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Bioinformatics and the politics of innovation in the life sciences: science and the state in the UK, China, and India

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Introduction

The contribution of bioinformatics to state strategies on life sciences innovation has become an increasingly visible concern to governments. Announcing a £32 million investment in bioinformatics in February 2014, the UK Minister for Science David Willetts emphasised its 'huge priority for government' and its 'potential to drive research and development, increase productivity and innovation and ultimately transform lives' (Medical Research Council (MRC), 2014). His statement built on the promise of the *Strategy for UK life sciences* to make the UK 'a world leader in genomics and bioinformatics' (Department of Business, Innovation and Skills (BIS, 2012: 41) and on the ambition stated by Jeremy Hunt, Secretary of State for Health, at the launch of Genomics England and the 100,000 Genome Project in July 2013 to make the UK 'the first ever country to introduce this technology in its mainstream health system – leading the global race for better tests, better drugs and above all better, more personalised care to save lives' (Genomics England, 2014). Meanwhile, in India the Department of Biotechnology (DBT) is clear that the aim of its bioinformatics programme and National Bioinformatics Network is 'to ensure that India emerges a key international player in the field of bioinformatics; enabling a greater access to information wealth created during the post-genomic era and catalysing the country's attainment of lead position in medical, agricultural, animal and environmental biotechnology' (India DBT, 2014). This sense of national priority echoes the tone of DBT's earlier strategy document *Bioinformatics policy in India* which emphasises that the requirements of innovation in science and technology mean that it is 'of utmost importance that India participates in and contributes to the ensuing global bioinformatics revolution' (India DBT, 2004: 3). And in China, the concern for keeping pace with global life sciences innovation through investment in bioinformatics is reflected in the projects funded in that field by the Natural Science Foundation of China (NSFC), the National High-tech Development Programme (863

Programme), the National Key Basic Research Development Programme (973 Programme), the National Science and Technology Major Projects, and the National Key R and D Technology Programme (Ai and Wang, 2011; Wei and Lu, 2008).

In terms of grand policy narratives, then, bioinformatics has come of age. States now see bioinformatics as a key component in life sciences innovation, in the pursuit of national advantage in the global knowledge markets of the future and in the servicing of the health needs of their populations. However, although they may agree on the importance of bioinformatics to the national interest, states disagree on how the value of its contribution to life sciences innovation can best be maximised. It is the purpose of this paper to explore the politics of innovation that shape the differences in government strategies on bioinformatics, focusing on the power relationship between science and the state.

The empirical vehicle for this analysis is the approach to bioinformatics adopted by the UK, China and India. In the UK we have an established player in the global competition for control of the future benefits of the life sciences, one accustomed to the nuances and difficulties inherent in the exploitation of its established science base. The situation of China and India is quite different. These are economies with an impressive track record in the penetration of existing global markets of established products but limited experience in the science-based anticipation of future markets through informed, but essentially speculative, state investment in emerging domains of the life sciences (Salter, 2009a and 2009b). Unsurprisingly, this does not limit their ambition to challenge the Western hegemony in biomedical innovation, as their rapidly expanding commitment to the life sciences eloquently testifies. The question is how far their strategies on bioinformatics in support of this ambition

are likely to impact on the respective positions of the UK, China and India in the global competition for advantage in the life sciences.

The paper is organised as follows. First, what is the contribution of bioinformatics to innovation in the life sciences, how has it developed and, in this context, what is the nature of its political value? What interests recognise this value and how have they sought to capture it by guiding the emergence of bioinformatics? Second, what is the role of the state and science in the emergence of bioinformatics in the UK, China and India? Is the state proactive in its identification of, and response to, the innovation opportunities created by bioinformatics or is it reactive to the demands of science? Finally, given this analysis of the politics of bioinformatics, what is the balance of power between the three countries in terms of their ability to exploit the contribution of bioinformatics to life sciences innovation? In pursuit of the answers to these questions, data was gathered in two phases. In the first, internet desk-based scoping exercises of existing policies on bioinformatics in the three countries were conducted through the analysis of policy documents of state and non-state governance actors, secondary 'state of the science' reports and expert overviews, industry trend reports, science journal article publication trends, academic reviews, and science journalism. Building on this initial understanding, semi-structured interviews were then conducted with 40 leading bioinformaticians, other elite scientists (particularly in the field of genomics), and policymakers evenly spread across the three countries. The interviews were recorded, transcribed and analysed employing the conceptual framework developed in the following two sections.

Biomedical innovation, bioinformatics and political value

The political rise of bioinformatics is a product of its value to the process of biomedical innovation and the future markets to which such innovation gives access. As a discipline and epistemic domain, bioinformatics combines the knowledge, skills and techniques of biology, on the one hand, and computer science, statistics and mathematics, on the other (Lewis and Bartlett, 2013; Luscombe *et al*, 2001). In terms of its application, its territory is broad 'covering anything from epidemiology, the modelling of cell dynamics, to its now more common focus, the analysis of sequence data of various kinds (genomic, transcriptomic, proteomic, metabolomic)' (Harvey and McMeekin 2002, 10). Behind its emergence lies the problem faced by biology when, from the 1980s onwards, the volume, complexity and variety of bio-data production outstripped the discipline's capacity to conceptualise, coordinate, analyse, and interpret it (Ouzounis and Valencia, 2003). The fear of being overwhelmed was palpable and public (Butler, 2002, Rechardt, 1999), with official bodies such as the US National Institute of Health Research recognising that 'the computers, algorithms, and software, let alone the support infrastructure, are not keeping up with the exponentially rising tide of data in biomedical research' (Botstein, 1999). It is a concern that is still very much evident among our interviewees, with the view often expressed that 'data generation kind of goes up quicker than computational power...essentially the bottle neck is not generating that data, it's how to use that data' (Interview 4) and that 'a new technology [such as sequencing or microarrays] comes out and then bioinformatics is just thrown in and has to somehow work out what to do with the new data that's generated from it' (Interview 4). Part of the perceived problem is that it is structural, embedded in funding agency policy where 'funding is not usually provided to help understand data, it's provided to generate data' (Interview 2).

