Bioinformatics Imaginaries in the Engine-Room of Genomic Health Policy:

Integration and Heterogeneity in India and the UK

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Abstract

Bioinformatics comprises a diffuse field of technologies, knowledges, databases and software for medical and pharmaceutical innovation. It is becoming a major target of policymaking for global health goals, but experiences conflicts including over ownership and access; national versus commercial agendas; disease targeting; genomic versus clinical data. The paper draws on the political economy of states, and the performativity of policy and 'sociotechnical imaginaries' to identify diverging framings and imaginaries in a comparison of India and the UK. It argues that bioinformatics policies are diversified in India and increasingly co-ordinated in the UK; integration of clinical with genomic data is more prominent in the UK and more geared to hegemonic 'platform' technologies; India has more nation-focused, societal policy in disease strategies, and notable heterogeneity in the social production of genomic knowledge. The paper develops STS concepts by linking them to political state theory, highlighting social heterogeneity in technoscientific innovation.

Keywords: bioinformatics, sociotechnical imaginaries, India

Introduction

Biomedical innovation has become a priority in the industry policies of many states worldwide with scientific ambitions. States' pursuance of innovative life science research and bio-industries takes place under conditions of globalisation. A recent study identifying the 'top 10' biotechnologies that would further the UN Millennium Development Goals of 2000 (aimed at alleviating conditions of the world's poorest people, three of which are directly health-focused) included:

- bioinformatics to identify drug targets and to examine pathogen-host interactions; and
- combinatorial chemistry for drug discovery. (Daar et al., 2002)

The unravelling of the human genome is said to have stimulated a 'gold rush' in this field of bioinformatics (Howard, 2000). Visions of the potential impact of genomics- based medicine on public health objectives globally have consequently escalated. Sociological analysis proposes that bioinformatics changes the way scientific research is undertaken: "Laboratory life has changed to become more virtual, and the experiment has become redefined to rely increasingly on the construction, curation and mining of large scale databases" (McNally and Glasner, 2006). The worldwide mushrooming of 'data science', 'big data', whole genome sequencing, and medical informatics is replete with utopian visions of a revolutionary impact on global health, perfectly exemplified by the founder of Microsoft Corporation:

> Today, we're in the midst of a remarkable transformation that will see computing revolutionize scientific discovery (…) In healthcare, data-driven medicine and the ability to compute genomics and proteomics on a personal scale will fundamentally change how medicine is practiced. Medical data will be available in real time to be analyzed against each person's individual characteristics, ensuring that medical care is truly personal (…) All of these advances will help medicine scale to meet the needs of the more than 4 billion people who lack even basic care today (Bill Gates, opening an academic computing centre in the US; Gates, 2009).

The type of techno-utopian, global vision shown by Gates is a familiar trope for STS scholars, but the huge resources at the Foundation's disposal means that its vision has to be taken seriously for its performative effects in the globalised health research and policy arena. This paper examines the framing of the emerging paradigm of data science, in the form of bio-informatics, in the bioeconomic policies and practices of two contrasting democratic states, India and the UK. As Salter et al. (2016) have suggested, bioinformatics constitutes a new 'epistemic domain' in the life sciences, and is thus the subject of political initiatives that frame bioinformatics in terms of states' overarching ambitions and national visions. Conceptually, therefore, this paper envisages these policy framings in terms of 'sociotechnical imaginaries' (Jasanoff and Kim, 2009, 2013, 2015), images of technoscientific developments that are linked to projections of global innovations, nationhood, collective identities, institutional and infrastructural designs and societal visions, "collectively held, institutionally stabilised and publicly performed visions of desirable futures" (Jasanoff, 2015:4).

Bioinformatics comprises a diffuse, hybrid and unstable field of technologies (e.g. biochips, microarrays, supercomputers, 'the cloud'), skills, knowledges, databases and software tools aiming notably at the development of new drugs as personalised or stratified medicine. Apart from the sheer quantity of 'big data', the distinctive, novel characteristics of the turn to computational methods in biology have been conceptualised to lie in the "methods, infrastructures, technologies, skills and knowledge" now required (Leonelli, 2014). As national life science policies have become ever more ratcheted up governments' political agendas, it is clear that bioinformatics specifically is becoming a clearer target of policymaking through investment schemes, infrastructure-building and skills development. The development of this computational biology is increasing the scales of international collaborative activity and reconfiguring inter-disciplinary boundaries between biology, computer science, bio-engineering, and statistics. However, different countries and their nation-state polities are enacting this digital revolution in different ways (Hardy et al, 2008). In broad terms, it is important both to biomedical actors, and to the theoretical project of STS, to try to document and understand "why differences persist in (…) the constitutional position of science and technology in the political order" (Jasanoff, 2015:4). The national and transnational policy visions – 'imaginaries' - and actions driving policy trends in bioinformatics do indeed show wide geopolitical and societal variation, which this paper addresses, both conceptually and empirically.

Social science of bioinformatics

Bioinformatics has so far attracted little, though growing, attention from scholars in STS, sociology, anthropology and political science. Most of the work to date can be described as focused on 'internalist' accounts, describing and interpreting the epistemology, knowledges, disciplines, field-shaping claims, data forms and processes internal to the field. For example, Lewis and Bartlett (2013) emphasize the lack of 'disciplinary coherence' in the field, its service status in relation to biology within academia, and the disciplinary identities of practitioners of bioinformatics as either developers of tools or service providers; Mackenzie (2003) emphasizes the potential for private property ownership in the field. Stevens (2013) has charted at length the emergence of bioinformatics focusing on the convergence of biology, mathematics, statistics and computing, producing virtual, computational experimental space. Zwart (2009) considers the implications for human identity. Less internalist, and from a perspective of economic innovation studies, Harvey and McMeekin (2009), have discussed tensions between property issues and 'the commons' in the field.

Conceptual approaches

In contrast to these accounts, the present paper draws together two main conceptual strands, first, theory of the political economy of states in the global context of biomedical innovation, and second, a methodological orientation to the performativity of policy discourse, here especially in relation to national health and related institutional projects, which draws also on the substantive concept of 'sociotechnical imaginaries' as noted above (Jasanoff and Kim, 2009, 2013, 2015). I introduce these approaches in the paragraphs below.

