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Open and Collaborative Developments

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Experimentation with radically open and collaborative ways of producing knowledge and material artefacts can be found everywhere - from the free/libre and open-source software movement to citizen science initiatives, and from community-based fabrication labs and makerspaces to the production of open-source scientific hardware. Spurred on by the widespread availability of networked digital infrastructure, what such initiatives share in common is the (re)creation of knowledge commons, and an attempt to redistribute innovative agency across a much broader array of actors.

In this working paper we reflect on what these emerging practices might mean for helping to cultivate more equitable and sustainable patterns of global development. For many commentators and activists such initiatives promise to radically alter the ways in which we produce knowledge and material artefacts - in ways that are far more efficient, creative, distributed, decentralized, and democratic. Such possibilities are intriguing, but not without critical challenges too.

We argue that key to appreciating if and how collaborative, commons-based production can fulfil such promises, and contribute to more equitable and sustainable patterns of development, are a series of challenges concerning the knowledge politics and political economy of the new practices. We ask: what depths and forms of participation are being enabled through the new practices? In what senses does openness translate to the ability to use knowledge? Who is able to influence and control open and collaborative production? Who is able to allocate resources to, and to capture benefits from, the new initiatives? And will open and collaborative forms of production create new relations with, or even transform, markets, states, and civil society or will they be captured by sectional interests?

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Contents

Acronyms

CERN	European Organization for Nuclear Research
GPL	General Public License
ICT	Information and communications technology
NGO	Non-Governmental Organisation
OSS	Open Source Seed Initiative
R&D	Research and development
TreND	Teaching and Research in Natural Sciences for Development in Africa
UK	United Kingdom
USA	United States of America
WHO	World Health Organization

Abstract

Experimentation with radically open and collaborative ways of producing knowledge and material artefacts can be found everywhere, from the free/libre and open-source software movement to citizen science initiatives, and from community-based fabrication laboratories and makerspaces to the production of open-source scientific hardware. Spurred on by the widespread availability of networked digital infrastructure, what such initiatives share in common is the (re)creation of knowledge commons, and an attempt to redistribute innovative agency across a broad array of actors.

In this working paper we reflect on what these emerging practices might mean for helping to cultivate more equitable and sustainable patterns of global development. For many commentators and activists such initiatives promise to radically alter the ways in which we produce knowledge and material artefacts – in ways that are far more efficient, creative, distributed, decentralised, and democratic. Such possibilities are intriguing, but also not without critical challenges.

We argue that key to appreciating if and how collaborative, commons-based production can fulfil such promises and contribute to more equitable and sustainable patterns of development, are a series of challenges concerning the knowledge politics and political economy of the new practices. We ask: what depths and forms of participation are being enabled through the new practices? In what sense does openness translate into the ability to use knowledge? Who is able to influence and control open and collaborative production? Who is able to allocate resources to, and to capture benefits from, the new initiatives? And will open and collaborative forms of production create new relations with, or even transform, markets, states, and civil society, or will they be captured by sectional interests?

1. Introduction

Schistosomias is a serious parasitic infection that damages the health of hundreds of millions of people, and kills thousands, mostly in poor, rural communities (WHO 2017). Praziquantelis, a cheap, off-patent drug is a highly effective preventative treatment, but it produces side effects and has a bitter taste. A priority for the World Health Organization (WHO) has long been to create a slightly different, but equally low cost, version of the drug, containing only the active enantiomer, because this would have fewer side effects and be less bitter, and would therefore more likely to be taken, especially by children. Yet with no financial motive for the pharmaceutical industry, and marginal appetite for scientifically uninteresting work within academia, little progress had been made. In 2010 Australian researchers performed partially successful experiments on a new synthesis, but faced a number of problems that they did not know how to resolve. They therefore deposited all their data in an open-source online electronic lab notebook, based on an open-source platform, Labtrove and, *via* a blog and other digital communication tools, invited the global process chemistry community to help. Scores of academic and industrial chemists, unknown to the team, contributed with ideas and experiments, with no reward other than peer recognition, thus changing the direction of the project in ways that the original team had not anticipated. Within a year a promising low cost method of creating the alternative synthesis had been created. As the researchers recalled, '[t]he crucial message of the open project is this: the research was accelerated by being open' (Woelfle *et al.* 2011).

This example of new ways of practising science has much in common with a range of other contemporary initiatives that involve radically open and collaborative forms of producing knowledge, material artefacts and/or forms of organisation (hereafter 'open and collaborative production'). In areas of application ranging from computer software and farm machinery, to agricultural seeds and environmental governance, and spurred on by the widespread availability of networked digital infrastructure, experimentation with highly collaborative, commons-based forms of production (based on the free flow of knowledge unencumbered by property rights and other restrictions) is flourishing. The central purpose of this paper is to reflect on the potential that these initiatives create for supporting more equitable and sustainable patterns of global development. For many protagonists, the new practices promise to alter radically the ways in which we produce knowledge and material artefacts in ways that are far more efficient, creative, widely distributed, democratic and sustainable. Such possibilities are intriguing, but not without critical challenges also.

We shall argue that the key to appreciating whether and how open and collaborative practices can support more sustainable and equitable patterns of development are a series of issues concerning, (a) the knowledge politics involved in the new practices, and (b) some political economy challenges. A key objective in this paper is therefore to raise, and begin to reflect on, a series of questions concerning those two issues, and we do so by drawing on what we know empirically about open and collaborative production, as well as on insights from innovation studies, science and technology studies and other fields of inquiry. Questions about the knowledge politics and political economy challenges of open and collaborative practices can be usefully grouped into the following issues:

- *Design* The affinities of different initiatives and methods to varied depths and forms of participation and openness;
- *Expertise and hierarchy* Who is able, legitimately, to shape agendas and ask questions about the validity of knowledge, and who is able to influence and control open and collaborative production;
- *Appropriation* Who is able to allocate resources to and capture benefits from open and collaborative production; and
- *The role of mainstream institutions* Whether open and collaborative forms of production will create new relations with investors, markets and states, or be captured by them.

Scholarly research into these kinds of questions is relatively limited. The literature consists of many interesting case studies and some highly abstract treatises and conceptualisations, but there is little in-between those two poles that looks empirically across different areas of open and collaborative practice with a critical but sympathetic interest in the broader possibilities and visions.[1] There is also very little research concerned with the meso-level possibilities of these emerging practices for nurturing more equitable and sustainable patterns of development in regions such as Latin America.

We begin by explaining what we mean by open and collaborative production and why it is relevant to development agendas, and we then briefly illustrate the range of fields in which experimentation in open and collaborative production is occurring. We then discuss the kinds of things that open and collaborative practices are claimed to be producing. We group these into three categories: the promise of efficiency and creativity; the promise of democratisation; and the promise of alternative trajectories of social and technological change. We reflect on what those promises might mean for cultivating more sustainable, globally equitable, pathways of human progress. We then raise a series of questions about the knowledge politics and political economy of open and collaborative initiatives. Finally we conclude with reflections on what we see as some of the central challenges and dilemmas in this field, all of which merit further attention through engaged research and reflective practice.

[1] That said, there is considerable research into the knowledge politics and political economy of more established and recognised forms of knowledge production, such as in social studies of science, and on whose methods and concepts we draw.

2. What is Open and Collaborative Production and why is it Relevant to Development?

It is worth clarifying, at the outset what we mean by open and collaborative forms of producing knowledge and material artefacts. By 'open' we mean that efforts are made to share knowledge and information that might otherwise be protected from unrestricted use by others via claims on intellectual property, such as copyright, trademarks or patents, or that might be kept secret (either deliberately or inadvertently) within an institution or community of practitioners, and to enable it to circulate as freely and widely as possible. By 'collaborative' we mean that efforts are made to widen the number of people involved in production, and to ensure that they work jointly in a shared activity or on a shared conception of a problem, especially by including actors in the processes of learning and productions that fall outside of the boundaries of traditional firms, institutions, research groups or other communities of practitioners.

Qualities of openness and collaboration are, of course, not absolute, but rather a continuum. Openness, for example, might range from specific organisations (like university research centres) sharing selected knowledge (like databases), to placing all relevant knowledge and information within a protected commons, available freely to all participants that abide by the rules of access and membership that those knowledge commons institutions require.[2] Collaboration might range from firms and other kinds of organisations working in partnership with other businesses or users or citizens more generally in innovation processes, to entirely new institutional means of organising production, such as decentralised production, in which traditional firms, markets and hierarchies are largely absent.[3] It is important to stress, however, that it is not so much the absolute level and qualities of openness or collaboration that defines the practices we are interested in reflecting on in this paper, but rather practices that combine attributes of openness and collaboration, and that maintain openness and collaboration over time.

