector, levels of consultation, and issues of dissemination and public understanding. Such research issues may need much more development in terms of conceptualisation and empirical evidence concerning the diversity of publics, communities of interest, and stakeholders in relation to the new technologies. The dynamic interactions between organisations around contested genomic issues could become a focus of social science study. Consider such possibilities as:

- 3.5.1 Supermarkets assume the role of proxy-consumers in Europe, and collaborate to launch a new range of GM foods with an industry 'seal of approval'.
- 3.5.2 New social movements emerge (e.g. eco-preservation versus eco-sustainability), and diverse old ones combine in new ways (e.g. elements of pro-life and environmental lobbies). Scepticism and / or hostility towards science and various forms of new age movements combine in developing an anti-modernist public sentiment.
- 3.5.3 New non-governmental agencies with diverse representation develop as agrifood/agropharmaceutical counterparts to the new medical ethics bodies.

3.6 Military Utilisation

Genomic technologies have the potential for greatly enhancing the risks and effectiveness of biological warfare. Assuming that genomic knowledge can be used for military purposes, it is probably also wise to assume that it will continue to be developed to do so. For instance, genetically modified biological vectors may develop new delivery vehicles for pathogens; genetically modified pathogens may counter existing protection technologies or increase their pathogenic effectiveness. From a social scientific point of view, issues of the accountability of the state in the development of genomic technologies for military purposes, offensive or defensive, suggest requirements for global governance where existing treaties and conventions have proved inadequate. One "forecast" that might be of relevance here is:

- 3.6.1 Social scientists become active in documenting the scale of military development of genomics, and in assessing the risks of accidental and deliberate use of these technologies, in a way similar to that in which physicians and others were active in the 1980s anti-nuclear movement.

Thematic Priority 4: Knowledge, Communication and Learning

Genomics, of course, involves a body of knowledge, and many questions arise concerning the production of this knowledge, and the learning and communication issues that are associated with this. Bioinformatics is a particularly significant development, with ICT being employed to organise and disseminate information about genomics developments of many kinds.

In the genomic era,³ the current trend in developments of bioinformatics is likely to bring about major changes in industrial structure. For instance, we are perhaps already seeing the emergence of new types of knowledge-intensive business, new forms of communication of biological information, as well as major changes in curriculum and learning techniques for the biological sciences. Issues relating to IPR and personal-social rights over knowledge under data protection provoke new ethical dilemmas, whether this relates to

³ Recall the discussion of terminology earlier.

individual genomic profiling or to genomic knowledge of local-national biodiversity. Questions arise over the public accountability of scientific and technological knowledge, and the intermediary institutions that assess or underwrite risk. Science-based epistemologies will meet new challenges from 'common sense', variously informed publics, interest groups, commercial intermediaries, each with their own distinctive epistemologies and 'truth tests'. The social science studies of these will in turn have their own epistemologies, and will position themselves in relation to others.

4.1 Popular Science & Its Communication

As new levels of complexity and mathematisation emerge in the biological sciences, there will be a corresponding decrease in the extent to which this knowledge is readily accessible to different social groups. With the subject of this knowledge being close to public interest, there will be an increased role for popular science writing – texts that take an intermediating position between the state-of-the-art knowledge and its description in accessible forms. These activities will provide a new empirical domain for social scientists investigating the communication of complex ideas and for those studying the public understanding of science. There is a range of possibilities that might be of interest here, including:

- 4.1.1 Competing accounts of new biological understanding achieve considerable prominence (e.g. as best-sellers, as media debates) with high profile stand-offs between 'media-friendly' scientists (e.g. Richard Dawkins vs. Steven Rose) concerning issues including genetic determinism, scientific ethics, and the like.
- 4.1.2 There remain significant domains of expertise which lack popularisers who are able to translate developments to the broad public, and these become "grey areas" which elicit little of the attention that other fields achieve, for better or worse.