The paper undertakes a comparison of bioinformatics innovation policymaking in two democracies, the UK and India. This comparison enables the development of a theorisation of innovation policy that goes beyond simply politico-economic or neoliberal capitalist framings. While it is not necessary to rehearse in detail the well-known key characteristics of these two countries' recent healthcare, academic and medical histories, some important features can be noted here. Notably, the UK has a publicly funded national healthcare system (the NHS); recent years have seen the government-driven growth of infrastructures to embed highly-resourced bioscientific and clinical research enterprises ever more deeply into this system. At the same time, large pharmaceutical companies are based in or have major facilities in the UK, with a primary motivation toward new drug development and close academic ties. In contrast, India is known for its strong IT sector and as a destination for the outsourcing of clinical trials from the more advanced bioeconomic states. The pharmaceutical industry in India has since the 1970s been dominated by its 'generics' industry, supported by strong political opposition to restrictive patenting by foreign pharma companies, though this situation has become more complicated in the last decade (Sariola et al., 2015) . At the same time, the healthcare system in India is largely based on out of pocket payment along with public hospitals and some private insurance, with some strong private hospital chains emerging. The two countries, of course, have vastly different sizes of population, overall standards of living, and population disease profiles, although it is important not to overstate the latter – cancers in general, for example, being highly prevalent in both countries. However, the "rise of the middle classes" is having a significant impact on India's disease profile, especially diabetes and its related symptoms, and certain cancers show far higher incidence in one country than the other (Ferlay et al, 2015).

The geopolitics of biomedical innovation governance has become a clear feature of the emerging global bioeconomy. With the rapid rise of, especially, China and India in the life sciences, the position of the United States (US) and European countries is being challenged. As a result, a new political dynamic is emerging as states, multi-national corporations, academic research institutions and civil society organisations jostle to set innovation agendas, obtain and deploy resources and establish politico-economic positions (Salter & Faulkner, 2011), governance being defined as political processes in which a variety of actors may play a part, not confined to direct government institutions and agencies (Rhodes, 1996). This dynamic thus constitutes a key force in global health governance. Because their perceived innovation needs, capacities and population health ambitions are different from those of the states and regions of the West, BRICs countries such as China and India are likely to pursue their collective interests and particular strategies on scientific biomedical knowledge production in global health in distinctive ways (Salter and Faulkner, 2011).

Political economy of states

In terms of international political science, the UK has been conceptualised as a 'competition state'. In this perspective, the advanced economies of North America and Europe were understood to react to the uncertainties accompanying the shift to post-Fordist modes of production and consumption with an approach to seeking national advantage around knowledge innovation itself in the context of globalisation (Hay, 2004). States such as Japan and South Korea were seen as 'developmental states' attempting to join the existing Western economy, and by contrast, India and other BRICs countries have been seen as moving to become 'adaptive', 'post-industrial developmental', 'flexible' or 'transformative' states (Weiss, 2000; Kim, 1999; Wu, 2004), seeking not only to participate responsively in existing markets but also to forge their own novel spaces, knowledge and technologies.

Although addressing states' and nations' issues of political economy from an anthropological and ethnographic rather than state theory perspective, and focusing on the workings of capitalism in the 'postgenomic' age, Sunder Rajan (2006) writing from a Marxian perspective, also has emphasized a 'market logic' as the fundamental and almost exclusive motivating force behind states' outward-facing ambitions, resulting in a claimed biotechnology-inspired expansion of the rules of global capitalism. This author's portrayal of (India's) state divergence from the hegemony of US free market economics is not wholly consistent, though his account does allow not only for embrace of, but also 'selective resistance' and 'remodelling' of the paradigm attributed to the US (Sunder Rajan, 2006: 232). However, the apparent significance of such moves Sunder Rajan (2006: 219). judges to be weak, public good goals such as food security and health targets of bioscience, for example, being deemed the dwindling preserve of a 'dying breed.'

However, market logic and a politico-economic capitalist dynamic should not be seen as a simple, one-dimensional process of competition. I will argue that the emerging global, regional and national biomedical innovation ecology is more complicated, and that some local and national innovations amount to ideologically driven counter-movements to such over-arching narratives. One alternative is a more 'modular', decentralised R & D system where different aspects of R & D are distributed globally and conducted almost autonomously in different locations' (Goodall et al., 2006; Sariola et al., 2015). Thus, while in bioinformatics what have been called the 'Rising Powers' are developing innovation governance strategies to compete for a place on the world stage, a variety of different sociotechnical imaginaries are emerging to achieve global reputation, scientific esteem, economic advance and health impacts. As Harvey and McMeekin have pointed out, for example, while Brazilian bioinformatics is not on the same scale as clusters and centres in Europe, Japan, and the USA, where major bioinformatics-based genome and proteome projects have been undertaken for over a decade, the opening up of distinctive innovation pathways with potential global significance offers the possibility of a geopolitical redistribution of scientific innovation. Crucially, "Processes of transformation of a given geopolitical economic order may be less about nation-states catching up leaders or swapping places in league tables and more about *creating new games, increasing the heterogeneity of the global,* rather than being subordinated to or converging with homogenized global leadership" (Harvey and McMeekin, 2005: 654, my emphasis). An example of this possibility in the case of India is discussed below.

Given this global biopolitical context, sociotechnical visions may relate to broad social and national imaginaries as well as health and science agendas per se. Inevitably, there are always tensions between different governance actors, whether defined in terms of a 'triple helix' of industry, government and academia (Etzkowitz, 2008) or more broadly in network governance terms incorporating a fourth dimension of civil society agencies. Given such diversity of actors, governance will be 'co-produced' with science in interaction with its societal and economic contexts. This means a focus on how "knowledge making is incorporated into practices of state-making (…) and in reverse, how practices of governance influence the making and use of knowledge" (Jasanoff, 2004). This in turn implies that in order to understand the dynamics of the contemporary development of innovative biomedical knowledge under conditions of scientific globalization, we must turn our attention to innovation governance policies that enact the sociotechnical imaginaries of policy actors.