Both caveats are important. There are, for example, a wide range of relatively recent business models that develop and/or exploit new forms of digital collaboration in one form or another, but where openness is severely restricted (and collaboration is controlled by one group rather than organised in common by all the participants). Technology firms such as Amazon and Facebook, for example, rely to a significant extent on capturing the user-generated information that arises from peer-to-peer connectivity, but their business models depend on imposing a strict monopoly on that knowledge. Likewise the slightly confusingly named phenomenon of 'open innovation' Chesbrough (2006) refers to collaboration in the development and improvement of products and processes outside the boundary of the firm, for example between firms in the same value chains and/or with other intermediate and end users. But firms typically possess the power and control to capture value, at some later stage, through the private appropriation of knowledge. Industry has also become increasingly adept at crowdsourcing ideas from much wider sets of actors (e.g. for design ideas or for opening up a product for modifications) but then closing down those practices as they move into production. What then distinguishes our focus in this paper from a much wider range of 'collaborative economy' activities is that we are interested in

[2] See, for example, the definition of 'open' from the Open Knowledge Foundation: 'Knowledge is open if anyone is free to access, use, modify, and share it — subject, at most, to measures that preserve provenance and openness, http://opendefinition.org/od/2.1/en/

[3] Polenske (2004) has argued that there is a difference between collaboration (which involves direct participation in the resolution of a shared problem) and cooperation (which involves agreements, including for instance establishing certain divisions of labour) to share resources and knowledge in order to solve specific parts of a problem.

practices that are both open *and* collaborative, and that that see openness and collaboration not just as a temporary input but as a continuous way of working.

Innovating and experimenting with open and collaborative forms of production is not in itself novel. The remarkable Green Revolution in seed innovation in the 1950s and 1960s, for example, was based on formalising a global commons in plant material, and establishing institutions to support intensive international collaboration to develop new high yielding crop varieties. Yet, what marks out considerable enthusiasm for, and the flourishing of, more recent forms of open and collaborative production - from the free/libre and open-source software movement, to citizen science experiments, to open design, to community-based prototyping spaces such as fab labs[4] and makerspaces - is the on-going information and communications technology (ICT) revolution (combined with some broader cultural shifts, such as the rise of network culture and the expansion of higher education). Certainly, ICT and the networked digital infrastructure (and network culture) that is being created with and through those technologies is fundamentally changing the scope and opportunities for working in ways that are based on openness and collaboration. The ICT revolution can give an alluring impression of widely accessible knowledge but, as we discuss later, in reality it enables the sharing of information (including information about knowledge). Much more is involved in order that people can become knowledgeable contributors to, and users of, such platforms and archives. Furthermore, as the examples in the previous paragraph indicate, the ICT revolution also throws up many new possibilities for proprietary forms of production, extending the reach of those who wish to enclose. The massive diffusion of networked digital infrastructure is thus best thought of, not as an undisputed technological enabler of distanciated, commons-based practices, but as a new terrain for a contestation between commons-based and proprietary approaches. Here it is useful to recognise open and collaborative experimentation as emergent socio-technical configurations, rooted in particular places and contexts, that are contingent and underdetermined as regards the social practices and possibilities that they create and enable.

Many commentators and activists insist, however, that open and collaborative initiatives have profoundly transformative economic, social and environmental potential. The example outlined at the beginning of the paper pointed to the prospects for more rapid and efficient means of development of techno-scientific knowledge, and perhaps to bring attention to a problem that markets and incumbent scientific institutions cannot, or find it challenging to, address. More generally, commentators have pointed to how open and collaborative production creates the scope for articulating more democratic social values and norms within innovation processes; to widening access to and accelerating the diffusion of socially useful artefacts; to fostering diversity; to creating alternative, more inclusive and sustainable pathways of social and technological development; and even to the embryonic forms (and drivers) of a post-capitalist future (Mason 2015; Benkler 2006; Moulier Boutang 2011). These and other possibilities are of considerable interest to a very wide range of actors and commentators, everyone from ultra-free market enthusiasts working in Silicon Valley to anarchist movements.

Amidst the considerable enthusiasm (and hype) for new open and collaborative practices, it is notable that the potential implications for nurturing more sustainable forms of development from the perspective of the Global South have not been widely discussed. And yet open and collaborative practices of learning and production suggest an intriguing response to development challenges. In large part this is because capabilities, on the part of individuals, firms and organisations, to develop and apply new *knowledge* in order to solve problems - to do new things and in new ways - arguably sits at the core of processes of development (Foray and Lundvall 1988). The limited opportunities to develop and realise such capabilities are reflected in a number of problems typical of many developing countries. Prominent amongst these are very narrow production structures, based on obsolete technologies and overly

[4] Fab Lab or Fabrication Laboratories are spaces where people meet to learn and experiment with digital fabrication technologies (e.g. 3D printers, laser cutters, etc.) in order to create individual or collective projects.

concentrated in extractive and natural resource based industries and the high levels of unemployment, underemployment, inequality and ecological damage that accompany that kind of structure.

In principle at least (as we shall argue), open and collaborative models of production could help to:

- diminish the knowledge and resource dependencies typical of developing countries by redistributing knowledge and knowledge-generating capabilities across diverse contexts;
- address problems typically unattended to by mainstream models of production and innovation, such as the needs of more marginalised groups;
- diversify production structures, and create opportunities for developing alternative, more sustainable, pathways of industrial and agricultural development.

The pertinent question is whether the new practices can enable societies to transcend the kinds of historical reasons that have have hindered a full role for the global south in modern knowledge production and its benefits; problems which are largely rooted in institutions and political economies. Our argument will be that open and collaborative knowledge practices *per se* do not really permit societies to do that, but rather recast the issues in ways helpful to those building wider movements for sustainable developments. The development of domestic knowledge generating capabilities and the agency that this entails for development still requires transformed institutions and political economies, but this time appropriate to, and facilitated by, open and collaborative knowledge production.

3. Recent Growth in Open and Collaborative Activity

We begin by setting the scene with a very brief description of the emergence, in recent years, of a number of different, open and collaborative practices. Several of these practices are relatively well known and benefit from a voluminous literature, others less so. We nevertheless cover both in order to identify the connections, commonalities, and also differential reach that open and collaborative processes are having in different domains. We outline why those initiatives have emerged, how they function, and some of the key visions behind those practices.

3.1. Open Source Software

Free/Libre open source software (hereafter 'open source software') has been a game changer in demonstrating the possibilities and potential of open and collaborative production within a networked digital infrastructure. It has created some of the world's leading software products, it has fundamentally challenged a series of mainstream ideas about the need for hierarchical modes of organisation in firms, and property rights to support innovation, and it has inspired similar kinds of initiatives in a large number of fields especially in information/knowledge dense areas such as scientific research and cultural production, but increasingly in other more 'material' areas of production too. The two key organisational innovations behind open source software are, the use of contract and copyright law to keep intellectual property out of the way of both software innovators and software users, and the development of a modularised approach to development, which allows a widely dispersed, and potentially very large, community of users/developers (communicating through digital networks) to test and make incremental improvements to software code, and for their contributions to be integrated into a usable whole (Weber 2004; Bonaccorsi and Rossi 2003).

The phenomena emerged in the early 1980s, in response to attempts by commercial firms to constrain the then longstanding tradition amongst software programmers of freely sharing source code. Richard Stallman's group of programmers at MIT insisted that the freedom to study, adapt and share software is a prerequisite for both individual and collective control over what computers can do, and more generally for fostering a more cooperative and egalitarian society. They decided to write a free version of the operating system UNIX, and invited users to collaborate on improving it or adapting it to their needs under the condition that they must continue to share the programme. A legal innovation, the General Public License (GPL), enforced that proviso because it required that the source code for a piece of software released under such a license, and any subsequent modifications to that code, remains freely accessible to others, as long as they in turn agree to the provisions of the same license. Thus, the license enforces *continued* sharing as the programme and any derivatives are disseminated. This prevents any entity from being able to appropriate either the individual components or the product as a whole. Software developed under the GPL, or many of the other 'copyleft' type licenses that were subsequently developed, is therefore released not into an open access commons, but into a 'protected commons' populated by those who agree to share (Levy 2010; Weber 2004).

The development of a modularised approach to production (i.e. breaking down a task into smaller parts that can be solved by different actors) has enabled a networked model of production without the necessity for formal hierarchies. Importantly, modularised collaboration, through digital networks, can draw on the collective intelligence and labour of a potentially unlimited number of co-producers in ways that no commercial developer can match. The argument is that if anyone and everyone is free to contribute to the development of software, then the capacity for creative, rapid, problem solving, continuous improvements and quick and robust adaptation to different needs can be achieved in ways that outstrip other forms of organisation (Raymond 2001; Moglen 1999).

What is striking about the open software phenomena is not the scale of activity (there are tens of thousands of open source software development projects (Schweik and English 2012) or that no single

entity owns an open source programme or manages its continuous improvement, but the fact that open source software is often superior, in terms of performance, reliability and adaptability, than proprietary software produced by some of the largest companies in the world (Schweik and English 2012; Weber 2004; Lerner and Tirole 2005). The market for server software, for instance, is dominated by the open source Apache project, whilst the open source Linux operating system - created out of part-time 'hacking' by several thousand co-developers - competes successfully with those developed and owned by Microsoft and Apple. Many large companies such as Google and Amazon run their web servers on Linux, not, as Benkler (2006) suggests, because Linux is free but presumably because those firms believe it to be more reliable than the proprietary alternatives.