The problem has been particularly acute in the field of genomics where, fuelled by large government investment in projects such as the Human Genome Project (HGP) and skilful

scientific PR, expectations of this new field of 'big science' (the HGP became known as 'Manhattan Project' of biology) were high but the promised benefits for public health remained distant (Galison and Hevly, 1992; Lenoir and Hays, 2000). With the bio-data deluge generating more complexity and less clarity, something had to be done if genomic science was to maintain its impetus and access to public and private resources. Bioinformatics was presented as the epistemic and political answer. Hence reports on genomics from the UK House of Lords Science and Technology Committee and Department of Health in the 2000s reiterate the difficulties faced by genomic medicine, the challenges to bioinformatics posed by the new genome technologies, the 'painfully slow' translation of scientific research into 'patient benefit', the promise that, as Professor Dame Janet Thornton, Director of the European Bioinformatics Institute, put it: 'it will be the biomedical informatics that will allow translations from knowledge and research into medical practice', and the importance of investment in the research and training needs of bioinformatics (House of Lords Science and Technology Committee, 2001 and 2009; Department of Health, 2003). In 2009 the Department of Health duly recognised that 'The expansion in EMBL-EBI [European Molecular Biology Laboratory-European Bioinformatics Institute] data management capacity is vital in underpinning the sustainable development of the substantial investments in genetic, genomic and systems biology made by the Research Councils' (Department of Health, 2009: 18). The formal political narrative was established with bioinformatics centre stage.

As the public solution to a major problem in biomedical innovation, the position of bioinformatics in the policy narrative is secure. Yet at the same time its epistemic identity in science remains fraught with political tensions. Integrating epistemic domains is a quintessentially political task because disciplines are constituted not only in terms of

intellectual constructs and practices but also in terms of institutions with their particular interests and ambitions (Whitley, 1976; Lemain *et al*, 1976). Although the issue of how to deal with large amounts of biological data had been present since at least the 1980s, the impact of the importation of mathematical and computer science knowledge and skills into biology had initially been filtered through the existing power structures of biology; a process which rendered bioinformatics acceptable as a service function to the biological paradigm (Leonelli and Ankeny, 2012: 29-31). Genomics changed all that because it is large, well-funded, highly complex and, most importantly, a state project that cannot be seen to fail. As a result, its political muscle is helping to re-engineer the balance of power between the epistemic partners of bioinformatics. At the heart of this reconfiguration is the question of which epistemic paradigm should guide the organisation and analysis of the bio-data: mathematics or biology? In the initial stages of the partnership it was assumed that mathematics and computer science would perform a data processing function guided by the hypotheses of biological theory. There appeared to be a natural convergence between the partners such that scholars described it as a 'natural marriage', albeit one where one partner was manifestly dominant over the other (Chow-White and Garcia-Sancho, 2012: 14). More recently, this view of relationship development has been shown to be an over-optimistic interpretation of epistemic co-habitation. In its place has emerged a view of balance in the interdisciplinary production of bioinformatics and a recognition that it 'will require some fundamental changes in biological assumptions on the part of biologists, and mathematical assumptions on the part of the "import" disciplines' (Harvey and McMeekin, 2002: 21). In that happy situation the new mathematical tools produced for analysing bio-data are then seen as both 'the objects of knowledge production for the expert bioinformatician community and instruments for knowledge production for the wider molecular biology community' (Harvey and McMeekin, 2007: 20). Bioinformatics performs a creative as well as a service function.

The political tensions inherent in this epistemic transition constitute part of wider shifts in the role of 'big data', as it has become known, in the scientific endeavour. The collection, storage and analysis of very large datasets is not peculiar to biology. Indeed, compared to disciplines such as physics, chemistry and climate science, biology is very much a late arrival in the big data domain (Mayer-Schonberger and Cukier, 2013; Hey *et al*, 2009). Practices devoted to the extraction of inferences from data *in silico* have become sufficiently sophisticated that 'computational tools for data analysis are assigned a prominent role in facilitating the extraction of patterns from data, while experimental work is conceived as means to verify and explain those patterns' (Leonelli, 2012a: 50). The consequence is that the creative power in the inter-disciplinary relationship moves to mathematics and computer science. The effect of this power transfer is to challenge the ways in which science is organised and practised through the forms of collaboration, division of labour and integrative strategies (of models, data, theories, software) set up to deal with the fact of big data. As a result, Leonelli claims, 'Data-intensive methods are changing what counts as good science' (Leonelli, 2012b: 2). As the bioinformatics space is progressively institutionalised, so new power roles are emerging to allow the benefits of the data bases to be exploited by a variety of global audiences. For example, curators (not usually biologists) act to create bio-ontologies, and adapt existing ones, in order to organise the data into a form capable of meeting the research needs of bioinformaticians and biologists alike (Leonelli, 2012c: 58-59).

Such is the significance of the power transfer that the traditional paradigm of hypothesis-driven research is being replaced by what has been termed 'discovery science' where the database is established first and the explanations of the patterns they contain follow later (Chow-White and Garcia-Sancho, 2012: 146). Biology is becoming a 'data-bound science'

driven by the imperatives and logic of the database rather than by hypotheses derived from biological theory and applied to observation (Lenoir, 1999: 35). In the workplace, the *in silico* 'dry labs' of electronic databases and computation are becoming equally as important as the traditional *in vivo* 'wet lab' as the primary location of disciplinary activity (Biotechnology and Biological Sciences Research Council (BBSRC), 2012). It is in this political space that the identity of bioinformatics is being forged. The evidence of our interviews suggests that the struggle within science for control of this political space, and its strategic position in the territory of biomedical innovation, continues. There is no agreed definition of the bioinformatics identity but a strong awareness of the fact that the space exists, its scientific and political significance, the formative role of genomics and of the competing disciplinary ambitions for its future. How does the state then deal with the both the potential and the uncertainty of this new territory?