The discourse of sociotechnical imaginaries

Hence, the second conceptual strand deployed here aims to draw on concepts of policy discourse analysis and developments in order to shed light on the different ways in which the various governance actors of the UK and Indian states co-produce, frame, configure and construct their bioinformatics-related endeavours. Governance processes are pursued through a wide variety of narratives that construct biomedical materials as contributors to future healthcare, conveying also broader imaginaries such as normative visions of the nature of a particular nation state and principles of socio-political value. As Sunder Rajan (2006: 57) pointed out, the production of biocapitalist value is "to a large extent a discursive act". The grand, and not so grand, narratives of governance policy enact not only visions of the governance object, in this case bioinformatics, but also enact and generate (see Faulkner, 2012) the realities of various social goods such as national identity, national health projects, economic power positions of stakeholders, empowerments of actors participating in the policy domain, and actual innovations in the conditions of knowledge production. As Gee (2014: 8) has it: "(…) when we use language, social goods and their distribution are always at stake, language is always 'political' in a deep sense". These various formulations accord closely with the concept of sociotechnical imaginaries introduced above. Discourse analysis techniques have been used to analyse governance initiatives in genetics, addressing "what sorts of social relations (these) policy documents are a part of; (…) and the dominant forms of representation of science, the economy and patients that they embody" (Kerr, 2003:145). Hence in the case examined here, we can ask: what are the dominant or less prominent policy framings and strategies for bioinformatics, in terms of the states' bioeconomic visions, life science entrepreneurship and population health projects, and what imaginaries of national or international science, bioeconomy and disease priorities do they project?

In the light of these considerations, the paper argues broadly that the innovation ecology, both emerging and imagined, of bioinformatics in the UK is relatively 'joined up', and that in India it is relatively diversified, 'dispersed' and 'modular'. More specifically, policies incorporating bioinformatics are increasingly co-ordinated in the UK, and distributed in India; integration of clinical with genomic data is more prominent in the UK; UK (and EU) initiatives are more oriented to hegemonic 'platform' technologies, whilst India has more nation-focused disease strategies and 'social' (and socialist) bioinformatics infrastructure. In terms of the global health academic field I assume that the innovation ecologies and co-produced governance actions of the two states discussed here are imagined and performed by the participating actors, in a context of a developing global bioeconomy and perceived health policies and problems which display somewhat different patterns between the two cases, and which mobilise different broad political cultures and values. Hence, via bioinformatics imaginaries, both states and their state governance, funding, commercial, biomedical, technoscientific, ethics and social actors participate in different ways in global health governance (Lee and Kamradt-Scott, 2014).

The structure of the paper is as follows. First, the research on which the paper is based is briefly described. This is followed by the two main substantive sections of the paper, the first on the UK's policy development and commitments to bioinformatics, and the second on India's. The two accounts are then discussed in terms of states' innovation ecologies and the co-production of governance through the sociotechnical imaginaries of policy and its discourses in the concluding part.

A note on method

This paper is based on research conducted as part of a UK Economic and Research Council (ESRC) funded team research project, conducted at King's College London and the University of Sussex, UK, from 2012-15, which examined strategies of governance of biomedical innovation in the UK, China and India (Salter et al., 2012). The project focused on regenerative medicine and 'personalised' medicine. Ethics approval was obtained from King's College London Research Ethics Committee (REP-L/12/13-10). A wide range of documents were assembled including government policies and plans, stakeholders' position papers, scientific articles, media reports and commentary, and market analysis. Fieldwork consisted of semi-structured interviews, conference/meeting observations and 'policy workshops'. One multi-stakeholder workshop held at the University of Sussex in the UK was conducted on bioinformatics in 2015. Thirty interviews directly on bioinformatics/pharmacogenomics policy or referring to it were conducted by members of the research team including the present author, mainly in academic centres and with policymakers, in the UK, US, India (and China). However, the present paper draws mostly on systematic and comparative thematic content analysis, and data analysis, of the types of documentary and publicly available sources noted above.

UK imaginary of bioinformatics: genomic medicine and translation frames

The most prominent actors shaping the collective imaginaries of UK bioinformatics policy have been government departments, special government committees, charitable and government-based funders, and elite science institutions. Medical and health applications have superseded agribusiness in recent government policy development (Harvey and McMeekin 2002). Much of the policy development in UK bioinformatics is thus now framed in terms of 'genomic medicine'. A close connection between the UK's National Health Service, genomics and computation was signalled as early as the 1990s:

> The United Kingdom National Health Service (…) has the potential to serve as a unique resource for population genetics research (…) require appropriate scientific and clinical skills matched with large-scale computational infrastructure and proactive, transparent, and coherent policies for addressing the ethical, legal, social, and political issues arising (…) (Fears and Poste, 1999: 267-268; cited in Martin and Hollin, 2014)

It was also argued by Fears and Poste (1999) that public-private partnerships would be essential to realise this vision. Continuing in this vein, the UK's House of Lords conducted an inquiry into this topic in the late 2000s, to which the government responded (Secretary of State for Health, 2009). Their response included noting recent investments and a range of measures specific to bioinformatics, notably:

> In 2009 more than £9 million (…) awarded by the MRC (Medical Research Council) to support the UK research community's access to high quality equipment for DNA sequencing via substantial investment in the latest technology. Four regional hubs located across England and Scotland will provide technical support and bioinformatics expertise
>
> We recommend the establishment of a new (i.e. national) Institute of Biomedical Informatics to address the challenges of handling the linking of medical and genetic information in order to maximize the value of these two unique sources of information (…). The Institute would guide the NHS in the creation of NHS informatics platforms that will interface with databases containing personal genetic data and with publicly available genome databases (Secretary of State for Health 2009, Paragraph 8.23).

In the above we see how bioinformatics is being brought under the umbrella framing of genomic medicine, and also strongly linked to the public healthcare system of the NHS, with the transformation of patients' health records into research data. The emphasis on central and national imaginaries of data and data experts is clear.

