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Following the Open Source Trail Outside the Digital World: Open Source Applications in Agricultural Research and Development

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Abstract: In this article, we assess the application of the open source development model in the field of agricultural research and development, as a potential tool for upholding both public scientific research, and farmer-led innovation and farmers' rights. First, we provide an overview of the problems associated with the rise of IPRs in agriculture in view of global challenges such as food security and environmental sustainability, and present the debate on farmers' rights, including its rationale and international policy and legal responses. We then review open-source initiatives in the digital domain, including successes and shortcomings, and offer our understanding of relevant terminologies. We explore the parallels between software development and innovation in agriculture, review ongoing open source agriculture-related initiatives, and identify lessons learnt. We particularly assess the potential for open source systems to address existing asymmetries in capabilities and contribute to global challenges such as food security.

Keywords: free software, open source, farmers' rights, research and development, intellectual property rights, patents, plant breeders rights, copyright, copyleft, food security, agricultural biodiversity, innovation

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Intellectual property is neither - The Anarchist in the Library, by Siva Vaidhyanathan

Knowledge sharing has been common practice throughout human history, and the exchange and remix of cooking recipes serves as a notable example. But also at the start of the food production process, farmers have been exchanging seeds and agricultural knowledge for centuries. Until recently, agricultural innovation was farmer-led, and depended upon open systems aiming to ensure both the sustainability and adaptability of production and the conservation of agricultural biodiversity—a term which refers to the outcome of interactions among genetic resources (the seed), the environment (the surrounding ecosystems), and farmers' management systems and practices (the knowledge) (Tsioumani 2014, 4). In this context, the seed integrates the tangible with the intangible.

The modernization of agriculture and the green revolution dramatically increased world food production through scientific and technological advances, including modern plant breeding. The professionalization of breeding and the emergence of the commercial seed sector however resulted in both the erosion of agricultural biodiversity, due to the uniformisation

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promoted by the dominance of commercial varieties, and the marginalization or, in cases, criminalization of customary farmer practices, in favour of corporate-led research supported by intellectual property rights (IPRs). The vast expansion of intellectual property protection in the field of biotechnology in particular has led to concerns that innovation will be blocked unless action is taken to preserve access to and create additional tools to enable further research and development (Hope 2004).

In this article, we assess the application of the open source development model in the field of agricultural research and development, as a potential tool for upholding both public scientific research, and farmer-led innovation and farmers' rights. First, we provide an overview of the problems associated with the rise of IPRs in agriculture in view of global challenges such as food security and environmental sustainability, and present the debate on farmers' rights, including its rationale and international policy and legal responses. We then review open source initiatives in the digital domain, including successes and shortcomings, and offer our understanding of relevant terminologies. We explore the parallels between software development and innovation in agriculture, review ongoing open source agriculture-related initiatives, and identify lessons learnt. We particularly assess the potential for open source systems to address existing asymmetries in capabilities and contribute to global challenges such as food security.

1. The Rise of IPRs in Agriculture

IPRs are supposed to foster and reward creativity and innovation by protecting inventions of the mind. There are several different types of IPRs, and their use depends on the invention at stake. In the field of agricultural development, the types of IPRs that are mainly in use are plant breeders' rights and patents.

Historically the first to appear, in association with the emergence of scientific plant breeding at the times of the green revolution in the 1960s, plant breeders' rights are a common type of IPR protecting plant varieties. They were established by the 1961 International Convention for the Protection of New Varieties of Plants (UPOV Convention), which promoted a system of private ownership 'with the aim of encouraging the development of new varieties of plants for the benefit of society' (UPOV mission statement). Standards adopted under the UPOV Convention, which was amended in 1972, 1978, and 1991, provide protection to novel (in terms of prior commercialization) and distinct, uniform and stable plant varieties.

As a result of the novelty requirement of intellectual property protection, farmers' varieties have been regarded as 'prior art' within the public domain. In addition, farmers' varieties are neither uniform nor stable, thus they cannot satisfy the UPOV criteria for protection. This asymmetry between scientific and farmer-developed varieties has led to widely-perceived unfairness, particularly among smallholder farmers in developing countries, a perception also shared by their governments: their varieties could be acquired and shared freely and could be used in the development of modern varieties, which would then be protected by exclusive property rights. Finally, a series of famous biopiracy cases involved the granting of patents on hardly invented or novel plant varieties and traditional uses that were previously in the public domain (CIPR 2002).