3.2. Open Science

Open science is inspired by, and is based on similar principles to, the open source software movement (Schweik 2011). It attempts to make scientific processes more collaborative, within and outside the global scientific community, and to openly share the knowledge outcomes of such processes. Practices include those of open archiving and open publishing to support rapid, unrestricted access to, and reuse of, scientific material, including a range of intermediate outputs. Novel processes of collaboration, based on digital tools, such as open lab-books, wikis, on-line databases, and open peer review tools, are used to create what Nielsen terms, 'a conversational commons for the rapid collaborative development of ideas' (Nielsen 2008). New kinds of collaboration may also extend beyond the professional community of scientists in the form of what is sometimes termed 'citizen science' or crowd science', in which digital tools are used to involve wider publics in the research process, typically as volunteers undertaking data collection and data interpretation tasks. There is also interest, on the part of some practitioners, in enabling citizens to play a more substantial role in open scientific production, for example in defining problems, formulating hypotheses and exploring novel problem solving approaches (Fetcher and Friesike 2014; Franzoni and Sauermann 2014). A number of related practices exist, such as citizen generated data (see Box 3.1.).

Open science might appear to be a redundant term because an essential and defining feature of modern science has long been held to be its commitment to cooperative inquiry and the free sharing of knowledge (David 2008). In practice, however, the supposedly open qualities of science have become truncated. Openness is usually restricted to final outputs, in the form of publications (and even so, obtaining those outputs requires access to a well-funded research library), whilst a whole range of intermediate outputs, in the form of raw data, certain experimental information (including negative experimental results), the heuristics used to solve problems, software and so on are not usually shared. The 'public good' nature of scientific knowledge is also being eroded in some fields, particularly in the life sciences, where commercial funding of academic science is significant and where, in some institutions, market cultures have been enthusiastically embraced, As a consequence, the ability to use freely some scientific knowledge is restricted by the deployment of intellectual property claims over new knowledge. Traditional practices of collaboration, on the other hand, run into constraints based on geography, of knowing only a limited number of colleagues, and the competitive nature of academic careers which can hinder scientists' desire to share ideas and findings prior to publication (Franzoni and Sauermann 2014). Collaboration is thus traditionally limited to small teams of scientists and their colleagues, limiting the scope for more widespread input to and involvement in research from the scientific community, and indeed from wider publics.

Proponents argue that by enabling and encouraging scientists to share more of what they do, and to collaborate at different stages of the research process with those from outside their research groups, including in some cases with the public, open science has a number of advantages. These are that it; increases the efficiency of knowledge creation, by lowering the costs of solving problems, increasing the speed at which they can be solved, and improving the reliability of knowledge; improves the democratisation of knowledge; and renders the scientific endeavour more responsive to social demands (Stodden 2010; Wiggins and Crowston 2011; Fecher and Friesike 2014).

Box 3.1: Citizen Generated Data

> Citizen generated data is a practice that crowdsources information through *voluntary*, consensual contributions from the public (as distinct from the reams of data harvested from citizens in an involuntary way, or the limited data produced by measurements taken by dedicated field researchers) using cheap open source tools such as participatory web forms, mobile phone applications, low cost sensors, and social networks. It allows organisations to provide information on, and monitoring of, issues where official data is absent or incomplete, at relatively low cost. Citizen generated data initiatives usually involve civil society organisations such as social movements, non-governmental organisations (NGOs) and small citizen associations making visible problems that are occluded or ignored by States and media, and trying to create reliable information on an issue. The open source nature of the tools means that practices can potentially be replicated and adapted by other organisations at little cost.

3.3. Open Seed Innovation

Until the mid-1980s, seed innovation in most countries was, to a significant extent, an open-source (and sometimes highly collaborative) phenomenon. Breeders in both public and private sectors routinely shared germplasm with one another. This is because, just like software, seed innovation is an incremental, cumulative phenomenon. A new seed variety may contain one or more new traits (i.e. characteristics) that have been developed, or improved upon, by a seed breeder, but it will also contain hundreds of other agriculturally important traits that are the historical outcome of decades of professional seed breeding and thousands of years of farmer-led selective breeding. Traditional seed intellectual property rules, known as plant variety protection, sought to support an open source model of innovation because they allowed seed breeders, whether in the public or private sector, to freely use any and all protected varieties as a basis to create new improved varieties.

A striking example of sharing and collaboration in the production of germplasm is provided by the Green Revolution' example mentioned earlier. This post Second World War development, and worldwide diffusion, of high yielding cereal varieties resulted in an extraordinary period of food crop productivity growth. A product almost exclusively of the public sector, it was organised by a group of international agricultural research centres, which together with national agricultural research systems, formalised a global biological commons in genetic resources. This was implemented through a system of international nurseries with a breeding hub, the free sharing of germplasm, collaboration in information collection, the development of human resources, and an international collaborative network. It allowed for the best breeding materials and knowledge to be widely and freely available, enabling more than eight thousand modern varieties of rice, wheat, maize, other major cereals, and root and protein crops to be released by more than four hundred public breeding programs.

As was the case with software, private seed firms began to constrain the free sharing of germplasm from the 1980s onwards. In particular, patents on engineered gene sequences, and on the methods and materials used to produce genetically engineered crop varieties, initially in the USA but subsequently elsewhere too, allowed firms to restrict both seed breeders´ and farmers´ access to, and the ability to share, germplasm. Many commentators argue that such restrictions will reduce the ability of farmers and breeders to adapt varieties to diverse agro-ecological conditions, and diminish the within-species genetic diversity available for the development of new plant varieties, threatening food security and the resilience of agricultural systems.

In reaction to these developments, there have been a number of initiatives to reintroduce an open-source model of seed innovation, inspired by the free/libre open source software movement. In 2010, the Open Source Seed Initiative (OSSI), created by a group of plant breeders, farmers, seed companies,

civil society organisations, and policymakers in the USA developed a Pledge (rather than a license) intended to ensure that germplasm, and all future derivatives of that germplasm, can be freely and continuously exchanged, so maintaining open access to plant genetic resources (Luby *et al*. 2015). OSSI remains relatively small, with some 250 or so varieties developed by about 30 breeders now released under their open source pledge (Luby and Goldman 2016), but there are a number of similar initiatives being developed in other countries, including Germany, France, India, South Africa, Venezuela and Argentina, exploring the use of copyleft type licenses and other mechanisms to preserve open-source access to seeds (e.g. Kotsch and Rapf 2016).

3.4. Open Hardware

Open Hardware refers to tools and machines whose blueprints (including code, assembly instructions and tutorials) are open for others to explore, manufacture, improve, replicate, share or resell. The open hardware movement has roots in both the hacker/free software movement of the 1970s and 1980s, and the community of DIY entrepreneurs and radio and electronic hobbyists who tinkered with their own designs and/or hacked existing artefacts (Powell 2012). What is novel, as with many of the other emerging practices described here, is the use of digital tools and online collaboration which has allowed huge scope for bringing those practices to a new public. The movement started in earnest in the mid-2000s with initiatives such as Arduino (an open source microcontroller) and RepRap (an open source 3D printing machine), which allowed for the assembly of almost anything (Cuartielles 2014). It now covers dozens of different technologies in areas such as electronics and printing, furniture and housing, robotics, communications, industrial machines, sensors, automobiles, prosthetics, and scientific instruments. The phenomenon of community based fabrication and makerspaces is closely related (see Box 3.2).

Box 3.2: Community Based Fabrication and Makerspaces

> Closely linked to the open hardware movement are 'makerspaces', community-based workshops where people can access the tools, skills and collaborators to design and make almost anything they wish. Typically, a makerspace is equipped with small-scale versions of versatile, digitally-enabled design and fabrication tools developed originally for rapid prototyping in industry, as well as more traditional hand tools. Inspired by the open source movement, by ideas of free information and a new economy of sharing, makerspaces emphasise practices of collaboration and learning, between what is now a global community of amateur users, freelance designers, social entrepreneurs, and technology activists. As of early 2017, there were over 1000 fababs in 116 countries. Participants in these spaces learn by doing and swap skills with one another. The motivations of participants vary widely, from the personal fulfilment of making things and sharing that pleasure with others, to the pursual of entrepreneurial activities, and to educational projects and socially-oriented innovation.

By allowing users to design, copy and manufacture their own devices, open hardware enthusiasts are attempting to translate open software ideals into artifacts. As with open software, there are differing motivations behind the open hardware movement, ranging from those of education and capability building, to the desire to create cheap, appropriate technology for social problems. For example, the conjunction between open hardware and open science is allowing scientists in developing countries to obtain access to tools and instruments that are either expensive or difficult to import in their own countries. The Open Labware initiative, organised by Teaching and Research in Natural Sciences for Development in Africa (TreND), the Open Neuroscience initiative, and the Baaden Lab, are all promoting collaboration in the construction of low cost, open scientific equipment for developing countries for educational and research purposes. (Baden *et al*. 2015). This phenomenon is not only confined to

relatively marginal actors. The European Organization for Nuclear Research (CERN) has been working on open hardware since 2013 and has recently launched a repository for open scientific hardware (Gibney 2016).

An example of another motivation behind open source, participatory design and fabrication is 'Open Source Ecology', an initiative created by a former PhD student in nuclear fusion, Marcin Jakubowski, who created a platform and open-source blueprints for fabrication of 50 of the, 'most important machines that it takes for modern life to exist' (Quilley *et al.* 2016). These include tractors, ovens, and circuit makers, and are based on blueprints that emphasise modular design, low costs and the ability of users to construct, repair and modify their equipment when necessary. Open Source Ecology seeks to make tools accessible to everyone, especially those in small communities, in order to create a self-sufficient, sustainable society.