States, science and the politics of innovation

The competition between states for control of biomedical innovation is driven by the anticipated demand of future populations for improved and more efficient healthcare, the future knowledge market generated by this demand and the economic benefits that will accrue to those able to shape access to that market to their advantage. In the bioeconomy as elsewhere, the advanced economies of North America and Europe met the uncertainties accompanying the shift from Fordist to post-Fordist modes of mass production and consumption with the evolution of the 'competition' state as the vehicle for the pursuit of national advantage through innovation (Cerny, 1997; Hay, 2004; Hersch, 1991). Rather than concerning themselves with government interventions to ensure full employment and respond to market failures, states began to focus their attention instead on the neo-liberal supply-side

policies that would give a sharp edge to their competitiveness in the global knowledge economy. Particularly in the case of the knowledge driven bio-industries, this meant a concentration not only on the infrastructures of innovation but also on 'agglomeration and network economies and the mobilisation of social as well as economic sources of flexibility and entrepreneurialism' (Jessop, 2002: 110). As a consequence, the competition states of the West have moved away from the national sponsorship of particular firms and technologies and towards policies designed to foster 'the conditions necessary for innovation'. Rather than specific structural change, the competition state goal is seen to be one of stimulating a dynamic that enables the knowledge production process to become self-sustaining. Within this framework of understanding, a policy orthodoxy has emerged where regional (sub-national or trans-national) governments initiate programmes to foster cluster developments in sectors such as biotechnology (Asheim and Gertler, 2004); commercialisation is facilitated through academic-industry collaborations and high profile, publicly funded R & D centres act as magnets for venture capital investment; networks of science and industry are enabled (Cooke: 2004); regulation is facilitative rather than restrictive (Hansen, 2001); and intellectual property rights (IPR) favour the operation of the market.

Whilst this analysis provides insights into the state's likely role in life sciences innovation in the developed economies of the West, a different approach is necessary in the case of the emerging economies of the developing world. Focusing in the main on South Korea, Taiwan, Japan, and Singapore in the 1980s and early 1990s, the earlier work on the 'developmental state' highlights its role in the promotion of rapid economic development through the targeting of particular industries with large global markets. The markets were already there. The political task was to penetrate them. To achieve this goal, the state protected its chosen industries using a range of policies such as import and credit controls, promoted them

through state investment, guided private capital through incentive schemes, and measured their progress in terms of export achievements (Onis, 1991). Backed by a strong, professional and autonomous bureaucracy, the state sought to define the specific path of industrialisation through the 'government of the market' (Wade, 2003). In this analysis, the essence of those states' commonality is that they sought to challenge the control exercised by the developed world over the dynamic of globalisation. If they were to access the wealth of global markets, if they were to 'catch up' with Western countries, then the power of the state was required to make globalisation work for them.

However, having caught up using the targeting of known markets as a primary policy objective, developmental states face the problem of 'keeping up' in the context of future markets like those generated by the life sciences that are either unknown or decidedly uncertain (Weiss, 2000). Like competition states, they are obliged to adapt their strategies of direct state intervention when faced with the innovation requirements of a science with a speculative future, an uncertain market and a difficult path to commercialisation (Lee and Schrank, 2010). As a consequence, scholars have noted the evolution of developmental state governance into new forms described variously as the 'adaptive state', the 'flexible state', the 'speculative state', the 'post-industrial developmental state', the 'transformative state' and the 'catalytic state' in their studies of Japan, China, India, South Korea and Taiwan (Kim, 1999; Salter, 2009a; Wu, 2004; Wong, 2005). In seeking to move from borrowers to innovators in the life sciences, developmental states are obliged to review their *modus operandi* and the style of the bureaucracy that helps formulate and implement their innovation policies.

Central to the state's role in life sciences innovation is a clear understanding of how the state relates to the scientific community and to the interests of that community. Like all enduring

political arrangements, in the developed economies that relationship has historically been founded on an exchange of mutual benefits. Science supplies the state with a flow of knowledge that can enable the delivery of economic and social benefits to its citizens. The state supplies science with the resources to pursue its research interests. Supporting this core agreement is an infrastructure of embedded institutions and values designed to maintain the relationship's authority and legitimacy, promote continuing engagement between the two partners and facilitate the addition of new, mutually beneficial, scientific dimensions to the agreement (Jasanoff, 2004). Political exchange is continuous with scientists lending their expertise and authority to the activities of the state's policy advisory system and the state facilitating and legitimising science's system of self-regulation (Jasanoff, 1994). Although a permanent marriage, tensions undoubtedly exist within it and commentators differ in their interpretation of how these tensions impact on its internal balance of power. In his work on the scientific elite of the UK and the US, Mulkay emphasises the power of the scientific elite, arguing that it 'operates as a "buffer group" [between science and state], successfully resisting instrumental demands from outside and maintaining considerable freedom for members of the academic research community to pursue their own "scientifically defined" interests' (Mulkay, 1976: 445). Here the state sets the overall budget but the scientific elite decides which area of science gets what. Others are skeptical of this view of scientific autonomy and present the state as the dominant partner who defines the scientific agenda in terms of the state's political interest, and, in the case of the US, uses science to legitimise government policies and programs (Mukerji, 1989; Solovey, 2001).

Interpretations of the balance of power between science and the state in developed economies may vary but all are agreed that the political relationship is one of mutual dependence where political resources such as finance, expertise and decision making are exchanged through an

established complex of institutions, networks and understandings. The situation in the emerging economies is quite different. On the one hand, the commitment to investment in science is clearly present. Between 2001 and 2011 the R and D investment of the economies of East, Southeast and South Asia (including China, India, Japan, Malaysia, Singapore, South Korea and Taiwan) increased far more rapidly than that of the West with the result that their share of global R and D rose from 25% to 34% (National Science Foundation (NSF), 2014: Chapter 4). Much of this change has been driven by China which has experienced a real annual growth in its R and D budget in this period of 18%, reaching $208 billion in 2011 and making it the second highest in the world league table of R and D expenditure. On the other hand, these impressive figures are not a product of joint science-state initiatives characterized by evenly balanced partnerships. Rather, governments have led and science has followed, certainly to begin with. The reasons are not hard to find. First, until recently, the developing countries did not see investment in science as a priority: they were concerned with existing not future markets. For example, China's R and D investment in 1991 was 0.73% of GDP rising to only 0.91% in 2001. The US equivalent was 2.72% for both years (NSF, 2014: Appendix Table 4.13). Science, and most of all basic science, lacked political value - until the developmental state adopted 'innovation' as its leitmotif in the late 1990s (Wong, 2011). Second, and consequentially, the scientific community in such countries is still building its epistemic identity, institutions, status and relationships with the state. In China, for example, a scientific elite is emerging but it is inexperienced and lacks the characteristics normally associated with successful scientific communities such as self-regulation and promotion by merit (Cao and Suttmeier, 2001; Suttmeier and Cao, 1999). Third, science is a transnational enterprise dominated by the West. The continuing migration of scientific labour from the developing to the developed countries reinforces existing scientific communities and constrains the formation of new ones (Hunter *et al*, 2009). At the India Institute of Science,