At least, the model of plant breeders' rights as epitomized by the 1978 version of the UPOV Convention clearly permitted the use of protected varieties as the source material of further breeding (breeders' exception) and the re-use of saved seeds by farmers (farmers' privilege) (Correa 1999, 3). Both are important mechanisms to protect farmers' livelihoods, allow for farmer-led innovation based on traditional seed-saving and exchange practices and in general guarantee the continued exchange of material for public research and global food security purposes. These exceptions however were restricted in the latest revision of the UPOV Convention in 1991. The plant breeders' exemption was preserved; acts done "privately and for non-commercial purposes" or "for experimental purposes" were also exempted; but the farmers' privilege for replanting was restricted; while the scope of protection was extended beyond the propagating material of protected varieties to include "essentially derived varieties". According to this amendment, farmers were required to limit the amount of saved seeds or to pay an equitable remuneration to the right holder. In addition, use of protected varieties by farmers is permitted only for propagating and planting on their own holdings, but not for informal sale, thus also restricting exchanges among farmers (Chiarolla et al. 2013, 85).

UPOV membership was boosted with the adoption of the Agreement on Trade-related Aspects of Intellectual Property Rights (TRIPS Agreement) under the auspices of the World Trade Organization (WTO) in 1994, as WTO Member States are required to provide for the protection of plant varieties either by patents or by an effective sui generis system (TRIPS Agreement Article 27.3b). Although, according to the latter option, countries are free to identify a system to suit their particular agricultural and socioeconomic conditions, the UPOV Convention provides a ready-made sui generis framework, and therefore appears as an obviously easy choice. Developing country membership is thus constantly increasing, despite the fact that the UPOV system is tailored to the needs of the commercial seed sector and the commercialized farming systems of the developed countries rather than the subsistence agriculture of the developing ones (Yamin 2003; CIPR 2002).

Exceptions aiming to protect farmers' and breeders' activities are usually even more limited under patent law. Patents provide the strongest form of intellectual property protection, in the sense that they normally allow the patent holder to exercise the greatest control over the use of patented material. Protecting plant-derived innovations under patent regimes requires an applicant to demonstrate novelty, an inventive step, and the potential for industrial application. At the moment, to the authors' knowledge, patents on conventional plant varieties are only allowed in the United States, Japan and Australia (Chiarolla 2012, 62–63; CAMBIA PatentLens). With the breakthrough of modern biotechnology in the 1990s however, the patent subject matter expanded dramatically, with an ever-increasing number of patents to cover not only transgenic plants but also particular plant traits and parts, components such as genes, plant breeding methodologies, and vectors and processes involved in the production of transgenic plants (Aoki 2009, 2296). Geographical application also expanded, as transgenic plants became patentable in Europe under the terms of the Directive 98/44/EC on the legal protection of biotechnological inventions.

Some examples can usefully illustrate the breadth of patents currently granted: In February 2010, US-based company Mendel Biotechnology won a patent in the US on plant transcriptional regulators, a class of genes that control the degree to which other genes in a cell are activated. These genes reportedly confer improved stress tolerance in genetically engineered plants, not for a single abiotic stress, but for drought, shade and low nitrogen conditions, and extend to virtually any transgenic plant and seed encoding a specified DNA sequence. BASF US patent on "transcription factor stress-related proteins and methods of use in plants" lays claim to transgenic plants transformed with isolated DNA sequences that confer increased tolerance to environmental stress, including salinity, drought and temperature, and covers virtually all flowering plants, such as maize, wheat, rice, soybean, potato and tomato, to mention only some. Monsanto's international patent application, published by the World Intellectual Property Organization (WIPO) in February 2010, describes novel proteins derived from bacterial cold shock proteins, which, upon expression in transgenic plants, provide the plants with enhanced stress tolerance to heat, salt and drought (WIPO Patentscope). The application makes extremely broad claims, not just to the modified plant cells that exhibit improved stress tolerance but also the processed product derived from the transgenic plant. All these extremely broad patents refer to plant components and processes which could be relevant for adapting agricultural research and production to the challenges of climate change (ETC Group, 2010).