3.5. Summary

Open and collaborative production is an emergent field that covers a number of different areas of application, practices, actors, institutions, and aims. The vast majority of open and collaborative initiatives are small and remain under the radar of scholars and policy makers (Schweik 2011) who are only just beginning to understand the extent (and potential) of these kinds of activities.

The different areas of application and practice share much in common in terms of visions and motivations. As the examples in this section illustrate, many are a reaction to the enclosure of knowledge, seeking to (re)create knowledge commons, as well as to distribute innovative agency to a broader array of actors. And many have been inspired by the free/libre software movement. Such commonalities point to an embryonic change of paradigm in knowledge production (Bradley and Pargman 2017) At the same time, there are important differences between these practices, in terms of scale, economic sustainability, the diversity of participants, levels of institutional development, and the degree of support from mainstream institutions and/or acceptance or insertion of such practices into more mainstream practices. Such differences bring specific questions such as, how can open and collaborative practices be sustained? What business models or arrangements for obtaining resources are best suited to such practices? What kinds of organisational and institutional models can and should govern the production of commons knowledge and technologies? How do practices of collaboration, production and appropriation differ once we move from information-based, digital goods to more material forms of production such as open hardware or open seeds?

The diversity of actors and practices and their relations with more mainstream forms of practice also raises questions. For instance, who can participate and how in these processes, and who gets to decide what it is produced and how? Who is able to allocate resources to open and collaborative production, and who can appropriate benefits? At the same time, the similarity of overall visions and commonalities in practice also provides the opportunity to take advantage of lessons across different areas. In the following sections, we attempt to discuss open and collaborative production as a singular but highly heterogeneous phenomena, recognising the common potentials and challenges that these practices face, as well as some of the differences.

4. What Might Open and Collaborative Production Produce?

The products of the kinds of open and collaborative practice summarised in the previous section extend well beyond the creation of new knowledge or new material outputs *per se*. Such practices are, or rather are potentially, creating - amongst other things - new capabilities, new forms of social and productive organization, a redistribution of power and agency in innovation, and novel forms of diversity. In this section we discuss these potential products under three general headings: (1) the promise of efficiency and creativity, (2) the promise of democratisation and (3) the promise of greater diversity.

4.1. The Promise of More Efficient and Creative Ways of Innovating and Producing Knowledge

A central claim made by proponents of open and collaborative production is that such practices significantly increase the efficiency, efficacy and creativity of knowledge production. (Nielsen 2012; Benkler 2006). This is for at least four reasons. The first is based on the argument that commons-based, non-proprietary systems of production are able to draw on a much wider range of human motivations than those deriving from participation in markets, or coercion by managerial command and waged labour. Benkler (2006) suggests that the freedom to co-operate in collaborative ways with others to make things of value to humans, and to be generous and kind (behaviors and patterns familiar to us from social relations generally) motivates people far more effectively and efficiently than traditional market mechanisms or hierarchical models of social organisation.

The second rests on the fact that intellectual production, whether in the form of scientific knowledge, cultural goods, or technological innovation, is essentially cumulative; it depends critically on access to (and an understanding of) a prior body of knowledge. 'If I have seen further, it is by standing on the shoulders of giants', in Isaac Newton's[5] famous phrase. The unrestricted availability of information, data, ideas and designs that openness supports increases the pool of knowledge in common use, and the argument is that this makes on-going knowledge production cheaper, more rapid, and more creative because it avoids the expense and time of having to duplicate knowledge that already exists, and because it increases the number and diversity of actors who might otherwise not have access to that knowledge but have the capacity to contribute to its further development and exploitation. (Tennant *et al*. 2016) As David put it:

> Wide sharing of information puts knowledge into the hands of those who can put it to uses requiring expertise, imagination and material facilities not possessed by original discoverers and inventors. This enlarges the domain of complementarity among additions to the stock of reliable knowledge and promotes beneficial spillovers among distinct research programs.
> David 2003: 22

A third reason is that creativity is amplified when large, heterogeneous groups of actors collaborate in the production of knowledge, what has been termed 'the wisdom of the crowds' (Nielsen 2012; Surowiecki 2004). This is partly because a wider range of backgrounds and experiences can help utilise novel knowledge resources and unconventional ideas to solve problems. It has long been noted, for example, that innovative ideas in both scientific research and technological innovation often arises in situations of diversity, for example from outsiders in terms of disciplinary or technological background (Ben-David 1960; Bijker 1995)

Finally, intensive collaboration among more homogenous groups of peers amplifies collective intelligence because it allows ideas, assumptions, hypotheses and avenues of inquiry to be validated, ruled out and deliberated on more rapidly that might otherwise be the case, thus increasing a

[5] Isaac Newton 1642-1726, English mathematician, astronomer and physicist.

community's capacity to solve problems (Nielsen 2012). Web-based technologies amplify this tendency because they eliminate or diminish spatial and time constraints, allowing ideas to quickly move back and forward, augmenting the capacity to solve problems.

Claims about the increased efficiency and creativity of open and collaborative production arise in many different fields, for example, in scientific research, (Tennant *et al*. 2016) and in software development (Bonaccorsi and Rossi 2003; Weber 2004;). They are based mainly on case study or anecdotal evidence, rather than more systematic evidence which, given the nature of the qualities that are claimed to be enhanced, would be difficult to measure or estimate, and which tend to lack adequate counterfactuals.

4.2. The Promise of Democratising Knowledge and Material Production

A second central set of claims about open and collaborative production practices is that they involve a fundamental democratisation of knowledge and material production. The argument is that enabling much wider access to knowledge, and creating new capabilities and new forms of participation and inclusion, radically redistributes power and agency in knowledge and material production. Such ambitions have inspired many of those championing open and collaborative practices. Amongst the early hackers in the free software movement, for example, commitments to notions of freedom, of non-coercive collaboration, of making technology available to all, of learning as a tool of empowerment, and of technology as a form of expanded autonomy and self-realisation were central to motivating and shaping commons-based collaborative practices (Powell 2012; Coleman 2004). Subsequent broad based treatises on commons-based collaborative production have also emphasised how such practices foster autonomy, human freedom and a more genuinely participatory political culture (Benkler 2006; Bauwens 2005).

More specifically, a number of novel practices are held to foster new and/or qualitatively different forms of participation in knowledge and material production. First, the building of a *knowledge commons*, via unrestricted digital availability of information, unencumbered by patents or other restrictions, whether in the form of scientific research, digital libraries, open access data repositories, or hardware blueprints, and a commitment that those creating new information and knowledge on the basis of those resources continue to share it. Although access to information and (codified) knowledge is not in itself sufficient to enable novel or expanded forms of participation, it is an important prerequisite to being able to do so. The argument is that this permits citizens and communities who would otherwise not have access to certain kinds of knowledge and information to obtain, copy and modify information, designs, code, or technology blueprints and other knowledge resources for their own purposes, for example to participate in the production of artefacts, at least where they already have appropriate expertise and skills (Powell 2012).

Second, and closely coupled with the free circulation of information, is the emphasis, in many fields of open and collaborative practice, on supporting *collaborative learning*, through the intensive use of tools such as online courses and open notebooks, and by documenting development processes, of say new artefacts and digital fabrication techniques, through online repositories and wikis. The aim is to qualify citizens to use those techniques so that they can participate in knowledge and artefact production for societal development. As well as learning through digital networks, some open and collaborative initiatives, such as community makerspaces also enable in situ learning *via* a hands-on, collaborative approach to solving problems, allowing skills to be shared and obtained in practical situations of production. These kinds of practices, both access to technical knowledge and access to communities of makers, help to foster the development of new capabilities in science, engineering, design, electronics and software, enabling actors to participate in the production of material artefacts in circumstances where they would not otherwise be able to do so. As Gershenfeld puts it, such practices are, '[…] democratizing access to the modern means to make things' (Gershenfeld 2012: 48).

Third, alongside the free circulation of information and the support of both in situ and digitally networked learning, are a set of social innovations designed to enable *collaboration in shared work activities outside of the communities of practice that normally monopolise knowledge and artefact production*. In particular, digitally networked peer to peer production, based on the development of a modularised approach (allowing for production to be split into discrete, independent tasks), a granularity to the modules (allowing small contributions from different participants) and the availability of low cost integration mechanisms and quality control has enabled, large numbers of people to participate in the production of software. (Benkler and Nissenbaum 2006) Those practices have also inspired new ways of organising production in open science and in open hardware.

A key social and political consequence of the above processes, at least in principle, is a significant *redistribution of access, power and agency in knowledge and material production*. Different groups of people, including non-professionals and those based in geographically diverse locations, may be able to access, and to contribute to and influence the creation of, knowledge, designs and artefacts in ways that were not previously possible. A number of potential consequences follow. First, knowledge, and the possibilities that access to knowledge create, diffuse much more rapidly, and become much more widely distributed, than would otherwise be the case, tempering some of the effects of resource inequality associated with continued lack of access to information and knowledge (Benkler 2006). Second, distributed production is matched with a more distributed form of control. For example, collective choice systems, characteristic of some forms of peer-to-peer production, eliminates the power located with certain individuals and groups over what to produce (Bauwens 2005). Third, greater diversity of knowledge and values are brought to bear on knowledge production and innovation, diversifying those outputs, and opening up new questions among participants about the direction and purposes of innovation. Fourth, new subjectivities and relationships between people are formed as people discover opportunities to learn new skills and become knowledge producers, designers, innovators, and entrepreneurs, amongst networked communities of actors (Smith 2017). In these new roles, actors and communities can explore the possibilities for a more open and innovative interaction with both knowledge production and the material world. Finally, collaborative forms of production, in the absence of proprietary rules, themselves foster fundamentally democratic virtues and behaviours in participants, such as meritocratic respect, gift giving, civic virtue, friendship, generosity, and kindness (Benkler and Nissenbaum 2006; Coleman 2004).