4.2 Multiple Perceptions of Risk

Related to the above, there will be broader questions about how public(s) understanding(s) of genomic science will form the basis for multiple perceptions of risk associated with genomics. For social science, there is a range of important questions about the causes and consequences of these multiple perceptions. Potentially we could "forecast":

- 4.2.1 Changes in the relationship between risk perception and the formation of trust in expertise and political representation of various kinds; associated with intensified development of ethical stances towards genomics by many social institutions.
- 4.2.2 New institutions developed for the communication and management of genomic related risk.
- 4.2.3 Profound restructuring of the relationship between risk and trust, and the development of appropriate regulatory frameworks and institutions.

4.3 Learning and Memory

Developments in post-genomic neuroscience will reveal new understanding of the workings of the brain, with new claims emerging about the biological processes underpinning learning and memory. Social scientific explanations of learning will need to respond to these developments in the natural sciences. In particular, there will be opportunities for interdisciplinary studies that consider interactions between biological and environmental processes.

- 4.3.1 Memory enhancing techniques are developed, and extended beyond use in medical conditions of impaired memory.
- 4.3.2 Debates about “recovered memory” and “false memory” are rekindled, with ramifications in court cases (witnesses recall of events, recalled childhood abuse) as well as in wider cultural perceptions (e.g. of the boundaries between autobiography and fiction).

4.4 Ownership of Knowledge about Living Entities

Further developments in genomics will continue to raise questions concerning the ownership of knowledge about living entities, across effectively all species. As such, issues ranging from the ‘ownership of biodiversity’ to the ‘ownership of the human genome/ proteome/ transcriptome’ will continue. Social science will be required to confront these issues by considering the legitimacy of different knowledge claims and their consequences. Issues will most likely include:

- 4.4.1 Legal and political challenges in legal concerning individual/personal vs. collective/communal ownership rights.
- 4.4.2 Similar issues arising as to public vs. private ownership, and National vs. Regional vs. International ownership rights.
- 4.4.3 Further fuel being added to debates concerning the relationship between ownership and innovation, and how this is to be treated in IPR regimes.

4.5 Inter and Intra-Organizational Processes

The development of genomics is taking place within networks of public and private organisations (as with innovation in other areas). As such, genomics offers a highly active empirical domain for research into inter- and intra-organisational processes of learning, and new institutional forms that may be emerging to handle the problems encountered here. However, it will be particularly interesting to consider whether the learning associated with genomics differs from learning processes in other fields of innovation. Some relevant forecasts are:

- 4.5.1 A visible growth in the importance of knowledge intensive business services as providers of specialised genomic knowledge within networks of genomic innovation.
- 4.5.2 Evidence accumulates that there are specific and even unique features of genomic knowledge that present particular challenges for the organisation of learning across institutions (For example, the need to

combine knowledge of cellular biology, ecosystems, epidemiology, and agricultural practice might cause intense problems for knowledge management, with difficulties arising in communicating across specialisms, in project management, and in risk assessment and investment appraisal.

- 4.5.3** Networked computing becomes even more important for facilitating inter-institutional learning / knowledge flows in genomics (raising issues such as those of bio-GRID and interoperability of systems and data structures).

4.6 “Redisciplining “ of Many Fields

The genomic and bioinformatic revolution facing the biological sciences could require a major “redisciplining” of the field, with consequences ranging from primary education through post-graduate studies, and to issues of workplace training. Social science studies might find themselves being called to address.

- 4.6.1** Major problems associated with the development of new curricula during a period where there is considerable flux in received wisdoms.
- 4.6.2** The needs for new processes, to foster high-quality interdisciplinary learning and research, as genomics and especially bioinformatics span traditional disciplinary boundaries, which become the subject of significant national initiatives by Research Councils and groups of Universities, and also receive substantial support from the European Union.
- 4.6.3** The restructuring of labour markets for new skills and areas of expertise.
- 4.6.4** The formation of new skills relevant to genomics applications, which becomes widely recognised as one of the most important bases for national / regional competitiveness.