The UK government also produced a national Life Sciences Strategy (having earlier created an Office for Life Sciences within its then Department for Business, Innovation Skills (BIS)), which was launched by the Prime Minister in November 2011. The policy makes some specific provisions for increasing bioinformatics capability in the UK, including involvement in key European infrastructures, which are based in the UK, notably:

> ELIXIR is a programme to assemble and manage biological and genetic information generated by research. (…) It is vital that this data is collected, stored and curated in user-friendly ways that allow its efficient retrieval and rapid exploitation. ELIXIR will allow us to do just this. (BIS Office for Life Sciences, 2011: 11)

In this policy vision, we see that the imaginary of national informatics-based genomics is linked to broader European infrastructures addressing the technical challenges of collecting and exploiting biological data. The central role of the UK is presented as fundamental to these developments.

> We recommend that the Government show leadership on leveraging sustainable funding to the European Bioinformatics Institute (EBI), through the European Research Infrastructure (ESFRI) instrument and through the UK Research Councils (…). This forms a key part of the emerging pan-European science project, the European Life Science Infrastructure for Biological Information (ELIXIR), an initiative involving 32 partners from 13 countries. (House of Lords, 2009: 50)

The UK's central role in the broad imaginary of the entire European 'Life Science Infrastructure' is envisioned here, highlighting the national dimension of a life science project broader even than genomics. In a sign of the joint, integrated commitment to EBI, it is funded by the Wellcome Trust, the Biotechnology and Biological Sciences Research Council, the Medical Research Council, the EU, European Member States, National Institutes of Health (NIH), the European Molecular Biology Organization, and the pharmaceutical industry.

Further, in 2012, Sir Mark Walport, then director of the Wellcome Trust, which spends more than £100 million a year on genomic research, endorsed the recommendations of the report on genomic medicine, emphasizing a link between genomic data and 'improvements in healthcare', in other words the much vaunted field of 'translational' medicine (e.g. European Society for Translational Medicine, 2014):

> We particularly support the proposal to link genomic data to patients' anonymised medical records through a secure national centre, which would create an unparalleled resource for research and diagnosis without compromising confidentiality or privacy. (Department of Health, 2012)

The centrality of 'translational research' in the genomics-related big data domain is exemplified by the way in which 'translation' has become an integral part of the vocabulary of biomedicine's and genomics' policy actors, becoming an 'actor's category' (Sunder Rajan and Leonelli, 2013).

However, tensions in the innovation model to take forward the genomic and life science visions are conspicuous in UK debates. For example, a representative of the Medical Research Council (MRC) asserted that for the true potential of life sciences in the UK to be realised, "industry and academia will have to engage in much more complicated partnerships that in the past (…). The science must remain at the forefront, but each company will see the science question in a different way, so a shared and very well-developed science agenda will be critical" (Mulkeen, cited in Taylor, 2013).

Similarly, medical media headlines have included comments such as:

> Health informatics is set to be a major driver of success for UK life sciences, but the sector - and industry in particular - does not yet have the necessary analytical skills, according to leading experts…"We need to build up a cadre of people who can do this," (government life sciences champion) …Sir John Bell called for the whole process to begin again "with a clean sheet," and to focus on "open and adjacent' innovation" (Taylor, 2013).

In 2012-2013 the UK government announced the formation of 'Genome England'. Genome England would be a company owned by the Department of Health that "will introduce high-tech DNA mapping for cancer patients and those with rare or infectious diseases and link that new data to the patient's medical records" (BusinessWire, 2013). It is the organisational form devised to implement the '100,000 Genomes' project announced in 2012. The £100 million funding would also be used to train healthcare professionals in the clinical application of genomic data, and new genetic scientists to develop novel treatments. From the outset, Genome England was planned to manage the contracts for specialist UK-based companies, universities and hospitals to supply sequencing, data linkage and analysis services. It would have responsibility for regulating issues of data storage and security and patient consent to participation. It was claimed that the project would enable the UK to become the first country in the world to introduce genomics and bioinformatics technology into its mainstream healthcare delivery system. Furthermore, emphasizing the economic dimension of the genomic data imaginary, a prominent feature in the leading British Medical Journal stated that: “the project’s broader goals are to kickstart a national genomics industry and make the UK the first country to routinely use DNA sequencing in mainstream healthcare” (Peplow, 2016).

Now called Genomics England, the DoH company is developing a range of partnerships with companies in different parts of the world, including three big pharma multinationals (namely Roche, GSK and AstraZeneca), and especially in the US:

> The new partners are Cambridge-based Congenica, developers of the Sapientia™ genome analysis and interpretation platform, and California-based Omicia, developers of genome analysis solution, Opal™. Berg Health and NGM Biopharmaceuticals will be joining its industry collaboration, known as the GENE Consortium (Genomics Expert Network for Enterprises). BERG is a Boston based biopharmaceutical company and NGM Biopharmaceuticals is based in South San Francisco (…). (Bazeley, 2015).

These developments in commercial partnerships mobilise the cross-national, and inter-institutional imaginaries that are shaping UK bioinformatics infrastructures for genomics. In parallel, it is important to note the development of initiatives aimed at further embedding genomics data and research in the UK’s National Health Service. Key to this is the development of the Genomics England ‘Clinical Interpretation Partnership’ (GeCIP; Genomics England, 2016), with a growing range of clinical disease aims and some cross-cutting subjects such as health economics. GeCIP’s ‘research themes’ also confirm that the main focus of research is on cancers and ‘rare diseases’, with infectious disease a more recent third priority. The infectious disease theme is being led by Public Health England, especially with its aim to eradicate tuberculosis from the country, partly associated with population migration (Public Health England, 2016). The attention to rare diseases is significant, because a great deal of entrepreneurial therapeutic pharmaceutical innovation is focused on such diseases, which attract various commercial and regulatory incentives (especially as ‘orphan drugs’) (e.g. Meekings et al., 2012).