4.3. The Promise of Alternative Trajectories of Social and Technological Development

A third set of (closely related) claims about open and collaborative production practices is that they foster a far more diverse set of agendas for driving knowledge production, and as a consequence can nurture alternative trajectories of social and technological development. The argument is that by enabling the free re-use of knowledge and information, by radically redistributing and decentralising the locations in which knowledge production and learning occur, and by operating outside of formal hierarchical institutions and, in some contexts, of markets, open and collaborative practices can foster far more diverse forms of knowledge production and learning, and can respond to and engage with problems and societal demands that are ill-served by markets and states. For their protagonists the new practices constitute a demonstration that there are alternative ways of organising production, relative to those prevalent within incumbent capitalist market structures, and in the context of the current global division of knowledge-based capabilities.

Specifically, the practices characteristic of open and collaborative production outlined in the previous section, namely the building of a *knowledge commons*, the support of *collaborative learning*, and the *widening of participation* in learning and production outside of established communities of practice, means that a much wider variety of actors are able to access, reuse, modify and create knowledge for their own purposes. The ability to access, re-use and modify knowledge not only fosters the diffusion of know-how, techniques and artefacts, but it also induces greater diversification. Since people often have various motivations, it is possible that they will create unexpected uses for existing forms of knowledge,

whether in the form of code, data, techniques or technologies, and may modify and use that knowledge in new ways. For example, in the area of Open Hardware, microcontrollers allow users to combine different sensors, from oscilloscopes to music pads, to create technologies for a wide variety of needs, from art performance to drones, 3D printers and even scientific instruments. This widening of actors and participation can bring different values, priorities and desires to the design of technologies, code and even institutions, and it allows experimentation with new solutions to old problems and/or the exploration of new issues that are neglected by incumbent institutions and innovation systems (Smith and Stirling 2016). The opportunity to explore alternative ways of combining information, knowledge and techniques is particularly important in areas like agroecology, or sustainable energy production where novel technological practices and artefacts are sought that are not otherwise available (see Hess 2007).

The Open Source Ecology project, for example, aims to challenge traditional technological practices in farming by developing and sharing the ability to produce open source, low cost tools that can enable sustainable farming. Likewise, the idea of a 'reMaker society' in which open-source participatory fabrication is combined with a culture of collaborative consumption and a more ecologically restrained, localised and co-operative based mode of production implies that technologies and practices that contribute to a more sustainable and redistributed manufacturing economy (or an 'open source circular economy') can be created (Nascimento 2014; Quilley *et al.* 2016).

An additional reason as to why open and collaborative forms of production may foster a far more diverse set of agendas for driving knowledge production (and in turn novel pathways of socio-technical change) is that many such practices operate outside of both formal markets and established hierarchical institutions. The argument is that this means that they are able to respond to problems and societal demands that have no market demand, or that are ill-served by states. More generally, some commentators and activists claim that open and collaborative practices will usher forth new non-market modes of production. Benkler (2006), for example, argues that commons-based peer-to-peer production demonstrates a practical alternative to production within capitalist market structures, insofar as digital information goods, at least, can be produced without market incentives because individuals require few resources to contribute. They 'gift' their knowledge and informational labour, thus creating a non-market and cooperative mode of producing economic value.

4.4. Possible Implications for Uneven, Unsustainable Patterns of Development

Many of the claims detailed in the three sub-sections above are particularly interesting when thinking about the challenges of highly uneven and unsustainable patterns of global development. Here it is worth reminding ourselves that despite massive technological advances over the last century or two, and high rates of global economic growth (6.9 per cent per annum over the last 30 years) extraordinary levels of inequality in income, wealth and many other factors key to human well-being, persist, both within and especially between countries. Indeed, most developing countries still struggle to provide basic needs for the majority of their populations. It is also overwhelmingly clear that existing trajectories of global (but highly uneven) development have serious or even catastrophic consequences for key ecosystem services, the adverse implications of which will fall most heavily on developing countries, and in particular the most marginalised communities in those countries. The challenge of fostering more sustainable patterns of development that are, socially just, economically resilient and ecologically viable has never been greater.

Open and collaborative practices of learning and production suggest an intriguing response to that core challenge, for several reasons. One of those stems from the point made at the beginning of this paper. This was that the capacity, on the part of individuals, firms and organisations to develop and apply knowledge in order to solve their problems, and to do new things and in new ways, is fundamental for enabling development processes understood, as Sen put it, as, '[…] the removal of various types of unfreedoms that leave people with little choice and little opportunity' Sen (1999: xii).

Indeed, central to facilitating the development of what are now advanced industrialised countries was unconstrained access to knowledge, as evident for example in the absence of intellectual property rights in the earlier stages of development of countries like the USA and Germany (Mazzoleni and Nelson 2007). Access to knowledge was a necessary (though not sufficient) condition to both reuse it and, in turn, to develop domestic knowledge-generating capabilities. The current on-going process of privatising more and wider kinds of knowledge threatens to further exacerbate and 'lock in' the enormously skewed global distribution of knowledge generating capabilities, which are overwhelmingly concentrated in wealthy industrialised countries. This constitutes a clear threat to the prospects for development, in all its senses.

Radically open and collaborative modes of knowledge production offer an alluring way of helping to counter this trend because they make it easier, in principle, to both access existing knowledge, and in particular to allow actors to participate in processes of collective knowledge creation. The latter is critical if we consider that the knowledge restrictions that developing countries face are by no means related only to problems of access, but often to the fact that much existing knowledge is ill-suited and inappropriate to addressing problems of development in all its diverse contexts.

Problems of access to existing knowledge nevertheless remain important, and have been the focus of much discussion about intellectual property rules in the Global South, especially in fields such as pharmaceuticals. Here, for example, it is noteworthy that prior to 2005 developing countries could lawfully copy patented medicines. With, in effect, open access to this area of advanced knowledge (produced by global pharmaceutical firms who recouped their investments by selling in patent-protected markets in the North), countries such as Brazil, Argentina, India and China reverse engineered patented medicines, producing 'generic' drugs for the domestic population at low cost (Coriat *et al*. 2006). This became illegal in 2005 after the Trade Related Aspects of Intellectual Property Rights Agreement came into force. More recently, initiatives in 'open-source pharma' seek both extensive collaboration in the development of new drugs and unrestricted access to intermediate and final products, though there remains the thorny issue of how socially to invest in (in this case costly) processes of knowledge production (Balasegaram *et al.* 2017). Open access and collaboration does not transcend the problem that knowledge production can be expensive and requires someone to fund it.

Another area where access to (existing) knowledge is important is scientific equipment. For scientific laboratories in developing countries, where there are restrictions on both budgets and the availability of foreign currency to import equipment, open hardware promises to substantially lower the costs of obtaining equipment. Here, not only is knowledge in the form of designs and blueprints made available without intellectual property restrictions, but so too are efforts to render accessible the (open-source) tools and know-how to manufacture that equipment.

Yet, probably more important than access to knowledge is the promise afforded by open and collaborative practices to participate in knowledge production. For example, peer to peer production of open source software can enable software programmers from developing countries to learn to program, acquire skills and then enter global markets with services and applications, as has occurred, for example, in India, Brazil and Argentina. Entering new industries and activities early on, when these are being developed is important from an economic point of view, because it provides first mover advantages for local actors (Nelson 1989). It also means that contributors from developing countries have a voice and thus might be able to influence the path of development of the activity in question and propose alternative trajectories that better fit the needs and problems of their own countries.

Open and collaborative practices also have the potential to support efforts on the part of developing countries to protect domestic knowledge generating capabilities, and the development agency this entails. For example, the location of global seed innovation has shifted markedly over the last thirty years from being widely distributed across firms and public sector institutions in many different countries, to becoming heavily concentrated in five or six multinational agro-chemical firms, a trend

closely associated with the transformation of seeds from a public good to a proprietary one. This trend undermines local and national capabilities in seed research and development (R&D), and the ability to determine the directions of seed innovation and, in turn, the kinds of agricultural systems that seed systems can and cannot support and the forms of food security that are deemed locally important, a key source of developing country autonomy. Open-source initiatives in seed innovation constitute a potential strategy to protect domestic seed R&D capabilities from this trend.

One of the most significant reasons why open and collaborative practices of learning and production are a potentially promising response to the challenge of (sustainable) development is that such forms of production do not typically depend (or depend exclusively) on market incentives or State-led initiatives. New knowledge, artefacts and social practices can therefore be developed in response to needs and problems that are not expressed through economic demand or that are neglected by State institutions. Such needs and problems are significant in all geographical settings, but they are particularly important in many developing countries where large proportions of citizens lack sufficient incomes to exert market demand, and/or where States are relatively weak, and are unable or unwilling to respond adequately to development challenges.