Thematic Priority 5: Lifecourse, Lifestyles and Health

Genomics and changes in biological understanding can be expected to have significant effects on the understanding of human nature with consequences for life-course, lifestyles and health. The interaction between biological and social scientific understanding of human nature is a continuing historical one, and the development of genomics will doubtless stimulate a new spiral of reconceptualisation. Old models of gene determinacy vs. social determinacy will be problematised by both emergent new biological models and new social scientific paradigms. New capacities, however expressed, to alter the nature of biological organisms, or organism-environment interactions, may challenge conceptions of what is natural about the biological in the genomic era. The very concept of health may be refashioned in a way that will require reconsideration of the relationship between life-style and health.

A number of specific issues arise involving the relationship between these effects and social science understanding of them: extension of life-expectancy, genomic therapeutics, delivery of health care, consumption and

preparation of food, reproductive technologies and genetic screening. Equally, the whole concept of life-course will require social scientific reconceptualisation in terms of life-stage analyses.

5.1 Ageing

How will experiences of ageing be affected by enhanced genomic/metabolomic understanding and manipulability of senescence? We could imagine social research issues raised by such developments as:

- 5.1.1 Private medicine offers packages of treatment to extend active life.
- 5.1.2 Different social systems and individuals make different choices on commencement and duration of paid employment, and paid retirement.

5.2 Extended Longevity

What will be the social and economic consequences of extended longevity derived from genomics? Relevant “forecasts” could be:

- 5.2.1 Changes in working time duration within the lifecycle, leading to crises, failures and reforms in different welfare systems
- 5.2.2 Increased productivity of labour in high skill economies creating enhanced consumption and leisure opportunities.
- 5.2.3 Effects of changes in working time duration within the lifecycle facilitating significant (and varied) changes in household and kinship structures, and their economic and social roles.

5.3 Data Integration

What will be the effects of the informatics revolution on the collection of socio-economic data? Here one of the major issues raised by the development of bioinformatics, and the integration with chemo- and other informatics, is how data is to be organised and managed between bio- and social sciences.

- 5.3.1 The integration of bio-, medico-, and demographic informatics provides major new databases - but such increased integration can produce tensions between data protection requirements and research opportunities.
- 5.3.2 Longitudinal lifecourse data from the social sciences become resources for socio-environmental studies on gene expression.

5.4 Health Care

Genomic diagnostic and therapeutic techniques will transform the delivery and characteristics of health care. This will raise new social scientific questions about when is a patient a patient and the social interactions between the carers and recipients of care. For instance:

- 5.4.1 Medicine response profiles lead to individualised therapies, and effectively the end of generic technologies.
- 5.4.2 The doctor-patient relationship is transformed through pharmacogenomics and elective therapeutic choices.

5.5 The Role of Food

Genetic modification of food will transform both the production of food and the range of foods available. A range of issues follows for social scientists studying the consumption of food in particular. Questions arise about whether and how far the demand for food is the demand for taste, sustenance, health and novelty, and in what combinations. Further there will be issues as to whether this demand is for social goods or individual purchase. These issues will undoubtedly have a strong geographical basis that will also require social scientific investigation. The following events might be the subject of such study.

- 5.5.1** Delivery of nutrient enhanced foods and nutraceuticals in China enhance quality of life and reduce healthcare budgets.
- 5.5.2** Designer foods create high value niche markets in the USA.
- 5.5.3** Food logistics are transformed by arresting food quality deterioration.
- 5.5.4** Macular degeneration is eliminated as a major health problem in rice-based culinary societies.