Alongside government departments, charitable funders and scientific and commercial elites, civil society organisations and academic actors on ethical issues have been (and continue to be) prominent in the evolution of the UK’s health-related bioinformatics policy. This has taken the form both of critically collaborative involvement, indeed including government-enrolled specialists, and of activist opposition to genomic personal data processing. While this is not the place for a detailed exposition of the ethical issues, I briefly refer to the most notable actors. Most notable at the outset was Genomics England’s own in-built ethics working group, led by a prominent academic ethicist (Parker, 2013). This initiative went on to become an ‘ethics and social science’ theme of GeCIP (Genomics England, 2016). Likewise, a major independent ethical body, the Nuffield Council on Bioethics, convened consultations and reported on issues of data privacy, including bioinformatics applications (Nuffield Council, 2015). Opposition to the data privacy issues has come from various quarters, most notably activist group GeneWatch UK (e.g. GeneWatch UK, 2015). Thus, we can observe here signs of a participative engagement with institutional constituencies representing social and ethical concerns. Whether the involvement of such actors represents effective challenges to the genomics imaginary, or lends it legitimation, is open to debate.

Thus, overall we can see bioinformatics being strongly drawn into the agenda of a sociotechnical imaginary in the form of a future nation state-based vision for healthcare and medical innovation based on the genomic revolution. Its innovation ecology notably envisions an embedding of bioinformatics in healthcare delivery organisations through integration of electronic patient record data alongside the genomics research agenda, this integration typically being articulated in the terms of ‘translational research’. Cancer and rare diseases are high on the medicopolitical agenda, with strong emphasis on genomics-based drug development and identification of new biomarkers and diagnostics, in other words 'pharmacogenomics'. The location of EBI in England enhances the interconnectedness of bioinformatics in the UK with a broader stabilising and standard-setting network of academic and commercial institutions, and Genomics England further embeds a public-private model in international, Western private enterprise. We also see a strong agenda in developing platform informatics technologies with multiple possible applications. These features provide a striking contrast with developments in India, to which I now turn.

India's bioinformatics imaginary: nationalism, business, disease projects and social participation

The most prominent actors in shaping India's health related bioinformatics vision are government departments, national medical funders, pharmaceutical trade organisations, and elite scientific institutions. However, unlike the UK, the major government departments involved are said to be quite diffuse. One well-placed academic interviewee opined that:

> The Ministry of Health has a different approach [to biomedical innovation]. Within the Ministry of Science and Technology, CSIR (Council of Scientific and Industrial Research), which is a department in itself, has a different approach. DBT (Dept. of Biotechnology) has a different approach, and DSD (Dept. of State Development) has a different approach. And then you have the Ministry of Commerce which has a different approach. (Interview biomedical scientist, New Delhi, 2014)

As noted, India's well-acknowledged expertise in IT and its huge generics drug industry certainly shape the landscape in which its bioinformatics imaginary is developing as a national project. India was one of first countries in the world to establish a nationwide bioinformatics network, which comprised 57 connected informatics centres set up in 1987 from the government department of science and technology. This was initially a technological network allowing electronic network communications. Now, the government Department of Biotechnology (DBT) is the main responsible government department. DST (Science & Technology) is involved especially for supporting biochip technology aspects. The Bioinformatics Institute of India (BII) (which has no equivalent at national level in the UK) was formed in 2002 registered as a professional society under Indian rules, for "academicians, scientists and engineers" (Bioinformatics Institute of India, 2014). The Indian DBT published a national bioinformatics policy in 2004 (again, no equivalent in the UK), with an explicit aim of making India a significant presence on the global stage. The emphasis in these initiatives was clearly at the computational and IT, rather than the biological end of the bioinformatics epistemic spectrum. Nevertheless, the Indian Council of Medical Research (ICMR) has initiatives in the bioinformatics field, outlined below. Thus, developments in India's national imaginaries for bioinformatics strikingly combine attention to the field as a business sector and as a vehicle of (some) national health goals and 'social' innovations in bioinformatics knowledge production, as I elaborate below.

The worldwide market for bioinformatics tools and services was estimated by Indian sources to exceed US$40 billion by the year 2017. Leading industry observer and commentator ABLE/Biospectrum in their Biotech Survey in 2013 reported: "Bioinformatics is growing as an independent discipline and is fundamental to the growth of biotechnology. India has achieved remarkable success in the software industry. BioInformatics sector grew by 11% (2003-13). The fragmented bioinformatics market will see a growth in the coming years because of government's spending on R&D in addition to increase in private fundings" (ABLE/Biospectrum, 2013). It was claimed that over 200 companies have some involvement in bioinformatics in India, divided amongst three types of companies – pure research bioinformatics, IT companies, and CRAMS (contract research and manufacturing services). A "huge proportion" of the sector is said to be focused on outsourced work (RNCOS, 2012), echoing the well-known market for outsourced clinical trials, showing the importance of a commercial dimension to the Indian bioinformatics imaginary.

Alongside the commercial sector, India also has significant activity in bioinformatics in the academic scientific and biomedical sectors. The Indian Council for Medical Research (ICMR) instituted its own Biomedical Informatics Centre, formed in 1999 with support from WHO's tropical diseases research fund (www.who.int/tdr/en/), an early indication of a focus on national disease priorities. A number of disease targets can be identified in their mission - nine centres were initially created. One of the original nine centres (now comprising seventeen 'projects') is the Biomedical Informatics Centre (BMIC) at the Tuberculosis Research Centre (Chennai). The aim of this centre, typical of the model, includes: "to enhance understanding of TB and HIV/AIDS using computational approaches; to provide bioinformatics support for biomedical research; to impart skills in bioinformatics through training programmes / workshops" (http://bmi.icmr.org.in/DDTRP/bic@trc.php). The other BMIC centres include those with a focus on or being part of: the National Institute of Cholera and Enteric Diseases, Kolkata, established 2006; National Institute of Nutrition, Hyderabad; National Institute for Research in Reproductive Health, Mumbai; Rajendra Memorial Research Institute of Medical Sciences, Patna (nano-informatics); All India Institute of Medical Sciences (AIIMS), New Delhi (drug design, protein modelling); Institute of Cytology and Preventive Oncology, Noida; Regional Medical Research Centre, Dibrugarh (malaria and mosquito-borne disease); Regional Medical Research Centre, Bhubneshwar (filarial and dengue disease). Also focused on a disease of major national importance, DBT sponsors TBNet India, a network of thirteen centres whose aims include attempting to understand different strains of drug-resistant TB and gathering and curating published protein sequences, unpublished submitted sequences and cellular, molecular and biochemical data publications on mycobacterial proteins in a Tuberculosis Reference Database. Thus, we see that the academic strand of India's bioinformatics is mobilised by a national disease imaginary comprising a range of predominantly regionally important health issues.