in 2005 90% of those who finish PhDs chose to move overseas (Jayaraman, 2005). In 2004, China's Ministry of Personnel estimated that of about 580,000 students who had travelled abroad to study since the late 1970s only 27% had returned (Li *et al*, 2004). In a sense it can be said that developmental and competition states have done what they have always done. The former have used bureaucracy and targeted finance to build innovation capacity in the future markets of science, the latter have relied on their historic dominance of the global knowledge markets through the transnational power of their scientific elites to persuade key elements of that capacity into the scientific jurisdictions of competition states. How far is this true of bioinformatics?

State strategies in China, India and the UK

A simple structural comparison of the state organisations with the responsibility for supporting the development of bioinformatics in China, India and the UK reveals some initial and instructive differences (Table 1). In China and, to a lesser extent, India, departments of state play the dominant role in the formulation and execution of policy on bioinformatics. In the UK, on the other hand, although the Department of Business, Innovation and Skills controls the overall size of the budget, the details of bioinformatics policy are worked out at the level of the research councils where the scientific community is the dominant influence. The developmental state, top-down, style of innovation governance is most obvious in China where the State Council sets the agenda across policy domains through its five year plans and the subordinate departments, the Ministry of Science and Technology (MOST) and the Natural Science Foundation of China (NSFC), then faithfully interpret that agenda within their established funding programmes. In India, likewise, the five year plans of the Planning

Commission, though less rigidly enforced than in China, nonetheless provide the priority setting framework for the Ministry of Science and Technology and the Department of Biotechnology (DBT).

[TABLES 1-3]

Using these plans as a policy tracking tool, we can see that the significance of bioinformatics was first recognised in India with the launch of the Biotechnology Information System (BTIS) network by DBT in 1986 'to create an infrastructure that enables it [India] to harness biotechnology through the application of bioinformatics' (DBT, 2014). A decade later in China, bioinformatics first makes its appearance in the 9th Five Year Plan of MOST's National High-tech Development Programme (863 Programme) with the commitment to fund a project on the 'Development and Establishment of a Database for Bioinformatics' and a centre for bioinformatics within the College of Life Sciences at Beijing University in 1996, with the intention it should act as the official mirror site for major international biological databases (Wei and Yu, 2008). Thereafter, an analysis of the five year plans of the relevant state agencies of both China and India show the continuing presence of lists of projects apparently designed to enhance the bioinformatics capacity of the two countries through the creation of databases, clusters, networks and skills (Datta, 2014; Zhou, 2014). In the decade up to 2014, the total funds committed were £303 million in China and £19 million in India (Tables 4 and 5). However, some caution should be exercised in interpreting the apparently large Chinese investment. Most of it is supplied by the industry-oriented Ministry of Science and Technology (MOST) and, within this, the majority funding (£216 million of the total £285.8 million) is via the applied 'New Drug Creation and Development' scheme. The role of China's agency for the funding of basic research, the National Science Funding Council

(NSFC), in state support for bioinformatics is a minor one (£14.8 million 2005-13.) Construction of a new bioinformatics epistemic identity is clearly not the objective. In addition, analysis of the policy documents shows that in neither the China nor India case are the numerous initiatives underpinned by any clear scientific conceptualisation of how state support for particular epistemic qualities of bioinformatics can enable the translation of genomic knowledge into healthcare products. Rather, there is an assumption that the components of such support are self-evident and only need to be listed in order to have the desired effect (Datta, 2014; Zhou, 2014).

[TABLES 4 AND 5]

The evidence from our China and India interviews strongly suggests that this deficiency is the result of the state's failure to engage and recruit relevant sections of the scientific community. The approach adopted to bioinformatics development in these states appears to be an outcome not of a scientific understanding of the needs of biomedical innovation (which itself is an outcome of epistemic political bargaining) but of the state's interpretation of what those needs might be. Disaffection with this approach is most evident in China where interviewees point to the failure to establish a national centre for bioinformatics as a symbolic example of the state's insensitivity to demands from the scientific community. One leading bioinformatician described how scientists from the Chinese Academy of Sciences (CAS) originally petitioned MOST for a national bioinformatics centre in 1999, but to little effect. The suggested explanation provides a flavour of the state-science relationship.

> Chinese officials don't know the importance of a national centre for scientific research in China. They think that a new national centre is a kind of waste because

> international databases are open access to Chinese scientists. Another reason is about leadership. More and more Chinese universities and institutes are conducting bioinformatics research and establishing their own bioinformatics centre. Which university or institute, or who, can be the leader of this large project? China won't take any action until we find a proper answer to this question.[Interview 25]

As the interviews make clear, the problem for Chinese scientists is that without a national bioinformatics centre they lack the political muscle, first, to integrate their many and various domestic bioinformatics activities and, second, to engage on equal terms with the major international databases of the West and Japan in terms of setting the agenda and direction for their development. The US's National Centre for Biotechnology Information (NCBI), the UK's European Bioinformatics Institute (EBI) and the DNA Databank of Japan (DDBJ) constitute core elements in the global infrastructure of bioinformatics and a 'dominant, hegemonic presence' to which China has only conditional access (Harvey and McKeekin, 2010: 492).

Indian scientists are equally concerned about the absence of a national bioinformatics centre and the fact that there is 'no common platform where all the data can reside together and people can join to do analysis and collaborate with people for analysis' [Interview 26]. Part of the problem are differences between state organisations regarding the appropriate model to be used in fostering biomedical innovation. As one clearly frustrated interviewee put it:

> The Ministry of Health has a different approach [to biomedical innovation]. Within the Ministry of Science and Technology, CSIR, which is a department in itself, has a different approach. DBT has a different approach, and DSD has a different approach.