5.6 Human Choice

Genomically based science and the derived reproductive and screening technologies will fundamentally affect the nature of human choice and this in its own right is an issue for social scientific significance. Additionally, how this choice is socially presented, exercised and organised will be a matter of social science study; and social research may play a role in informing and studying the development of associated policies. The following are some examples of future dilemmas that might arise:

- 5.6.1** Major genetically transmitted diseases are progressively eradicated.
- 5.6.2** Diagnostic techniques result in greater awareness of predispositions towards disease and expected quality of life, with or without potential for treatment.
- 5.6.3** A global Internet based eugenics movement develops, combining scientists and such institutions as dating agencies, and even P2P sperm and ovary bank markets.

Thematic Priority 6: Social Stability and Exclusion

New information and knowledge, and the applications that are developed from them, are acquired at uneven paces through societies. This is liable to confer differential advantages to those with different access to relevant resources. Such social inequalities are more than just a framework that shapes the diffusion of genomics-related information and applications. There is scope for applying the new knowledge in ways that might interact with existing inequalities and perhaps even form the basis for new forms of social

exclusion; some of these have already been touched on in the discussion of other thematic priorities (e.g. genetic screening at the workplace or for insurance purposes).

A wide range of social scientific issues related to social stability and exclusion arise from genomics, connecting with themes of lifecourse, lifestyles and health, governance and citizenship. There are major uncertainties in the social science implications of developments of genomics in this area. Genomically based knowledge is likely to change our understanding of just what genes are, let alone what explanatory roles they play in human affairs. The debates have already been reopened about how social and legal policies should relate to new biological-determinist theories of physical or behavioural characteristics and/or new environmental-determinist theories affecting gene expression. These debates imply potential new grounds for social inclusion and exclusion, for criminalisation and justice – and the debates are probably still in their infancy. Proteomics and an increasing knowledge of gene functionality based on experimentation with different environmental factors may present new possibilities for social policy. As yet the parameters used for this experimentation are relatively restricted – But in the long run developments in this field are likely to lay the ground for new and different social interventions.

At another level, diagnostic technologies related to biological or environmental factors may become the social instruments through which social inclusion or exclusion is effected. Questions of scarce resources, or socially discriminatory rates of adoption of rapidly changing technologies, are likely to present new grounds for inclusion and exclusion, within nation states, regions, or the global economy. These are some of the possible issues and questions for social sciences, both as new empirical fields of study and for social policy.

6.1 Opportunities for New Interventions

Current developments in genomics suggest that many shibboleths of Mendelian trait inheritance and the concept of a gene itself will fall. There is a great distance between a nucleic acid sequence and gene expression, the dynamics of which are complex and as yet a long way from being understood. The consequences of new biological understanding may be far reaching for social science in terms of how both biological-medical interventions or environmental interventions differentially affect different social groups. Some relevant “forecasts”:

- 6.1.1** Links between ethnicity (and gender) and epidemiology may emerge beyond the presently known ones.
- 6.1.2** National diets or sub-national diets (including culturally embedded cuisines), already epidemiologically related to disease, will be identified for interventions, social or medical, so defining some groups/nations as at risk and others as ‘healthy’, in different and more rigorous terms. Tea is genetically modified in China to minimise stomach cancers. Coffee becomes a proscribed drug in France.

- 6.1.3 Language development is found to depend on specific early social interventions, leading to changes in parenting and pedagogic methods, creating or intensifying advantage and disadvantage between different social groups, and different national skill resources.
- 6.1.4 Nutraceuticals are added to staple foods for purposes of disease prevention, as a matter of governmental policy in some countries - but they are discouraged or even banned in others.
- 6.1.5 Genetic modification of humans becomes a widespread technology for certain medical conditions, but is available only in some countries, and only to some social groups within countries.

6.2 DNA and Proteomic Based Discrimination

DNA and eventually proteomic profiling creates a new range of instruments for inclusion and exclusion across a number of different fronts.