The degree of linkage in Indian policy between bioinformatics and genomics is notably less than in the UK case. Nevertheless, the National Institute of Biomedical Genomics (NIBMG) was established near Kolkata as an autonomous institution by the Government of India in 2010, under the aegis of DBT. This is said to be the first institution in India explicitly devoted to research, training, translation and service and capacity-building in biomedical genomics. The main objective of the institute is to "promote better public health in India by conducting large genetic epidemiological studies on Indian populations on diseases of importance in India, including susceptibilities to infectious diseases and responses to vaccines against infections" (Shirodkar, 2010).

Thus we observe a range of different activity in the bioinformatics field in India, divided between commercial outsourcing enterprise and public government supported informatics activity most of which is targeted to 'Indian' disease issues, some of which is not. The arrival of biomedical *genomics* per se is clearly a very recent and relatively small-scale development.

Perhaps reflecting the diversity of activity in the bioinformatics field, there is notable criticism of the innovation pathway of bioinformatics within the country:

> The present Bioinformatics Policy lacks vision and fails to address the pertinent issues related to research and development in this arena. Hence, to realise this vision, it is essential to form of a stringent and functionary regulatory body, to systematise, control and facilitate projects related to bioinformatics and synthetic biology research. (Interview professor of bioinformatics, New Delhi, 2013)

So the extent of bioinformatics enrolment into the emergence of a national policy imaginary on pharmacogenomics in India is very recent. The Indian government has only since 2012 started addressing the translational issue of pharmacogenomics as part of national health strategy. The main action is to issue guidance on the design of pharmacogenomics clinical trials, which states that trial populations and the aims of trials must have relevance to diseases relevant to the Indian population, thus mobilising a national-level health imaginary. Likewise, the ICMR set up a task force on pharmocogenomics to focus on specific research topics, including identification of genes and pathways involved in "pharmacokinetics and pharmacodynamics of common drugs, and validation of human single nucleotide polymorphisms (SNP) haplotypes of short-listed genes in Indian population" (Shankar, 2011:1). The task force also intended to research the development of an "Indian pharmacogenomics chip" (Parveen, 2010). Survey of commercial activity in the field shows a number of life science companies moving to work in the pharmacogenomics field (Parveen, 2010). However, there is strong internal perception that India, in 'competitive state' terms, is a latecomer to this field:

> India's pharmaceutical market, mostly deals with generic drugs (…) far behind in addressing the foreseeable challenge of drug response monitoring or even on biomarker discovery (…). (…) Scientific journal, *Nature*, in 2010 indicated that India is way behind in the global map of genomic technology landscape. (Banerjee, 2011).

Trade organisations such as an Indian Pharma Industry representative organisation likewise compares India's position to other 'Rising Powers':

> India at this point is ahead of China in chemistry but the impression (…) is that India is weak on biology front especially in genetically modified animals, biochips and basic molecular biology. The biology capabilities are mainly in government institutes with a handful of companies having skills in molecular biology and protein expression.

Commentary on this position also alludes to a need to bridge the gap between bioinformaticians and experimental biologists (DBT, 2011).

In 2014, the ICMR reported that via its taskforce "'we have established 20 Biomedical Informatics Centres of ICMR at various medical colleges and medical research institutes. Our initiative of establishing a centralised ICMR Computational Genomics Centre is in final stages of approval by the GOI (Government of India)" (personal communication, ICMR Bioinformatics Lead, 2014). The vision of this centre is to bring together genomic data with medical information: "(…) the objective is to setup a centralized genomics facility which will provide expertise and infrastructure to researchers in using genomics tools for medical research. Long term plans are to transform the facility in self -sustaining PPP project" (personal communication, ICMR 2014). In mid-2015, suitable private partners to join in a partnership for the envisaged national Computational Genomics Centre were still being sought, showing the practical problems with materialising the genomics-related imaginary being invoked here.

Nevertheless, significant for the Indian genomics-based drug discovery/development sector, is a remarkable initiative with symbolic significance, namely the Open Source Drug Discovery (OSDD) program, supported by the national Council of Scientific and Industrial Research (CSIR), part of DBT. This development in what I call 'social' innovation in bioinformatics can be seen as an example of increasing "the heterogeneity of the global" in the international landscape of bioinformatics, in Harvey and McMeekin's (2005) concept. It is thus an important and distinct institution in India's genomics imaginary.

OSDD is claimed in policy discourse as one of the world's first attempts to apply an open source/participative innovation model drawn from the IT world to pharmaceutical innovation 'neglected' diseases. OSDD aims to discover novel therapies for tuberculosis and other neglected tropical diseases. Its activities are stated to "spread throughout every stage of the discovery process (from 'drug target identification to lead optimization') and has 'initiated discussions with pharmaceutical companies regarding pre-clinical and clinical trials' (OSDD website). Its main achievements to date, according to independent academic commentators, are: "the re-annotation of the *Mycobacterium tuberculosis* genome and the generation of 11 models for prediction of anti-tuberculosis activity" (Årdal and Røttingen, 2012). Årdal and Røttingen's independent Europe-based evaluation of OSDD states that volunteers are attracted to the project by publicity in academic journals and utilizing social media and networks. It has also 'effectively paired up with' Indian universities and colleges, incentivizing students to volunteer as parts of classroom assignments or positioning participation as valuable hands-on experience. They have also "built in an element of patriotism" (Årdal and Røttingen, 2012) linking finding cures for tuberculosis as an Indian responsibility due to the high prevalence of the disease. This effect is reinforced through marketing efforts, like the project's own music video and offer of prizes such as free holiday lets of property 'close to a bird sanctuary' (OSDD website). "Large number of students can participate and benefit from this activity. OSDD's focus is in Drug discovery and Development in TB, Malaria and other neglected diseases. Chemistry, Medicinal Chemistry, Biology and Informatic discipline plays a vital role…" (OSDD website). The OSDD Director is explicit about the local, national identity of this project: "it 'won't work in the Western world because it has to match the ethos of the society", "socialistic principles", "It will work with those students who are hungry to learn, not those who have been given plenty" (Brahmach, 2012; OSDD Director).