1.1. IPRs, Concentration and the Impossibility to Innovate

The rise in the number and breadth of patent claims is indicative of the radical shift from farmer-led, user-based innovation and public agricultural research to mass-market, seller-based innovation and corporate research (Aoki 2009, 2277). IPR systems, crafted around models of industrialized agriculture, discourage research on unprofitable subsistence crops in favour of high-earning crops destined for developed world markets; and create multiple obstacles to both public breeders and farmers, as it is further explored below.

Furthermore, while the number of patent applications is increasing annually in both the US and Europe, the number of applicants is decreasing. Dozens of mergers, acquisitions and strategic alliances since the 80s have resulted in a dramatic concentration of control in a handful of companies, sparking concerns regarding undue control of global food production, privatization of agricultural research and as a result, risks for food security. The degree of concentration in the agrochemical sector is described in the literature as "dramatic," leading to a "pervasive restructuring" of the plant breeding sector (Aoki 2009, 2297). According to ETC Group, the top ten seed companies account for 67% of the global proprietary seed market; the world's largest seed company alone, Monsanto, accounts for 23% of that market; and the top three companies (Monsanto, DuPont and Syngenta) for 47% (ETC Group 2010). The risks associated with this trend have been addressed also by the UN Special Rapporteur on the Right to Food (UN Special Rapporteur on the Right to Food 2009, 2010). In addition, a handful of big firms own most key enabling technologies. Ownership of patents on enabling technologies enhances their market power, ties smaller companies to them, and also acts as a barrier to market entry (Hope 2004).

Literature suggests that the two phenomena of patent expansion and market concentration might be more tightly linked than one thinks. Janet Hope for instance argues that the "merger-mania" has been driven primarily by the need to avoid high transaction costs associated with clearing multiple IPRs (Hope 2004). The combination of broad patents with market concentration has a number of additional consequences: first, at least in the US where the phenomena are more intense, it means that the legal framework can be lobbied to change. Enforcement of IPRs is not even needed, as competing companies and varieties are virtually absent and "the dominant oligopolists are in a position to dictate to farmers the very conditions of access to seed" (Kloppenburg 2014, 1229).

Second, researching and negotiating the IPRs that potentially surround the material and methods of their work in order to obtain "freedom to operate" is a substantial transaction cost for breeders (Kloppenburg 2014, 1230). An often-cited example in this regard is that of Golden RiceTM, a genetically modified rice variety heralded as a potential solution to vitamin A deficiency (Aoki 2009, 2297). A detailed analysis of the intellectual property dimensions documented approximately 70 patents and pending patent applications implicated in its development. The high media profile of the case facilitated negotiations with the patent holders. Humanitarian-use licensing was applied, an otherwise rarely used tool, which allows for humanitarian uses of proprietary technologies to support international development objectives.

Navigating the patent landscape is further complicated by the uncertainty generated by those patent applications that are still pending, resulting in an inability to even locate the ownership of patents for key enabling technologies (Hope 2004), as well as by the fees usually required for searching patent databases. The obscurity is further exacerbated by the fact that, while ownership of the patent is usually a matter of public record, ownership of the rights transferred through licenses is not. Most jurisdictions do not impose a responsibility on licensees to disclose, making it almost impossible for a researcher to assemble all the licenses needed to proceed with her research (Jefferson 2006).

This multi-level complexity has devastating consequences for public breeders, particularly in developing countries, who would wish to invest in research on undervalued crops relevant for local food security. In a clear inversion of the intent of IPR legislation, monopoly power is used to obstruct research and impede innovation: in the possibility only of patents and pending patent applications on material and methods they may use, breeders are advised not to proceed with their work out of fear of litigation and the cost involved, even if the patent claims are likely not defensible in court (Kloppenburg 2014).