- 6.2.1 Personalised medicine based on DNA/proteomic profiling leads to greatly enhanced drug development and treatment on the one hand, but lead to the identification of groups of 'new incurables' on the other.
- 6.2.2 DNA screening for employment, healthcare, education, insurance, and welfare enlarges the scope for policies of inclusion and exclusion, rationing and discrimination, or matching horses for courses. (For some this also leads to new forms of fatalism.)
- 6.2.3 Genomic diagnostic technologies are used to strengthen, weaken or inflict social divisions across existing dimensions of gender, ethnicity, sexuality, class background, and others.

6.3 Enhanced Longevity and Paid Work

Changing patterns of lifecourse resulting from gains in longevity, and/or delaying senescence through genomic technologies raise important issues concerning the social bases of inclusion and exclusion within societies. Paid employment is a major vehicle for social inclusion and exclusion, and if deviation from mean societal longevity increases, new possibilities of inclusion/exclusion arise, posing both empirical and policy issues for social sciences.

- 6.3.1 Retirement age becomes deregulated, and risks and choices are individualised with the role of the state becoming further diminished. Some continue in employment until 90 years, others are excluded from employment for various social reasons at 50 years. New categories of people become uninsurable against risks of non-employment, retirement, and ill health.
- 6.3.2 Working life becomes a continuously declining proportion of the lifecourse, and other social institutions assume an equivalent role of defining inclusion and exclusion. (An alternative forecast is one in which institutions bringing about social cohesion become less extensive and commanding.)

Thematic Priority 7: Work and Organisations

The development of genomics is taking place in socio-economic contexts that will have a strong influence on the particular trajectories that are pursued and on the rate at which they proceed. Issues such as globalisation and the increasing 'intensity' of competition are widely cited as strong forces shaping all kinds of innovative effort. These factors will similarly have a significant impact of the institutional basis within which genomic innovation takes place.

In turn, developments in genomics will present new opportunities for action on the part of public and private organisations, and their strategies can potentially impact on the nature of globalisation and competitive processes. Currently, such implications of genomics are perhaps clearest in the health and agrifood sectors, but in the future the sectoral reach of genomics is likely to be far wider. (The foreseeable spectrum ranges from genomic-based new materials and energy sources to biocomputing and beyond.) The implications for social science in this theme connect with those described in the economic performance theme, but now the questions are oriented towards implications for business organisation, strategy and management, and towards the nature and scope of employment patterns. Some of the specific social science issues that follow from this might include:

7.1 The Geographies of Knowledge and Resources

The geopolitics of genomics reflects geographically specific concentrations of expertise, genomic resources, or policy interventions. The geographic distributions of these features could become more concentrated, but also there are prospects for new centres of activity being established. What are the potential consequences of such concentrations for the geographical division of industrial labour and for the development of appropriate firm strategy? Forecasts could include:

7.1.1 Human genomics expertise becomes concentrated in the USA.

7.1.2 Amazon Basin biodiversity is proven to be a pivotal resource for the global pharmaceutical industry.

7.2 Business Models

A range of different business models will emerge as new opportunities in genomics are developed. These will reflect different orientations towards strategic decisions concerning the extent to which activities should be pursued as part of a firm's core activity and which should be out-sourced. Similarly, decisions to collaborate and license technologies will have a major impact on the industrial division of labour between firms of different types and sizes. Social scientists will need to study the extent to which these developments are specific to activities related to genomics, and also the ways that specific 'industrial ecologies' shape the rate and direction of genomic innovation. Issues for research could well include: the nature of relationships between TNCs and SMEs; and the management of innovation across networks of institutions and across disciplinary and professional boundaries.

- 7.2.1 Substantial changes occur in the relations between SMEs and large corporations, as the latter find that accessing the knowledge and innovations generated by the former requires new ways of fostering dialogue between personnel without weakening creative organisational cultures.
- 7.2.2 The emergence and sustainability of new types of firms with novel economic functions.
- 7.2.3 New approaches are developed to knowledge management as rapidly changing knowledge and expertise means that rigid classifications of issues and specialisms proves an obstacle to innovation/

7.3 Customer Focus and Firm Performance

Genomic technologies have potential for application in a variety of different sectors, including health, agriculture and food. How will these different genomic orientations influence discussions within the social sciences about the relationship between customer focus and firm performance?