Actually, according to these evaluators, the OSDD innovation model is not open source *per se* because it uses a protective license system and in effect a 'gated community' mode of access. It aligns itself with the Indian generics drug industry business model: "The drugs that come out of OSDD will be made available like a generic drug without any IP encumbrances so that the generic drug industry can manufacture and sell it" (...) "(this) creates the environment of affordability"(OSDD website). OSDD claims that:"OSDD brings in the concept of open source, crowd source, open science, open innovation and product development partnership concepts on the same platform and leaves delivery of drugs to market forces" (OSDD website). Thus a societally participative and indeed socialist imaginary mobilises this part of India's heterogeneous bioinformatics vision, extending to social innovation in the institutional means of production of genomics knowledge as well as the national public health targets of its knowledge practices.

India's bioinformatics activity also encompasses not only infectious and tropical diseases, but also non-communicable diseases, now endemic in states such as India. India takes part in the global International Cancer Genome Consortium. Its director (based in the Sanger Centre, Cambridge, UK), referring to the ambition to identify all the genes critical in the development of cancer and emphasizing regional participation, has "hailed the role of the Kalyani-based Institute of Biomedical Genomics" (…) "It is playing an important role in focusing on oral cancer which is quite prevalent in India.," said Stratton' (The Telegraph, Calcutta, 2011). Thus while taking part in an international genomics project, India at the same time promotes disease research that is high priority in its national public health policies.

In summary, these examples of the bioinformatics developments informed by national political and health imaginaries in India show an emerging 'sector' of very diverse activity and visions. On the one hand we see the well-known pattern of outsourcing of clinical trials from the advanced states (cf. Sariola et al., 2015) being reproduced in a developing bioinformatics service sector, and on the other we see a more steered biomedical economy being shaped by government biotechnology and medical initiatives and infrastructures, with some unique national elements and some notable international collaborations. This section has not included any reference to ethical dimensions in the shaping of India's bioinformatics imaginary. Although India has recently tightened ethical regulatory systems in biomedicine, there is no evidence of an equivalent to the UK's institutionalisation of bioinformatics-specific ethics dynamics in the field, local arrangements around specific genomics research centres being the most developed aspect (CSIR centre interview, 2013). In this respect the field strongly parallels that reported for nanotechnology (Beuma and Bhattacharya, 2013). In terms of disease target strategies, it seems clear that the national imaginary of medical and health futures is being constituted as infectious and neglected diseases are being addressed to some extent, and as growing noncommunicable diseases such as cancer are also impacting on the bioinformatics agenda. The published critiques referred to above of some commentators evidences the internal perception of India's lag in competition terms on the global bioinformatics stage, especially in aspects of expertise in biology, though this is a notable critique in the UK as well. At the same time, India has, at least in policy discourse and its sponsors claims-making, established an example of a unique imaginary in the form of a national socialised approach to bioinformatics-informed drug discovery targeting national health projects, through the OSDD. The OSDD in particular can be understood as a participative, national social imaginary that has no real equivalent in the UK (or the advanced bio-economies more broadly).

Concluding discussion

In this discussion, I compare the picture assembled to date in the cases of India and the UK focusing on the political economy and discursive sociotechnical imaginaries shaping bioinformatics in the context of medicine and health on the global stage. I point to the various tensions in the dynamics of the bioinformatics sector that are apparent, and conceptualise these in terms of the policy related concepts of state politics and sociotechnical imaginaries introduced at the beginning of the paper. I consider the significance of these developments for projects of national identity, economy, societal participation, and for specific population health and disease agendas. I highlight issues of policy integration and heterogeneity in the respective regimes.

This paper has shown some of the different stakeholders attempting to construct, through co-production of science and governance, a range of valued national bioinformatics objectives in a context of globalisation. These interventions are being constructed through various national and sectoral imaginaries mobilising bioinformatics work and its actors. Biomedical research is, to a greater or lesser extent, being brought discursively and in practice into the realm of 'translational' research, a metaphor that highlights the aspirational production of medical products while at the same time skating over the computational work involved, for example in centres for 'translational genomics'. Thus, as the comparison of India and the UK demonstrates, bioinformatics may be drawn into relationships with genomic research in a variety of forms, which may achieve an acknowledged status as one of the sectors of the global bioeconomy, alongside the other 'omics'.

In spite of the different emphases in policy discourse and actions, there is evidence that the genomic-related research agendas in India and the UK display a national imaginary geared toward the perceived health needs of the respective populations. The recent initiatives in the UK of Genomics England are most obviously geared toward introducing more personalised genetic/genomic testing directly into the healthcare system, notably in the field of cancer drug therapies. The governance frame in which bioinformatics is being co-produced is that of 'genomic medicine'. In India, the genomic medicine framing is not so strong, though recently being supported in policymaking, as is the ambition to embed genomics and thus bioinformatics into the fabric of healthcare delivery systems and clinical trialling, possibly because of the greater emphasis on commercial bioinformatics services.

The UK focus on 'rare diseases' in parallel to cancer, compared to India's on infectious and communicable diseases, responds to a discourse of 'unmet need' in the UK, in other words medical needs for which there is little research effort; in contrast, India's emphasis is on unmet needs for mass public health population needs. Further, the UK focus on rare diseases points to an emphasis on diseases where genomic science itself has a relatively high chance of progressing, thus supporting a national vision of developing platform technologies of eventual broader, global applicability.

The account provided in this paper provides evidence in terms of national policy of both inward and outward facing policies and actions. Technoscientific nationalist imaginaries can be seen in both cases. In terms of the sectorisation of bioinformatics as a technological zone (Faulkner, 2009), India appears to have currently a mixed bioinformatics economy model with a strong service element serving academic and commercial researchers globally, while the UK has a more public sector-based bioinformatics economy with strong outsourcing and a globally important node in Cambridge, with new nodes being built with new investments. India's plans for a national genomics focused medical bioinformatics central facility are at the time of writing still pending, while private commercial partners to the state commitment are sought.