The effects of the widespread patenting of germplasm, research technologies and breeding methods have been characterized as a "tragedy of the anticommons" (Heller 1998; Heller and Eisenberg 1998). Heller's tragedy of the anticommons mirrors Hardin's tragedy of the commons, where a resource is prematurely exhausted because no one has the right to exclude (Hardin 1968). In contrast, the tragedy of the anticommons refers to a situation where too many parties hold a right to exclude with respect to a particular property or resource, meaning that several permissions must be obtained for use, due to overlapping ownership claims. As a result, public breeders' innovation is obstructed and agricultural biodiversity is threatened. Unlike other natural resources such as forest and marine resources, conservation of agricultural biodiversity is performed through use: unless an agricultural variety is used, it cannot be conserved for more than a few decades before it eventually dies (Tsioumani 2014). Threats to agricultural biodiversity are exacerbated by the effects of IPRs on farmer innovation, which are briefly addressed in the following section.

1.2. IPRs and Farmers' Rights

In the meanwhile, as previously noted, farming communities around the world have been developing traditional crop varieties for centuries. As a subsistence strategy, they have maintained a high genetic diversity of plants and animals, as well as different location-specific bodies of traditional knowledge and farming practices. In these local seed systems, the primary emphasis is not on high yields and productivity, but on resilience and risk-adverse qualities in the face of harsh, variable and unpredictable conditions. Traditional varieties therefore serve as reservoirs of agricultural biodiversity, providing a much required safety valve in the face of threats such as pests, diseases and environmental stresses. They also form the basis of local and global food security: according to the UN Special Rapporteur on the Right to Food, over 70% of the world's food production relies on smallholder farmers (OHCHR 2014). In addition, as modern varieties often rely on the traits of traditional ones, traditional varieties and the traditional knowledge they embody are considered vital resources also for scientific agricultural research.

Traditional varieties cannot be protected by the formal intellectual property system. Their role and importance is recognized by environment-related international conventions, mainly the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGR) and the Convention on Biological Diversity (CBD). In these fora, farmers' contribution to agricultural biodiversity and global food security is generally acknowledged, along with the realization that their practices and knowledge should be supported. Two intertwined legal concepts were developed in this regard: fair and equitable benefit-sharing, and farmers' rights.

The CBD, adopted in 1992, established the principle of national sovereignty over natural and genetic resources. In the words of M. Halewood et al, 'if developed countries were able to exercise restrictive control over advanced biologically based technologies using intellectual property rights, developing countries could exercise their sovereign rights to regulate and restrict access to the biological and genetic resources within their borders' (Halewood et al 2013, 6). Adoption of the CBD reflected developing countries' efforts to react to the injustices embedded in the IPR system, as well as their expectation to share in the gains of the emerging markets for biodiversity-based products. The tool envisioned to support these goals was the legal notion of fair and equitable sharing of benefits arising from the use of genetic resources, which features prominently as one of the three CBD objectives, alongside conservation and sustainable use of biodiversity. Fair and equitable benefit-sharing has thus a central position in all the programmes of work and other soft-law instruments developed under the CBD, including the ones on agricultural biodiversity, as well as in the recently entered into force Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization (Tsioumani 2014). Benefits to be shared may include monetary or non-monetary ones. The sharing of experiences and the transfer of knowledge and technologies for instance are recognized in the CBD programme of work on agricultural biodiversity as specific forms of benefit-sharing (CBD Decision V/5). No specifications are offered, however, with regard to the obstacles posed by IPRs to the transfer of knowledge and technologies.

The ITPGR, negotiated under the auspices of the UN Food and Agriculture Organization (FAO), is the first legally-binding instrument to introduce the concept of farmers' rights. Farmers' rights emerged as a reaction to the asymmetry between farmers as donors of germplasm in the form of open-access traditional seeds/propagating material and the producers of commercial varieties that ultimately rely on such germplasm. While commercial varieties were protected and generated returns on the basis of plant breeders' rights, there was no system of compensation, reward or incentive for the providers of traditional germplasm. At the same time, farmers' rights were meant to ensure that the restrictions in use associated with IPRs would not adversely affect farmers' practices. That means that farmers should not only be allowed to continue, but also encouraged and supported in their contribution to the maintenance and development of plant genetic resources and food security globally (Andersen 2005, Correa 2000).