- 7.3.1 Businesses widely adopt new methods for creating markets for new products and new classes of product, and for capturing the value from such products. There is extensive crossover between methods used for creating or reaching industrial/institutional markets and consumer ones.

7.4 Appropriate Levels of State Funding

Genomic capability is being developed in public and private domains, with considerable investment in both. This raises important questions about the application and use of knowledge created in different domains and the management of knowledge flows between public and private domains. With the costs associated with genomics, proteomics etc., burgeoning attention will increasingly be focused on analysis and opinion regarding the appropriate levels of state funding. Consequently, a question that has exercised social sciences for some time, namely the justification for public science spending, will necessarily be recast in light of questions of ownership of biological knowledge. Relevant “forecasts” include:

- 7.4.1 A range of new metrics is developed for assessing the returns to research and other innovation-related expenditure in genomics and other areas of activity. Furthermore, these are embedded within systems that allow the quantifiable indicators to be used while avoiding a myopic focus on the immediately measurable.
- 7.4.2 Stresses associated with the differential performance criteria and rewards associated with public and private sector activities that are brought into collaborative arrangements lead to the institution and wide application of a range of new working arrangements.

7.5 Regulatory Approaches and Outcomes

The extent to which the regulatory environment for public and private organisations encourages investment and innovation in genomic technologies raises important questions for social science. These are suggested by such developments as:

- 7.5.1** Strong evidence is provided demonstrating that geographically different regulatory frameworks are increasingly important influences on the decisions of firms as to where to locate R&D activities.
- 7.5.2** Regulatory frameworks have to pay considerably more attention to achieving the development of trust amongst consumers, so that they can support innovation and market formation as well as exercising necessary diligence.
- 7.5.3** Formal intellectual property regimes become less important as an incentive for firms to innovate, while contracts and other tools rise in significance.

7.6 New Industrial Society

Genomics has the potential to create completely new industrial activity and also to substitute for existing industries. What are the creation/destruction consequences of genomic innovations for patterns of employment and unemployment? To what extent are there regional variations in the potential supply of the necessary skills and what are the consequences of skill migration? Some possible ways in which genomics might reshape the context in which social research questions are addressed are:

- 7.6.1** The petroleum based chemical industry is largely replaced by the use of crops as feedstock.
- 7.6.2** Pharmaceutical companies move into the delivery of health-care services, offering prevention rather than cure, on the back of developments in pharmacogenomics.
- 7.6.3** Establishment of a multi-billion pound genomic-based environmental clean-up industry.
- 7.6.4** Concentration of R&D in bioinformatics in the USA leads to major skill migration from Europe, and failure to maintain skill reproduction for informatics.

7.7 Change in the Workplace and Workforce

Within the workplace, genomics is likely to lead to new specialisms and skill requirements. The availability of genomics information concerning the workforce and knowledge about work hazards, for example, could have many ramifications. Additionally, the use of genomics may lead to new types of roles within user industries (e.g. health care) and the biotechnology sector. Research might be required to focus on the ways in which workplace relationships might be influenced by such developments as:

- 7.7.1 Information about individual workers' vulnerability to various hazards, and their exposure to these, is widely utilised in companies under a system of rules that allows for some decisions about recruitment and promotion to use such information, as well as more routine decisions about further exposure to hazards.
- 7.7.2 New types of paramedic roles are generated as genomics information, assessment methods, and treatments become less demanding of high levels of expertise.
- 7.7.3 New types of job and career structure are created around bioinformatics, and in the biotechnology industry more generally there is a proliferation of new occupational and professional groupings.