5. The Knowledge Politics of Open and Collaborative Production

The sets of promises outlined in the previous section, of more efficient, democratic, distributed and diverse ways of producing knowledge (and our argument that these potentially offer new ways for supporting more socially just and sustainable patterns of development), are not without critical challenges. In this section we begin reviewing some of those challenges by raising a set of issues and questions about the knowledge politics of the new practices.

5.1. Depths and Forms of Openness and Participation

We focus first on some questions of design and, specifically, the affinities of different open and collaborative initiatives to particular kinds of participation and openness. What depths and forms of participation are being enabled through different practices, for example, and in what senses does openness translate to the ability to use knowledge?

Before proceeding, it is useful to first distinguish between different kinds of knowledge, and particularly, following Foray and Lundvall (1998), to distinguish between *knowledge as more or less complex information*, and *knowledge as a set of skills and competences*. The first of these, includes knowledge about facts (which broadly approximates to information), as well as scientific and social-science knowledge, and can often be learnt by reading, attending lectures and, in the former case, by accessing databases, as (complex) information it is often codifiable. Knowledge as a set of skills or competences, however, which includes both the ability to do something, as well as the social ability to cooperate and communicate, is different. It is learnt in apprentice relationships and through social practice, it often takes years to develop, and it is extremely difficult to codify or render explicit. Importantly, both of these two dimensions of knowledge are required to contribute to scientific research or to produce artefacts, or indeed to produce and utilise any and all forms of knowledge. Even successfully using databases of codified information requires skills to select and practically use what is relevant.

With these points in mind, we begin with a key issue, which is that important elements of knowledge are 'sticky', that is they do not easily travel from one setting to another, frustrating the possibilities of both meaningful access and participation.

5.1.1. The Stickiness of Knowledge

A key assumption underpinning many open and collaborative initiatives is that knowledge and information can be shared and subsequently used and/or (collaboratively) modified and further developed amongst geographically and institutionally distant sets of actors. Many of the promises outlined in Section Three above depend on that ability. A key complication here is that it is widely recognised, in innovation studies, science and technology studies, and in many other fields, that knowledge is 'sticky', that it is immobile, or at least costly or difficult to move from one setting to another (von Hippel 1994). There are two major aspects to this. One is that knowledge possesses important tacit, non-codifiable dimensions (Polanyi 1966; Johnson *et al*. 2002; Collins 2010), particularly in the form of skills and competences. Such tacit knowledge is most readily shared and learnt through a socialisation process, such as hands-on apprentice work (e.g. within a firm or an active scientific research group). Certainly some knowledge, particularly *information,* is readily codifiable, and so might be shared and developed collaboratively amongst geographically distinct groups, but the immobility of other dimensions of knowledge is underplayed by those who celebrate the potential of collaborative forms of production. Craft knowledge, and many other human skills, for instance, are essential, not only to the production of artefacts, but also to scientific research and knowledge production more generally. But they are, to a considerable extent, tacit or embodied, and not easily shared through digital networks (although the use of video and online tutorials can make this slightly easier). One consequence may be that only knowledge that that is readily codifiable (i.e. data) ends up being readily shared, the effect of

which is that it will be data that is driving open and collaborative research, perhaps unwittingly closing down other forms of knowledge production.

Another major aspect of the 'stickiness' of knowledge concerns the attributes of those seeking it. Individuals and organisations must typically have or acquire related information and skills to be able to use new knowledge. This is a well-established finding in innovation studies: firms wishing to use new knowledge that is external to the organisation generally need to have made their own expenditures in R&D in order to develop the skills to be able to use it (Pavitt 1987). This surely applies to other circumstances. Tellingly, Johnson *et al.* (2002) describe open public access to science as, ' […] of course, a misnomer, in that it often takes enormous investments in learning before the information has any meaning'.

It is likely that some areas of open and collaborative production, and some practices within those areas, cope more effectively with knowledge 'stickiness'. For instance, Byerlee and Dubin (2009) argue that absolutely central to the success of the open and highly collaborative international Green Revolution in plant breeding were long and intensive international exchanges and field training of thousands of young scientists, as well as shorter exchanges with similar numbers of more senior plant breeders. This, the authors argue, enabled standardised, accurate approaches and hence comparable data over many different breeding sites around the world, and thus effective international research, as well as the creation of strong bonds and trust amongst scientists from different countries that were essential to facilitating ongoing co-operation.

In more recent years, community-based makerspaces, for example, manage to combine digitally shared, non-proprietary knowledge with collaborative physical spaces that enable shared learning by doing and using. They may, as a consequence, manage to get around many of the problems posed by immobile tacit knowledge, in the same way as the Green revolution. Makerspaces are nevertheless typically strongly committed to sharing knowledge more widely (e.g. via the production of design blueprints and instructions or tutorials) but an empirical study of fab lab participants emphasised the difficulties in moving beyond local sharing, given the tacit nature of much of the knowledge involved in making physical things. The study authors note that where global sharing of knowledge was accomplished, this typically only occurred within an exclusive circle of experts who already knew each other well and who interacted regularly (Wolf *et al*. 2014).

Linked to the difficulties of the immobility of tacit knowledge are a range of other challenges associated with sharing information and knowledge digitally between physically or institutionally distant locations. These include the problem of linguistic and cultural variation, of having to generate easy to use human-computer interfaces and, as Wolf *et al*. (2014) found in an empirical study of fab lab participants, the fact that people may find the task of documenting what they have done in digital form to be difficult, time consuming and boring. Their study respondents were typically committed to treating knowledge as a public good, but often did not find the time, or take the time to document their activities a way that they felt was good enough to be shared online and globally.

Open and collaborative practices, such as some citizen science initiatives or the sharing of scientific information via open access repositories that typically do not involve working together in physical proximity, may struggle to overcome these kinds of challenges. This is especially likely to be the case where participants and recipients do not have the necessary skill sets to use and to make sense of shared information and scientific knowledge. In such circumstances, *meaningful* access to knowledge and the ability to *participate* effectively in its production are likely to be very significantly limited. The obstacles are not necessarily insurmountable, but they do require careful attention to how sharing and collaboration is practiced, and to the development and distribution more generally of capabilities in knowledge production and comprehension.

5.1.2. What Kinds of Participation are Being Enabled?

On the face of it, the building of knowledge commons, the support of collaborative learning, and the opening up of established communities of practice, facilitates novel, broader forms of participation in knowledge/material production. But there remain critical questions about what forms and dimensions of participation are being enabled (and which are not).

Here it is useful to distinguish between different dimensions of participation. Drawing on a wide literature, Kelty *et al*. (2015) distinguish, amongst other things, between; participation in the setting of goals and the making of decisions (rather than merely the accomplishment of tasks oriented to pre-set goals); participation in the ability to own or use or control resources (rather than merely produce them); participation as an educational dividend (i.e. learning something valuable); and participation as a collective experience, a convivial and affective experience among peers (as opposed to anonymous, disconnected intercourse among strangers).

Certainly, some forms of participation in open and collaborative production are confined to accomplishing tasks that are pre-set, and that do not enable participants to exert much in the way of agenda setting, control or ownership of the resources that constitute the outcomes. In open science, for example, participation by those outside of the scientific community has so far generally been confined to producing (and in some cases helping to interpret) data, rather than identifying and defining problems or priorities, with little scope to influence how that knowledge is subsequently used. Often overlooked in this line of criticism, however, is that such participation does enable participants to learn about a particular project, and about the scientific process, i.e. participation as an educational dividend in Kelty *et al*.´s (2015) taxonomy.

Some open science initiatives have attempted to support a far more significant role for non-scientists in knowledge production, especially in areas such as community environmental health monitoring, where lay participants typically have a greater role in defining the objectives of knowledge production and in deciding how those are to be addressed, and where there is recognition that the knowledge produced is owned by all those involved in its production. Such initiatives (which connect, perhaps unknowingly, to a history of participatory action research, in the social sciences, *cf* Fals-Borda 1979) are often touted as enabling a broader democratisation of governance in areas such as environmental health. Yet, despite the novel, inclusive aspects of knowledge production, it is important not to over-exaggerate the wider impact. Participation generally remains limited to knowledge production alone, an important but by no means only aspect of environmental and technology policy-making (Kinchy 2017).

Other initiatives, such as in some areas of open source software and open hardware enable a more substantive role for participants in production, beyond contributing to pre-set tasks, although there may be tradeoffs between efforts to enable wide, meaningful participation in agenda setting and problem formulation, on the one hand, and practical co-ordination, on the other. For example, coordination in networked peer to peer production projects often depends on a core group of contributors doing most of the effort (Weber 2004; Bonnacorsi and Rossi 2003). Collaborative production exclusively through digitally enabled infrastructure does, however, typically mean that the conviviality of the participative experience will typically be absent. Zittrainin suggests that distributed production:

> […] risks extending the assembly line from the mechanical to the intellectual, spawning a new class of knowledge workers whose work lives are fully atomized, an existence blinkered even from fellow assembly-line mates. The challenge will be to ensure that the technologies that supplant full-time employment still enable human relationships to help the work stay meaningful and fulfilling.
> Zittrainin (2008)

Working remotely also means (as we suggested in the previous Section) that there are limited opportunities to develop the tacit skills and 'know-how' that come from being part of a non-virtual community of practice.