The ITPGR recognizes farmers' rights as collective rights, and acknowledges the 'enormous contribution that the local and indigenous communities and farmers of all regions of the world, particularly those in the centres of origin and crop diversity, have made and will continue to make for the conservation and development of plant genetic resources which constitute the basis of food and agriculture production throughout the world'. Leaving the matter of implementation to national governments, the ITPGR does not provide a definition of farmers' rights, but sets out measures a Party should take to protect and promote them, including: the protection of traditional knowledge; the right to equitably participate in sharing benefits arising from the utilization of plant genetic resources for food and agriculture; and the right to participate in decision-making at the national level on related matters (ITPGR Article 9). In addition, it reaches no final conclusion with regard to the link between farmers' rights and IPRs. Instead, it states that 'nothing in this Article shall be interpreted to limit any rights that farmers have to save, use, exchange and sell farm-saved seed/propagating material, subject to national law and as appropriate.' It does not, therefore, limit the customary rights of farmers to reuse, exchange or sell farm-saved seeds. Nor, however, does it safeguard these rights by establishing an international legal basis for their protection against IPRs. An acknowledgement of the need for farmers to access seed and be enabled to continue with their informal practices has come from the UN Special Rapporteur on the Right to Food. He has noted that human rights obligations in relation to the right to food imply that the commercial seed system needs to be regulated in order to ensure that farmers have access to inputs, including non-open-access seeds 'on reasonable conditions'; and that innovations leading to improved varieties and resources benefit all farmers, including the most vulnerable and marginalized ones. At the same time, States should ensure that informal, non-commercial seed systems can develop and be protected from interference and pressures imposed by the commercial seed sector (UN Special Rapporteur on the Right to Food 2009, 4).

The following question illustrates the clash between IPRs and farmers' rights: is a farmer allowed to save, exchange and re-use seed that incorporates an IPR-protected component? The possibility that farmers save seeds for further use has been a typical feature under plant variety protection, but it has been restricted under UPOV 1991 and is generally not provided for under patent laws. It can be argued that in the context of the entire spectrum of their international legal obligations, IPR-, biodiversity- and human rights-related, national governments may opt for supporting farmers' rights against the interests of corporations, through national legislation. National positions may vary. Jurisprudence in US and Canadian courts has affirmed the primacy of patent rights over the right of the physical owner of the seed to save and replant (Monsanto Canada Inc. v. Percy Schmeiser 2004, Bowman v. Monsanto Co 2013). India's 2001 Act on Protection of Plant Varieties and Farmers' Rights, on the other hand, establishes rights for farmers to save, use, exchange and sell farm-saved seed, conferring also related rights to breeders and researchers (Farmers' Rights Project 2009). A member of the WTO and the TRIPS Agreement, India considered its legislation to be in compliance with TRIPS provisions on plant variety protection, and applied for UPOV membership. The Act however was found not in compliance with the UPOV requirements and now, more than ten years later, India's UPOV application is still pending (Farmers' Rights Project 2009, UPOV Aug. 2015).

The tension between IPR rules and those related to the protection of agricultural biodiversity and farmers' rights is further illustrated by (currently negotiated, but mostly stalled) proposal to amend the TRIPS Agreement to make it consistent with the CBD, through disclosure of evidence of prior informed consent and benefit-sharing in patent applications. Those negotiations could reconcile the two systems, but are nowhere near completion. In the meanwhile, unlike the CBD and the ITPGR, enforcement of the TRIPS Agreement is linked to WTO's dispute settlement system and its rules are backed up by the threat of retaliatory sanctions (Aoki 2009, 2287). No case involving national implementation of farmers' rights, such as India's legislation, has reached the WTO dispute settlement system yet, but of course the convincing power of this threat for legislators around the world is significant. At the farmers' level, on the other hand, IPRs are easily enforced through contract law: Monsanto's "shrink-wrap" license for instance accompanies each bag of seed sold: opening the bag constitutes agreement to the terms of the license, which include, at length and explicitly, the obligation not to save or replant seed or hold Monsanto accountable for any form of liability. According to these terms, the farmer does not become the owner of the seed, but simply gets a license to use it (Kloppenburg 2014).