> And then you have the Ministry of Commerce which has a different approach. [Interview 27]

One noticeable effect of this fragmentation of direction at the state level is the lack of fit between bioinformatics skills training in India and the advanced needs of genomics based biomedical innovation such as dealing with very large data sets. An Indian interviewee observed:

> The one big grudge that I have is that they're [bioinformatics courses] doing the same thing over and over again, and not enhancing the skills of either programming, or the ability to develop algorithms; those require different kinds of skill sets. They require fundamentals of mathematics, fundamentals of statistics and computer science. [Interview 14]

Similar views were expressed by Chinese scientists, often placing their comments in the context of the absence of a national bioinformatics centre that could and should act as a focus for research-linked skills training comparable to that provided by the UK's EBI.

The presence of a national bioinformatics centre in the UK since 1994 and not, thus far, in China and India reflects the balance of power in the science-state relationship in the three countries. That balance of power is in itself a product of the ability, or otherwise, of the scientific community in the three countries to deal with internal epistemic change and, if successful, then drive forward the resulting agreement. The UK's European Bioinformatics Institute (EMBL-EBI) is Europe's hub for big data in biology (EBI, 2014). It exists because 'science has brought these things together', scientists 'have had to organize themselves in

terms of how they co-ordinate together' and European research 'works through a bottom-up approach' [Interview 22]. Contrast this with the situation in China and India where the identity of the new discipline remains unresolved with the biosciences insisting that computing science contribute a service rather than a creative function to the inter-disciplinary relationship. A leading Chinese bioinformatician commented: 'Many people recognize the significance of bioinformatics for studying bioscience as an instrumental discipline, but fail to see or value its existence and development as a discipline itself' [Interview 38]. In the UK, with science driving the process of change in bioinformatics through the internal politics of its scientific community, it is to be expected that there will be an underlying scientific paradigm guiding and legitimising that change – one that is absent in the state dominated initiatives of China and India. Hence we find that the BBSRC's annual reports over the last decade not only place a growing emphasis on bioinformatics but also conceptualise this change in particular ways. For example, the 2012 report *Bioscience for society. A ten year vision*, having noted with approval the exponential growth of experimental data and the increasing use of *in silico* based modes of research, develops a concept of 'predictive biology' with experimental data, models and bioinformatics tools at its centre (BBSRC, 2012: Figure 1).

The epistemic construction of the new disciplinary identity has been matched by a continuing search by the UK scientific community for resources from a variety of public and private resources. Thus, the EBI is located on the Wellcome Trust Genome Campus in Cambridge and is funded by the Wellcome Trust, the Biotechnology and Biosciences Research Council (BBSRC), MRC, EU, European Member States, NIH, the European Molecular Biology Organisation and the pharmaceutical industry. As this list implies, running the EBI is an internationally competitive business with other national bioinformatics centres the main

rivals. In this context, the support of the UK state for EBI bids for international resources such as those of the EU is a significant advantage [Interview 22]. At the same time, with scientific interests defining the agenda, the institutional expression of those interests across the research councils has been politically aligned through a division of funding labour between the BBSRC, MRC, EPSRC and NERC and their distinctive contributions to the development of bioinformatics made explicit through a Cross-Council Funding Agreement (see EPSRC, 2014). The result is a steadily increasing level of research council funding for bioinformatics totaling £163.9 million since 2005 (Table 6).

[TABLE 6]

Given that UK science has both an agenda and a plan for the development of bioinformatics, the role of the UK state in pursuit of national advantage becomes one of facilitating that agenda through financial and political support at national and international levels. With regard to the latter, it has a head start over its Chinese and Indian competitors because of the global hegemony of Western states in the life sciences. Originally propelled by the HGP and HapMap projects, the creation of global institutions supporting databases by Western states rendered 'genomics a selectively global industry, creating a specific map determined by Western science, technology, and government and economic interest' (Thacker, 2006: 18). Control of the databases ensures that Western science set the rules both for their operation and for the requirements of access to them. Hence there is a much lower chance of

incorporation of data from less prestigious, non-English speaking laboratories in developing countries and less chance of the scientists from such countries participating in the development of international databases (Leonelli, 2014: 10). One leading Chinese bioinformatician described how he was still waiting for access after applying to the NCBI database of Genotypes and Phenotypes (dbGaP) four years ago [Interview 23].

What Harvey and McKeekin have termed the 'political economy of self-regulation in bioinformatics' serves to fuel the continuing evolution of fresh forms of governance regarding quality, standards and norms by the international scientific community. They cite the proliferating range of bioinformatics tools developing standards for harmonizing the 'ontologies' of data in diverse databases through organizations such as the Microarray Gene Expression Data Society, the Macromolecular Structure Database as part of the worldwide Protein DataBank (wwPDB) and the Gene Ontology Consortium project (Harvey and McKeekin, 2010: 502). Such examples of the institutional controls continuously generated by Western science illustrate the hegemonic dynamic of bioinformatics governance which began with the creation of the Bermuda rules in 1996. Attended by the Wellcome Trust, the NIH National Centre for Genome Research, the US Department of Energy, the Human Genome project of Japan, the German Human Genome project, the UK MRC and the European Commission, this meeting set out the new rules for the deposition of genomic data as a precondition for international collaboration between contributing laboratories to the human genome project (Harvey and McKeeking, 2005: 55). Since then, Western transnational networks of science have constructed through their communities of experts a political architecture of bioinformatics self-regulation with which Chinese and Indian scientist are obliged to collaborate on Western terms. If they do not accept the standards embedded in this hegemony they will not get published [Interview 14].