5.1.3. Tensions between Collaboration and Diversity

One of the distinctive features of open and collaborative production is that a plurality of actors, with diverse motivations and goals, can become involved in learning and production (e.g. Benkler 2006). However, this plurality can create several tensions. One is that plural motivations are likely to be accompanied by a diversity of aims, foci, emphases and approaches to open and collaborative production. A risk is that collaborative initiatives succumb to that diversity, resulting in never-ending discussion and conflict, preventing the negotiation of common metrics, methods, analytical frames and so forth with which to produce coherent (and authoritative and valid) knowledge, designs or artefacts.

Another risk is that initiatives 'fork', in the terminology of software code, into inconsistent versions, branching off in different, often incompatible directions (Weber 2004). Such forking hampers the collective efforts of people willing to collaborate on the same project, slowing down the process of knowledge or technological production. However, where leadership is inconsistent, or groups fail to cooperate, it may just be easier to create a new project (favoured by the fact that open licences favour the freedom to re-use and modify software or designs, thus 'empowering exit' Weber (2004: 159). However, there are also cost associated with creating new projects, in particular the loss of synergies with previous projects and the need to create a new community of collaborators.

As Shaikh and Henfridsson (2017) illustrate, in open source software there is a wide variety of governing mechanisms that can accommodate the scale and diversity of participants in different projects. However, flexible governing mechanisms are not ubiquitous, and in fields such as open science there may be considerable difficulty reconciling the imperative to produce authoritative knowledge on the one hand, and encourage heterogeneous participation on the other. In citizen science projects, for example, there are few mechanisms for enabling flexible modes of collaboration between actors with differing conceptual and cognitive backgrounds, and so uniformity is imposed by limiting and standardising the participation of non-scientific actors. This ensures that contributions from the public are reliable, but perhaps at the expense of limiting the creative potential of diversity. A general challenge is how to promote collaboration without undermining the diversity of participants

5.2. Expertise and Hierarchy

A further set of issues on the knowledge politics of open and collaborative production concern a set of questions about expertise and hierarchy. In particular, we can ask how are participants and participation processes structured by coordinating bodies and through what processes? Who is able to legitimately shape agendas and ask questions about the validity of knowledge, and who is able to influence and control open and collaborative production?

Since authority in open and collaborative production does not derive from ownership, and because those practices typically allow (and empower) new uses and modifications to knowledge and other resources, the governing mechanisms in place end up being very flexible, characterised, as Benkler (2006) puts it, by the decentralisation of authority. In peer to peer production Benkler (2006: 67) argues that the absence of centralised authority is supplanted by a 'meritocratic hierarchy', where a range of self-governing mechanisms guide participation. This decentralisation of authority and command is often celebrated as enabling an egalitarian distribution of power and expertise and a far more democratic way of organising production, in contrast to the specialisation, professionalisation, and credentialing upon which modern bureaucracies rely. Yet Kreiss *et al*. (2011) argue that the kinds of social dynamics that underpin decentralised forms of peer production typically involve a host of norms and forms of regulation that may be less transparent than traditional hierarchical bureaucratic structures, for example based on charismatic authority or social connections, and that may simply reinforce broader

social patterns of discrimination and power. They argue that the kinds of rule-based mechanisms that govern bureaucracies (and that are often absent in open and collaborative initiatives) have sought to ensure inclusivity, equality, and fairness and diminish arbitrary discrimination.

Certainly, the potential for diversity in production does not always entail actual plurality. As some studies show, communities of open and collaborative production typically lack participation from women and minorities. A survey for Nesta in 2014 found 80 per cent of United Kingdom (UK) makerspace members were male and a similarly high percentage had white ethnicity (cited in Smith 2017) Other studies have also identified low levels of participation by women in open science (Terrel *et al*. 2016).

Likewise, the potential for a more egalitarian distribution of power and control over production may not fundamentally alter (and indeed may serve to reinforce) some very deep seated asymmetries in the distribution of resources and capabilities, in particular between the global North and the global South. For example, many initiatives in open and collaborative production that have a global reach, such as a number of open science projects, have been initiated by well-resourced universities and other institutions in the global North. There are considerable first mover advantages here, often related to network externalities. For example, the phenomenally successful global e-Bird platform initiated in the United States has, as of 2103, 140 million observations from 150 thousand separate observers, who spent 10.5 million hours collecting data (Sullivan *et al.* 2014). In a country like Argentina, it makes perfect sense for bird watchers' associations to link to this project, so as to make the most of the synergies in tools, data protocols and coordination, rather than create their own crowdsource platform. But the increased efficiency due to collaboration involves a number of risks, since both key decisions (e.g. about how data is collected, and about which tools are used) and the management of outputs end up being centralised. For example, in e-Bird, local portals are all integrated within the infrastructure of applications and databases located in the United States. Centralisation, originating in this case in first mover advantages and economies of scales, may undermine the potential for new players to benefit equally from the public goods that are being created. The point here is that actors in open and collaborative production from the global north, with favoured access to resources and capabilities, may exert controlling power over how such initiatives develop, reproducing existing north-south inequalities.

6. Open and Collaborative Political Economies

We now move on to raise and reflect on some of the political economy challenges posed by open and collaborative production, understood as challenges deriving from the nature of political and economic power within the *wider settings and structures* in which knowledge is produced (as distinct from the operation of power *internal* to the open and collaborative knowledge production process, discussed in the previous section). We begin with questions about *appropriation*, about who is able to allocate resources to, and to capture benefits from, the new initiatives and practices.

6.1. Appropriation

Practitioners working within open and collaborative initiatives typically adhere to a strict non-proprietary ethos, normally celebrating (and relying on) the voluntary contributions of people who provide their time and expertise outside of labour markets, and who act free of coercion by managerial command, and in all cases insisting that the knowledge and/or artifacts that are produced through those practices are public goods that cannot be exclusively appropriated by any single entity. There are important questions, however, both about how investment into open and collaborative production (including the labour input into those processes), and the capture of benefits from those practices, occurs in practice, and how this is affected by wider relations of economic and political power.

We can begin by asking who in practice provides the resources *for* open and collaborative production, whether in the form of start-up investment, finance for running costs, labour, and various kinds of infrastructure, such as digital repositories, buildings, and internet networks? In some areas of practice, such as open-source software, inputs are largely those of peoples' time and so initiatives can be sustained solely on gifted labour but other practices may be much more demanding of resources. Where these are provided by the State (as in the case of open science where labour, research costs and the creation and maintenance of infrastructure such as data repositories are covered by public funding), or by non-profit organisations (as is the case of initiatives such as Wikipedia), open and collaborative production is viable, but such initiatives remain vulnerable to those institutions' abilities to consistently secure and provide resources and to their changing funding priorities. In other cases, the private sector has also become interested in the innovative possibilities of some forms of open and collaborative production, providing funding, donating equipment and loaning space and infrastructure (e.g. in open software production and for makerspace and fab lab networks).

A key issue here, however, regardless of whether inputs are provided by public, private or nonprofit sectors, is that providers of inputs are likely to influence the direction and manner in which open and collaborative initiatives develop, and will do so in ways that reflect relations of political and economic power that lie beyond the influence of the initiatives they help to support. For example, research funding bodies and other state bureaucracies have expressed considerable enthusiasm for open science initiatives, but these seem to be driven primarily by an interest in increasing the efficiency, efficacy, and impact of investments in research. The visions of open science as supporting more democratic forms of knowledge production (as for example, practiced in the trades union-initiated 'hazards research' historically in the UK and elsewhere, where non-scientists were able to set research agendas) are likely to remain marginal to state support, sustained at the fringes by research groups committed to those aspirations, but without the resources and political support that other more conventional aspects of the open science movement are able to harness. Likewise, burgeoning interest in funding and providing space for makerspaces by city governments is often prompted by the hope that they will be a new site for entrepreneurship, leading to business spin-offs, rather than the idea that they might help forge a radical disruption and redirection of existing production and consumption practices; visions that are also part of the wider makerspace movement.

Labour in-put to open and collaborative production is typically provided voluntarily for many motives, but they generally include the expectation that the products of that labour will be, and remain, public goods. There are burgeoning instances whereby firms draw partially on ideas from open and collaborative production, and in doing so utilise unpaid, crowd-sourced labour as a source of ideas and designs for what ultimately become proprietary products. But even where production remains open, some commentators argue that its voluntaristic nature inevitably creates new forms of precariousness in a wage-based economy, with individuals possessing fewer resources to recognise their activities as work and to make claims on the value of their knowledge and creative labor, or to imagine themselves collectively standing in a particular relationship to capital (Kreiss *et al*. 2011).

There are also important questions about who is able to capture the *outputs* of open and collaborative production. Here is it important to make a distinction between the ability to appropriate exclusively those outputs (i.e. enclosure) and the ability to capture benefits but not exclusively. In the former case, practices such as the free/libre and open source software movement have developed copyleft-type licenses (i.e. utilising copyright law to create a protected commons), legally preventing exclusive appropriation of both outputs and, critically, all subsequent derivatives. Yet, there are many kinds of copyleft type licenses, some of which allow some derivative outputs to be protected. Furthermore, copyright law only applies to a limited range of creative, intellectual, or artistic forms of production. For many areas of open and collaborative production, the creation of a protected commons is a more difficult task, and knowledge or material outputs are vulnerable to exclusive appropriation, both by entities unconnected with the practice in question, and by those within it. A well-known example of the latter is the case of Makerbot, a 3D printer company that emerged from the hackerspace culture in New York, and which based its printers on the open source RepRap designs. As Makerbot grew as a company it began seeking intellectual property protection for its modified designs, and was subsequently bought by Stratasys, a large industrial 3D printer manufacturer, in 2013, effectively cashing in on a large pool of historical common collaboration, and angering former collaborators (West and Kuk 2016).