This brief examination of the international legal framework shows that the contribution of farmers to food security and conservation of agricultural biodiversity has been acknowledged, at least in the realm of international environmental law, and legal concepts have been developed to reflect this recognition. However, the complexity of the legal framework, the unclear relationship between international environmental and international IP law, and lack of enforceability of international environmental law, in combination with the power of the commercial seed sector, put both farmers and national governments wishing to protect farmers' rights in a vulnerable position. In addition, patent expansion and market concentration, as well as funding constraints, put public agricultural research at risk. The questions thus remain. How can farmers' and public researchers' contribution to global food security be supported? And how can it be defended against the obstacles posed by IPRs and other tools of the commercial seed sector? Looking for imaginative solutions, certain initiatives have started experimenting with novel tools inspired from developments in the IT sector, including open source seeds and technologies.

2. Terminologies

A number of conceptual and terminological clarifications are in order at this stage, regarding the meaning and operationalization of the term "open" in multiple contexts and the relationship of "open" concepts with the public domain and the commons (Louafi and Welch 2014). The commons is not the same as the public domain. Successful commons are frequently characterized by a variety of restraints, usually informal or collectively constituted (Boyle 2003). Their success and sustainability depends largely on skilled decision-making and cooperative management strategies (Hess and Ostrom 2007). Knowledge commons specifically refer to various types and regimes of information and knowledge managed collectively by a community of users. Enclosure, via privatization, commodification or withdrawal of information, is a key risk for knowledge (Boyle 2003), and the development and study of knowledge commons may be considered a response to this trend (Hess and Ostrom 2007).

The specific context of our research concerns resources, which are non-rivalrous (knowledge) and renewable (plant genetic resources). In economic theory, a good is non-rivalrous (or non-subtractive) when use by one individual does not reduce the benefits available to another (Hess and Ostrom 2007). This is obviously the case for knowledge, but also for plant genetic resources, which are self-replicating, and thus renewable. Plant genetic resources therefore, a natural but also human-made resource, do not have a key characteristic of other shared natural resources, such as fisheries: subtractability. Most types of knowledge, on the other hand, are non-subtractive. In fact, in the words of Hess and Ostrom, "the more people who share useful knowledge, the greater the common good" (Hess and Ostrom 2007). The same goes for plant genetic resources: the more they are shared, the better for food security and conservation of agricultural biodiversity.

Open systems have generally been associated with the practice of science and academia. These "open science" systems facilitate knowledge production through disclosure, sharing and reciprocal exchange, while they rely on a system of public expenditures (Louafi and Welch 2014).

In the current increasingly proprietary environment for material and non-material resources of scientific significance (Benkler 1999; Boyle 2003), the open access movement promotes public sector values by the removal of access barriers to academic research. In synthesizing a wealth of relevant literature, Louafi and Welch usefully argue that the open access movement represents a political response, seeking to democratize access to knowledge and innovation; it has been expanded by more recent open data initiatives, which refer more specifically to data and information that can be used for research purposes. Open source, on the other hand, refers to an economic response to information enclosures, and proposes an alternative model aiming to implement and manage open systems, in order to enhance production and innovation. Open source is thus more tightly linked with "legal and organizational rules meant to control behavior and outcomes" (Louafi and Welch 2014, 149). In this context therefore, open access systems and concepts are closer to the idea of the public domain, in the sense that nobody is excluded from use; while open source models are closer to the concept of protected commons, as they are open to a group of users and specific rules of access and sharing, including restrictions, apply (Louafi and Welch 2014). Similarly, while open access efforts maintain a flexible approach to the systemic inclusion of IPRs, open source relies on IPRs and licensing terms to establish and operationalize open systems.

3. Open Source in the Digital World

This section provides a brief description of the birth of the open source model and its relation with IPRs.