Chinese and Indian scientists recognize the fact of Western dominance in bioinformatics and typically see their development in this field as behind the global pace, describing themselves as '4-5 years behind the West' [Interview 18 – China] and 'we're always laggards' [Interview 14 – India]. A director of a Chinese genomics research centre commented: 'Bioinformatics in China is still at a relatively early stage, with few internationally influential articles, databases, algorithms, and software. The collaboration between bioinformatics research and experimental biology is not adequate.' [Interview 37] From the UK perspective, although bioinformaticians interviewed would frequently have collaborations with scientists in the US, Europe and Japan via common databases and networks, their collaboration with China and India is, at best, described in terms of potential and the provision of advice rather than regular interaction with equal partners. From this imbalance between developed and developing countries then stems the frustration of Chinese and Indian scientists with what they see as their governments' failure to fight their corner, documented earlier. A further difficulty for China and India is that the hegemony rests not just on the global reach of the Western scientific community but also on the market infrastructure that supports it. Bioinformatics in the developed world engages with a vibrant industry anxious to provide both services and creative input to the translation of genomic data into clinical utility (Harvey and McKeekin, 2007). EBI has an organizational arm devoted to the cultivation and maintenance of such relationships including an EBI-bioinformatics industry 'club' which meets four times a year to exchange views and develop agendas [Interview 22]. And the newly established Genomics England, although a government initiative, is contracting out much of its bioinformatics work to private industry in its project to bring biological and clinical data together (Genomics England, 2014). By contrast, India has a small bioinformatics sector constituting barely 2 per cent of the biotech sector (Federation of Indian Chambers of Commerce and Industry

(FICCI), 2012), and geared mainly to low level, routine bioinformatics services and not to the needs of advanced research [Interview 25]. Similarly, China's bioinformatics industry is, as a director of a Chinese university bioinformatics department put it, 'small scale and low level', focusing on the processing of bioinformatics data with little capacity for 'challenging research work' [Interview 38].

Conclusions

As a case study of an emergent knowledge territory, bioinformatics provides important insights into the roles of science and state in the national and transnational politics of innovation in the life sciences. The governments of China, India and the UK are unanimous in their belief that bioinformatics should supply the link between basic life sciences research and its translation into health benefits for the population and the economy. Yet at the same time, as ambitious states vying for position in the future global bioeconomy they differ considerably in the strategy adopted in pursuit of this goal.

At the political heart of these differences lies the interaction between epistemic change within the scientific community itself and the apparatus of the state. In the UK, although there are continuing tensions in bioinformatics between the epistemic domains of mathematics and computer science, on the one hand, and biology, on the other, they are tensions which have been institutionalized and managed through the scientific community's control of the research councils and access to private funding bodies such as the Wellcome Trust. Led by the political imperatives skillfully engineered by genomics, science has recruited the UK's competition state to a strategy that neatly blends scientific interest, national ambition and population benefit into a convincing vision of the future. The state, for its part, is able to

delegate to science the thorny political issue of how to maintain the UK's position in the global competition for advantage in life sciences innovation. With the state acting as facilitator and providing appropriate political and financial support, science then takes responsibility for the delivery of a common agenda. The customary concordat between science and state is thus maintained.

In contrast, both China and India lack an established and self-confident scientific community with the capacity to define its own agenda for the development of bioinformatics and relate that agenda to the needs of the state. For the most part, the negotiation of how the epistemic partners of mathematics and biology are to be brought together to produce a new discipline of bioinformatics capable of energizing life sciences innovation remains incomplete. Individual scientists have taken the initiative in India but these have not cohered into a plausible strategy. In China, scientists are unaccustomed to defining the future scientific agenda and so await guidance from a state apparatus which lacks the expertise to construct it. In both countries the absence of clear leadership from science has left the developmental state to launch a series of policy initiatives in bioinformatics backed by no clear conceptualization of their combined contribution to life sciences innovation. As a result, bioinformatics in China and India continues to perform a service function to biomedical science rather than a creative function to biomedical innovation. Confronted by the hegemony of a Western science sustained in the field of bioinformatics through a powerful global network of databases, scientific organizations, governance, and supporting markets, both science and state in China and India are obliged to wait in the wings for the opportunity to participate in the bioinformatics revolution. Their position is a reflection of the global politics of life sciences innovation where power is embedded through the historic control of epistemic territory.

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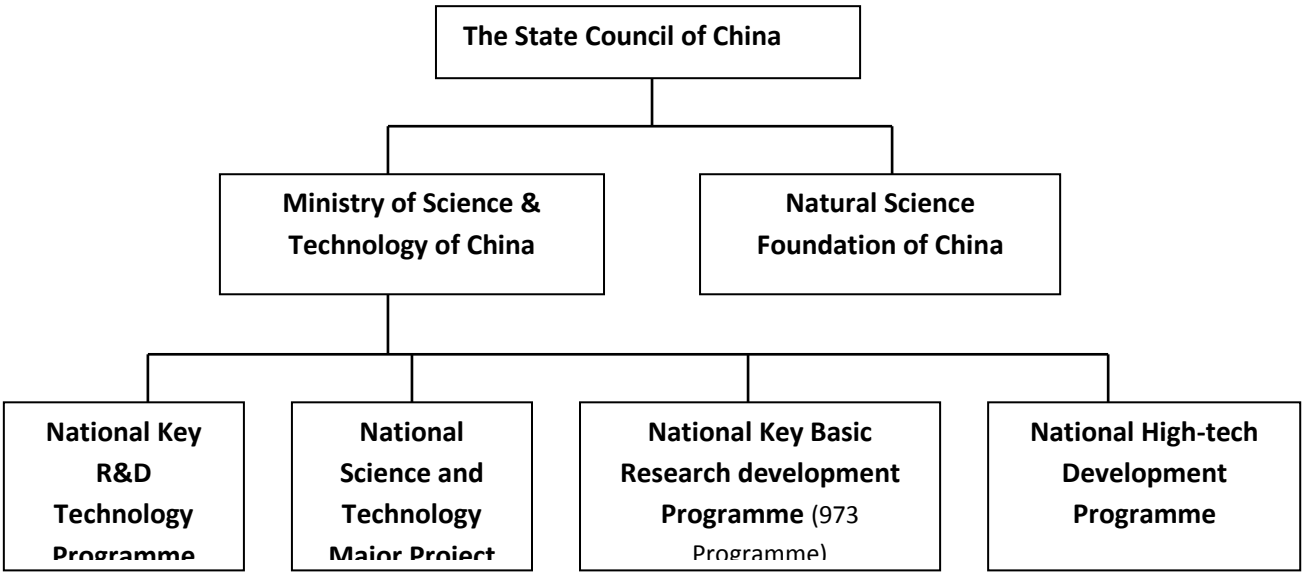
Table 1