There are some commonalities in India and the UK in the problems perceived for bioinformatics as a sector, notably the perceived need for more, and more advanced skill-building at the interface of biology and computation. Likewise, both states appear to identify issues in the sector that require regulatory policymaking. In the UK we see an attempt to show that the NHS is "open for business" (to use a phrase current amongst UK government politicians) – the business of clinical trials. In India we see, in competition terms at least, a 'late' emergence of pharmacogenomics discourse compared to UK, and relative lack of an attempt to engineer an integration of national healthcare system, clinical trials and health informatics and bioinformatics in a genomics-driven imaginary of scientific advance.

On this analysis, is India 'less advanced' than the UK or the European collaborations noted in this paper? Or, are there signs of alternative innovation like those mentioned for Brazilian genomics in the introduction here? The self-perception by some critical commentators is indeed that India is 'lagging', although some analyses suggest that India is moving toward a somewhat more innovation-oriented, hybridised (Sariola et al., 2015) pharmaceutical paradigm by expansion of activity in the 'biosimilars' field (Kale and Little, 2007). Nevertheless, the perception of relative 'lag' may be one shaped by imaginaries of Indian genomic health ambitions that are not shared by those non-elite actors active in providing bioinformatics services to customers in the global bioeconomic marketplace. It is thus not easy to define these bioeconomic polities in simple terms as competitive or adaptive states, participating by default in a hegemonically dominated ecology, without considering the different dimensions of its bioinformatics project in more detail. Both regimes are experiencing internal critiques of the gap between computational and biological domains of expertise.

The example of OSDD from India, though it is only one developing initiative, is symbolically resonant in this context. It shows an alignment of emerging, novel genomic-based and disease-targeted science with the existing imaginary of economic interest and market strength of India in generic drug manufacture. The discursive, ideological link forged between a commitment to crowdsourcing participatory science involving bioinformatics, the generics industry, and the infectious disease targets is particularly striking as an example of an imaginary of communitarian *medico*-techno-nationalism. Thus OSDD can be seen as a novel niche in the global innovation ecology of bioinformatics, nurtured by the Indian state governance agencies, which points toward a post-developmental state, participatory form of genomic science where India can lay claim, as it does, to a globally significant stake with a high degree of value-based societal legitimation. In this initiative, India is contributing to the emerging global paradigm of crowdsourcing apparent in many disciplines of biomedical and genomic research (Afshinnekoo et al., 2016). Indeed, here we surely see an example of Harvey and McMeekin's (2005) expansion of the "heterogeneity of the global" innovation ecology of bioinformatics, in other words a partial redrawing of "the rules of the game". This game redirects our attention to the *social means of production* of bioscientific and genomic knowledge as a significant aspect of the sociotechnical imaginary of bioinformatics in the Indian context. This feature remains significant even though the scientific knowledge *products* may be commodified through the existing generics pharmaceutical model. The fact that this novel niche enshrines a strong participatory discourse and practice emphasizes that even if states are competing for position on a global stage in bioinformatics, this stage is not defined purely in terms of economic or political advantage, but admits of more 'social' performativity (cf. Faulkner, 2012). Pressing this interpretation further, it is clear that the OSDD, as a nationalist project, can usefully be understood in terms of the broad tendency in the evolution India's science policy to strongly embrace social' goals, and specifically in the context of postcolonial 'genomic sovereignty' (Benjamin, 2009).

In contrast to India's OSDD, the UK, which has historically prided itself on the socialist roots of the publicly-funded National Health Service, has been forced to develop approaches to the societal aspects of the ethical governance of bioinformatics-based genomics via a high degree of expert academic attention to 'ELSI' (ethical, legal and social) implications of the Genomics England initiative (Martin and Hollin, 2014; Parker, 2015). This initiative inevitably requires major commercial investments and partnerships in operations that require the intimate genomic and clinical healthcare data of tens of thousands of citizens.

The UK's national bioinformatics imaginary, therefore, is characterised by primary attention to the building-up and coordination of infrastructure through public, charitable and private investment. The priority disease targets of Genomics England are those where the science is already most advanced and where therapeutic gains in the relative short term are most likely, at the same time enhancing the science base. Disease focus and infrastructure development are thus closely integrated in the frame of 'translational research'. As a director of a major academic biomedical informatics centre in the US told me, "we are agnostic regarding different diseases". This appears particularly strong in the case of the UK/EU developments, and is perhaps characteristic of genomic research effort focused more on a 'basic science' model of developing platform technologies. Nevertheless, as has been shown above, there are policy priorities and disease target agendas to be discerned in the health imaginaries shaping bioinformatics activity described above. As this discussion of the national political economies of innovation ecology and of the performative national and institutional sociotechnical imaginaries shaping bioinformatics has shown, the policy models of socioeconomic participation developed to pursue these ambitions has some broad commonalities, for example in the search for public-private partnerships, but some very distinctive disparities, notably the diverging models of participatory citizen science.

As the above accounts and analysis have shown, sociotechnical imaginaries work at different levels, through different framings, take different epistemic forms, and find expression through different political cultures, including those of the nation state. Bill Gates' apolitical vision presented at the beginning of this paper represents a very broad, Western, arguably hegemonic, informatics-driven imaginary. Similar dynamics, between powerful 'Western' globally influential institution-building and 'local' national heterogeneity, reinterpretation and resistance appears in other biomedical fields such as stem cell applications (Sleeboom-Faulkner et al., 2016). It appears from the analysis in this paper that the envisioned integration of data science with healthcare intervention is more prominent in the genomics-framed imaginaries of the UK than India, currently. However, one important feature of the 'technopolitical culture' of science and technology is the national style and valuation of social participation (Felt, 2014), and in this respect, India's participatory citizen science illustrated by the 'open source' drug discovery programme reflects a profound difference in political culture between the two states. Hence, we can understand that the ultimate political goals of bioinformatics in the genomics context may be seen not only in terms of the development of health and medicine, but also in the conveying of particular social values of civil society itself.

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