Although open source has generally been connected to the development of the internet, a notable contemporary example that predates the internet, is the Selden automotive engine patent case. After Henry Ford successfully challenged the patent, a new association, the Association of Licensed Automobile Manufacturers was formed. The new association instituted a cross-licensing agreement among all US auto manufacturers: although each company would develop technology and file patents, these patents were shared openly and without the exchange of money among all the manufacturers. By the time the US entered World War II, 92 Ford patents and 515 patents from other companies were being shared among these manufacturers, without any exchange of money (or lawsuits) (Flink 1977).

In computers, where software was initially produced mainly by academia, openness had long been established and software was distributed freely under the principle of cooperation. To further collaboration and research, the source code - the human readable version of a program - was also distributed for free.

By the late 60s, software started becoming more complex and production costs started increasing. This lead to increasing commercialization and subsequently, restrictions upon redistribution were imposed. By the early 80s, charging for software licenses had become mainstream and copyrights and trademarks were being widely enforced (Weber 2004). In addition, to prevent software from being used on their competitors' computers, most manufacturers stopped distributing the source code and began using copyright and restrictive software licenses to limit or prohibit copying and redistribution. This shift in the legal characteristics of software can be regarded as a consequence triggered by the US 1976 Copyright Act (Cringely 2005).

While many online communities were still building and sharing software, in 1983 Richard Stallman published the GNU Manifesto and started actively defending knowledge-sharing practices against the rise of software as a commodity. The GNU Project that was launched simultaneously had the goal of creating an open source operating system. Two years later, Stallman created the Free Software Foundation to support the movement. The philosophy of the free software movement is that the use of computers should not prevent people from cooperating with each other. In practice, this means rejecting "proprietary software", which imposes such restrictions, and promoting free software (Stallman 2004). According to Stallman and contrary to the IPR philosophy, this action will promote rather than hinder the progression of technology, since "it means that much wasteful duplication of system programming effort will be avoided. This effort can go instead into advancing the state of the art" (Stallman 1985).

To protect the result of the work of free software communities and the GNU Project, Stallman published the GNU General Public License (GPL) in 1989. The GPL is the most widely used free software license (Black Duck Software 2015), which guarantees end users (individuals, organizations, companies) the freedom to run, study, share (copy), and modify the software. The GPL is a copyleft license, which means that derived works can only be distributed under the same license terms.

The free software movement harbours no good feeling for IPRs. They deem the term as overgeneralized, as it includes at least three different sets of rights (copyrights, trademarks, patents) and a few dozen unrelated ones under one umbrella. According to Stallman "the term carries a bias that is not hard to see: it suggests thinking about copyright, patents and trademarks by analogy with property rights for physical objects" (Stallman 2006). Along the same line of thought, economists Boldrin and Levine prefer the term "intellectual monopoly" as a more appropriate and clear definition of the concept, which they argue, is very dissimilar from property rights (Boldrin and Levine 2005).

As evident by the existence and content of the manifesto, the free software movement was a political response to the diminishing freedoms of computer users. But there were many members of sharing communities that did not share Stallman's vision. They touted technological superiority, innovation and economic growth as reasons for supporting sharing practices in software. Distancing themselves from the notions that non-free software is a social problem or unethical, members of the free software movement founded the Open Source Initiative in 1998.

The "open source" label was created at a strategy session held on 3 February 1998 in Palo Alto, California, shortly after the announcement of the release of the Netscape source code. The strategy session grew from a realization that the attention around the Netscape announcement had created an opportunity to educate and advocate for the superiority of an open development process. Participants believed that the pragmatic, business-case grounds that had motivated Netscape to release their code illustrated a valuable way to engage with potential software users and developers, and convince them to create and improve source code by participating in an engaged community. They also believed that it would be useful to have a single label that identified this approach and distinguished it from the philosophically- and politically-focused label "free software" (Open Source Initiative 2012). Currently, the term Free and Open Source Software (FOSS) is commonly used to include both software practices; and FOSS plays a key role in most software markets (Moody 2015).