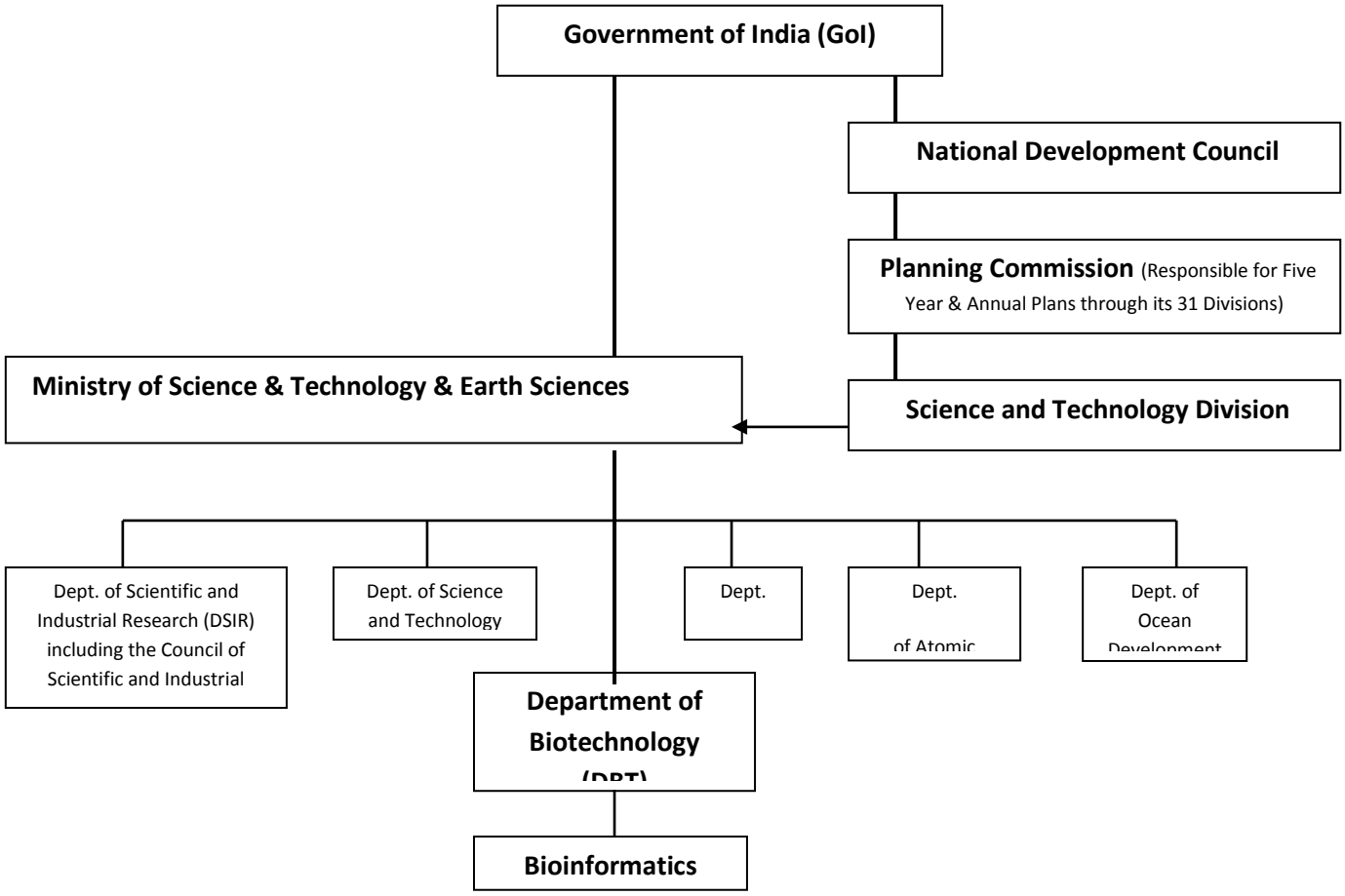
Bioinformatics policy and funding: China state structures



Source: The Ministry of Science and Technology of People's Republic of China (http://www.most.gov.cn/eng/programmes1/index.htm); National Natural Science Foundation of China (http://www.nsfc.gov.cn/)

Table 2

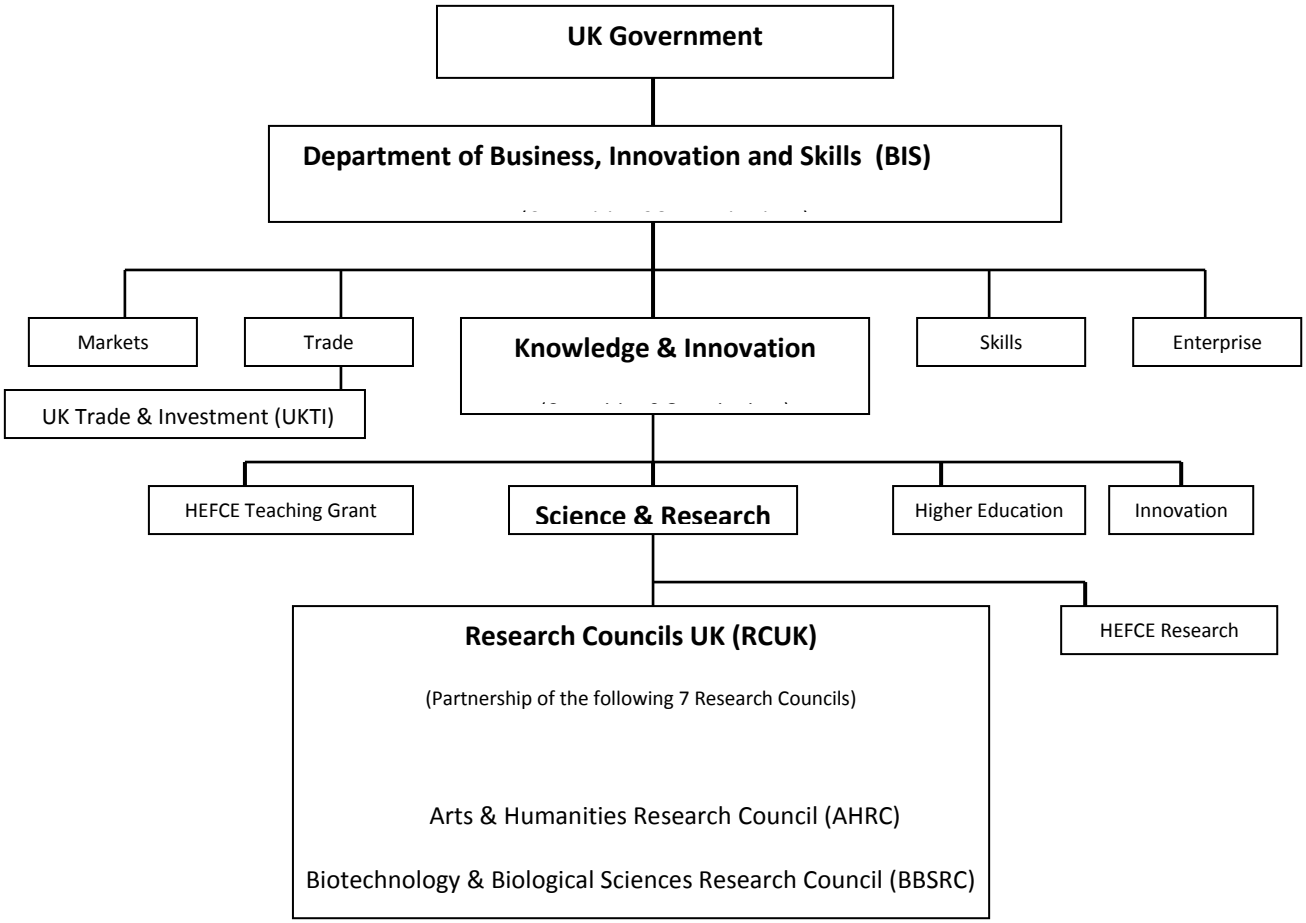
Bioinformatics policy and funding: India state structures