Of course, any entity is able to appropriate, on a non-exclusive basis, the outputs of openly shared production. In the open source software field, a range of firms have developed business models that, for example, reply on the sale of services associated with open source software, which is otherwise available freely or at marginal cost. Large firms are likely to be better prepared, and will have better access to complementary resources, to enable them to make the most of open source knowledge outputs. And they may have made no contribution themselves to the production of those resources, and may have no commitment to reinvesting in wider social commons-based activity. For some commentators this free riding reality is relatively unproblematic, knowledge/artefacts are being used widely and openly and if commerce benefits that is valuable. And of course anyone else is still able to access that knowledge, even when others are exploiting it more effectively and powerfully. Whether markets are genuinely open or whether there is concentration and power - thus generating asymmetries in the ability to exploit commons-produced knowledge - is, from this perspective, a different matter, one located in questions of wider market and economic power rather than the arrangements for knowledge production *per se*. For others, however, this is problematic, and has precipitated initiatives such as Peer Production Licenses, (also known as copyFARleft) which authorise free usage of digital material for noncommercial and commons-based organisations but require commercial users to pay a fee (Rigi 2014).

6.2. The Role of Mainstream Organisations

The points set out above are closely linked to a broader set of questions about the kinds of relationships that are likely to emerge between open and collaborative initiatives and incumbent institutions. Here we reflect briefly on whether, and if so in what ways, open and collaborative forms of production are likely to create new relations with investors, markets and states, or whether they will be captured by them.

An intriguing aspect of open and collaborative production is that it has attracted interest from a wide variety of mainstream institutions, such as mainstream firms, government departments, funding agencies, venture capitalists and other investors , well beyond, say, the social movements that have traditionally been associated with cooperativism, commons, and other parts of the left more generally. From the perspective of incumbent institutions it is primarily the promise of greater efficiency and creativity in knowledge production, set out earlier in this paper, and the disruptive potential of new ideas about processes of open, decentralised innovation, that underpins that interest. Open source software, open data, and open science, are now variously supported, in different ways, by a range of national governments, government agencies, international development institutions, and scientific institutions (Gregson *et al.* 2015; World Bank 2015; OECD 2015; Rossel 2016). Likewise, makerspaces, fab labs, hackathons, and other collaborative practices, have been increasingly supported, funded by firms, government agencies, and by municipal governments. And as noted in Section Two, many institutions and firms have selectively drawn on the ideas underpinning open and collaborative practice to variously crowdsource ideas, capture value from peer-to-peer generated data, or to develop makerspace-like initiatives or hackathons, while maintaining proprietary control of any subsequent developments. Examples include crowdsourcing initiatives like Mechanical turk, prize systems like Innocentive (Benkler 2016) or open innovation schemes such as the Structural Protein Consortium (Morgan Jones *et al*. 2014).

This widespread interest in, and support of, open and collaborative production by incumbent actors throws up interesting political opportunities as well as challenges. The latter concern, in part, the fact that insofar as open and collaborative practices are wealth-generating, they will be co-opted into mainstream modes of production (Kreiss *et al*. 2011). More specifically, where funded or initiated by mainstream institutions, the kinds of values and norms underpinning the design and practice of collaborative production are likely to reflect conventional innovation agendas, bracketing out visions about radically democratising knowledge production or fostering new kinds of socio-technical pathways of change (as noted in the discussion in the previous subsection). Thus, support for, and funding of, community based makerspaces by institutions such as Exxon, the US Defense Advanced Research Projects Agency, or city governments risks reducing those initiatives to instruments for fostering education and entrepreneurship alone (Smith 2017). Whilst those are not necessarily undesirable objectives, makerspace movement ideas about, say, fostering new kinds of material culture and technological autonomy are typically sidelined. As Smith notes, there is however generally a concomitant reaction to such trends. In the makerspace arena this includes experimentation with platform cooperativism, and other kinds of novel business models (as well as older models newly reconfigured with informational technologies), where activists seek to maintain the more radical ambitions of maker culture. Similar tensions, and responses, exist in most other areas of open and collaborative practice.

The challenges associated with the fact that open and collaborative initiatives are necessarily situated in wider settings and structures are not limited to concerns about deliberate cooption. Tensions can also arise more tacitly given the practices and cultures of the mainstream institutions that are attempting to experiment with open and collaborative production. For example, open science proposals are in tension with the traditional evaluation criteria of universities, which reward competitive behaviour (Riesch *et al*. 2013; Sheliga and Friesike 2014) and a culture of scientific competition for grants, publications and resources, for example, the fear that data might be 'scooped' by other scientists before analysis is complete and published (Bishop 2015). Another common concern is the reliability of open data, in particular when its collection involves process of citizen or crowd science (RIN/NESTA 2010; Wiggins and Crowston 2011). All this can make it difficult for scientists to adopt the more radical aspects of the new practice. The importance of various social and legal aspects of enabling individuals, groups, and organisations to engage in collaborative work can get lost in a fixation with information technology infrastructures, and other technical aspects of collaboration (David 2004).

More generally, the importance of the 'softer' elements of creating new kinds of collaboration, and in particular of enabling a more participative, democratic culture of learning and production (from the letting go of institutional forms of professional esteem to the careful construction and maintenance of social bridges between expert and lay actors) can simply be overlooked, even where there is enthusiasm for the more radical aspects of open and collaborative practice. Incumbent institutional cultures often remain a constraining factor unless explicitly addressed.

7. Conclusions

Reflection on the knowledge politics and political economy challenges of open and collaborative modes of production helps make explicit some central challenges and dilemmas in this emerging field of practice. These are important, in terms of informing further research, supporting reflective practice, and in thinking about the potential of such initiatives to support more sustainable and socially just pathways of development.

One such challenge concerns the ways in which important attributes of knowledge itself (namely its key tacit and embodied dimensions) limits aspirations for a far more democratic innovation culture; one that radically redistributes access, power and agency in and over knowledge and material production. Addressing that challenge means that attention needs to be directed at practices that can help develop people's capabilities and skills, at supporting collaboration *in situ* as well as remotely, and to recognising that digital infrastructure alone is insufficient to enable people to be able to access meaningfully knowledge or to become co-contributors in its production. This entails that capabilities need to be more evenly distributed than at present, which will require resources and sustained institutional support.

A second challenge concerns the operation of power internal to the process of producing open and collaborative knowledge. Can open and collaborative production transcend existing hierarchies and norms of expertise, asymmetric power relations between collaborators and wider patterns of social privilege and structure? Addressing that challenge means talking about, and seeking to support, democracy and the democratic content of knowledge production in open, participatory and collaborative practices, as much as in more traditional closed, institutionalised and distant knowledge production processes. This is a theme that openness and collaboration has affinities towards already, but it is important not to assume that the new practices, by dint of their aspirations, will satisfactorily address the tensions between new ideas about decentralised production and traditional centralised authority and patterns of resource allocation. Reflecting on the power in knowledge production, as this working paper indicates, rapidly brings to the surface broad questions about the characteristics of the social settings in which knowledge is produced. It is not simply an organisational or technical matter about building data platforms or including people in specific fieldwork activities. By attending to the democratic content of knowledge production we rapidly encounter questions about which kinds of visions, values and interests are motivating the research or productive activity.

A third challenge concerns the nature of political and economic power within the wider settings and structures in which initiatives in open and collaborative production are situated. As we have seen, initiatives in open and collaborative production have not only been created by activists seeking renewed political economies and material cultures. They have also attracted the interest of mainstream firms and government institutions, interested primarily in the efficiency and creativity aspects of the modes of production, and generally rather less so in ambitions to radically democratise knowledge production or to foster alternative socio-technical practices. As such open and collaborative initiatives can take the form of a reaction to conventional innovation agendas within modern industrial capitalism, as well as one that is entirely consistent with them. Put somewhat crudely, the challenge, in this case in the form of a dilemma, is will the new practices constitute ‘novel inputs for existing processes’ or 'novel inputs for transformed processes´? Addressing that dilemma is more complex. It points to a wider debate about the social structures and political economies within which knowledge is produced, and the kinds of institutions appropriate for learning about the futures we want. These kinds of transformative changes will require broader social movements, new business models and new institutions, but it is still not clear what kinds of strategies, interventions and institutions might best support open and collaborative developments, and avoid their capture by incumbent actors

A final challenge arises from the very diversity of areas and actors that are experimenting with open and collaborative production. As our paper illustrates, although there a set of common values and normative aspirations loosely shaping different areas of open and collaborative production, there are considerable differences too, resulting in quite different specific issues in each area, and distinct communities and institutions. While this multiplicity can be creative, there is also the challenge of seeking common ground, and building a common vision of how this phenomenon might contribute to building alternative, more sustainable and inclusive, directions of development. Such an ambition will require exploration of how the wide variety of what are still typically small scale and experimental initiatives might foster transformative changes in existing regimes of production; a task that will require continued experimentation and reflective practice with new organizational models, technologies, institutions and visions of a more equal and sustainable future.

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