Source: Department of Science and Technology, Government of India (see http://www.dst.gov.in/>); Planning Commission Government of India (see http://planningcommission.gov.in/aboutus/history/orgn.php?about=orgbody.htm).

Table 3

Bioinformatics policy and funding: UK state structures



Source: Guide to BIS 2012-2013 (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/34764/12-p120c-guide-to-bis-2012-2013.pdf).

Table 4(a)

China: MOST funding of bioinformatics (2005-14)

Year	Scheme	Category	Funding (£ million)
2005	The National Program for Sci-Tech Basic Conditions Platform Construction during the Year of 2004-2010		0.3
2006	863 Programme	Bioinformation and Computational Biological Technology	8.0
2007	863 Programme	Bioinformation and Computational Biological Technology	6.5
2008	863 Programme	Bioinformation and Computational Biological Technology	2.0
	863 Programme	Biological and Medical Technology- Genome-wide Association Study and Pharmacogenomics Study on Common Severe Diseases	20.0
	11th five-year National Key Technology R&D Plan	Key Technology Development and Demonstration of Public Information Share and Exchange for Biotechnology Industry	3.0
	Second call for 11th five-year plan National Science and Technology Major Project	New Drug Creation and Development (2009-2010)	216.0
2010	2011 National Science and Technology Major Project	New Drug Creation and Development	10.0
2011	2012 National Science and Technology Major Project	New Drug Creation and Development	N/A
2013	863 Programme (2014)		20.0
2014	863 Programme (2015)	Biological and Medical Technology - Key Technology of Biological BIG DATA Development and Application	N/A

Total			**285.8**

Source: the Ministry of Science and Technology of the People's Republic of China (http://www.most.gov.cn/)

Table 4(b)
China: NSFC funding of bioinformatics (2005-13)

Year	Funding (£million)
2005	0.9
2006	1.0
2007	0.9
2008	0.8
2009	1.2
2010	0.7
2011	2.4
2012	3.3
2013	3.6
Total	**14.8**

Source: National Natural Science Foundation of China (isisn.nsfc.gov.cn)

Table 5

India: Department of Biotechnology funding of bioinformatics (2005-14)

Year	Funding (£million)
2005-2006	1.7
2006-2007	2.3
2007-2008	2.1
2008-2009	2.1
2009-2010	1.2
2010-2011	2.2
2011-2012	1.9
2012-2013	2.0
2013-2014	2.5
Total	**18.0**

Source: Datta. 2014: Annex 1

Table 6(a)
UK: BBSRC funding of bioinformatics (2005-2014)

Year	Category/Theme	Funding (£million)
2005	Bioinformatics	0.0
2006	Bioinformatics and Biological Resources Fund Pilot	6.4
2008	Bioinformatics and Biological Resources	5.5
2009	Bioinformatics and Biological Resources	6.7
2010	Bioinformatics and Biological Resources	7.1
2011	Bioinformatics and Biological Resources	5.5
2012	2011-2013 Tools and Resources Development Fund Call 2	1.9
2012	Bioinformatics and Biological Resources	6.6
2012	Tools and Resources Development Fund Call 2 (bioinformatics tools and computational approaches to the biosciences)	1.5
2013	Bioinformatics and Biological Resources	6.0
2014	Bioinformatics and Biological Resources	6.5
Total		**53.7**

Source: * data from '*BBSRC 20 Years of Pioneering*': http://www.bbsrc.ac.uk/web/FILES/Publications/anniversary-brochure.pdf
Biotechnology and Biological Sciences Research Council (BBSRC): http://www.bbsrc.ac.uk

Table 6(b)
UK: MRC funding of bioinformatics (2012-15)

Year	Category/Theme	Funding (£million)
2012	MRC/BBSRC Systems Immunology of the Human Life Course	3.0
2012	Initiatives in Informatics Research	19.0
2013	Initiatives in Informatics Research	20.0
2014	Initiative in Medical Bioinformatics	39.1
2015	Initiative in Medical Bioinformatics	10.9
Total		**92.0**

Source: Medical Research Council (MRC): http://www.mrc.ac.uk

Table 6(c)
UK: EPSRC funding of bioinformatics (2013)

Year	Category/Theme	Funding (£million)
To present	Biological Informatics	14.2

Source: Engineering and Physical Sciences Research Council (EPSRC): http://www.epsrc.ac.uk/research/ourportfolio/researchareas/bioinformatics/

Table 6(d)
UK: NERC funding of bioinformatics (2012-19)

Year	Category/Theme	Funding (£million)
2012-2019	Mathematics & Informatics for Environmental Omic Data Synthesis	4.0

Source: Natural Environment Research Council (NERC): http://www.nerc.ac.uk