FOSS is produced and distributed either by informal communities and non-profit organizations or as commercial products by corporations. Arguably the most publicly recognized project is the Linux kernel and the GNU/Linux operating system (OS). While Linux-based OSs hold a small market share in desktop environments, in web servers it controls the market (W3Techs 2015)(W3Techs 2015b). On the mobile front, Android, an open source OS running a modified version of the Linux kernel, is running on 96.3% of all smartphones. (IDC 2015) Apache, has been leading the web servers market for the last 20 years and with ngnix, another popular open source web server, attribute to more than half of the market (Netcraft 2014). At the client side of the web, open source browsers like Firefox and Google Chrome hold more than 60%. Despite the free vs open source schism, the overwhelming majority of OSI-approved licenses and self-avowed open source programmes are also compatible with the free software modalities and vice versa.

3.1. Assessing Effectiveness Against Patent Laws

Today, patent laws mainly threaten free software communities. A patent serves as a blanket injunction against implementing a certain idea. It does not matter who writes the code, not which programming language is used. Once someone has accused a free software project of infringing a patent, in the face of uncertainty and fear of litigation, the project must either stop implementing that particular feature, or expose the project and its users to expensive and time-consuming lawsuits (Fogel 2015). Although companies using open source software can largely protect themselves by sharing patents, submitting new patents and battling patent litigation is extremely expensive for a free software community. As a result, most such communities are still vulnerable to patent claims.

And there lies the inherent weakness of the free software movement. Born in the hostile legal environment of copyright and trademark laws, it is still trying to defend the right to share knowledge. It can be argued that free software advocates are playing in a rigged game where laws can be changed by intense corporate lobbying and even when they don't, they can rarely protect those who cannot afford to fight in court.

Despite the shortcomings, using open source licensing and practices does offer a protection to some extent. OIN's patent portfolio can be used as a defense mechanism against patent injunctions through its cross-licensing network. It is less effective against patent trolls, as they count on the communities not having enough time or money to fight them. The network numbers more than 600 companies worldwide.

Additionally, modern open source licenses, including GNU GPL v3, incorporate some form of reciprocal patent agreement. And since many of the contributors to open source projects are patent-holding companies, this means that free software communities get automatically protected. When you contribute to the project, your ideas share the protection provided by the license.

Furthermore, the open access type of development that is used by open source communities, with mailing lists, forums, discussion and code out in the open, can act as a defensive publication mechanism to claim prior art against third parties trying to patent ideas of the open source communities. For example, the Linux Defenders program allows patent-like documentation of innovations to be added directly to a database used by the US Patent and Trademark Office in its analysis of new applications.

There are several reasons leading to this success. Computers have largely evolved in academia, where knowledge sharing was the de facto standard to further research. The hacker subculture that originally emerged in academia in the 60s, became more widespread as computers started penetrating the consumer market. The rise of the internet, made possible the creation of network structures of a global scale, expanding them beyond university compounds. In addition, while software quickly became a commodity, its immaterial form meant that, like information, it is non-rivalrous. Making a copy does not deprive anyone from their possessions. This realization casts doubts on the morality of imposed legal restrictions on copying and sharing.

There is another important factor: once the model reaches a critical mass of developers or software matureness, not only does it create a very high barrier for a commercial competitor to entry, but it continues to evolve and spread as people find it useful and expand on it to fit their needs. As the work of anyone that makes use of an open source piece of software has to be published and shared under the same license, the product is continuously improved.

In conclusion, the FOSS paradigm has produced several collaborative experiments, using the Internet as a communication platform and developing novel licensing tools built around copyleft. While it is certainly no panacea, further research would help identify the critical factors that lead to success stories. These including a governance system that leads to sustainability and, as Schweik puts it, those pre-conditions that "somehow establish a situation where participants and/or organizations are willing to devote time, energy, and resources to building these commons" (Schweik 2007, 303).

4. Open Source Initiatives in Agricultural Research and Development

Awareness is growing that the FOSS paradigm is not limited to software and that "it can potentially be applied in any domain that requires a team of thinkers to tackle a problem" (Schweik 2007, 302). Its successful applications have inspired a variety of analysts to propose applications of open source principles and practices to plant breeding and the seed sector. The idea has emerged more or less independently from a variety of disciplines, as Kloppenburg notes on the basis of a literature review: plant breeding, molecular biology, sociology and law (Kloppenburg 2014, 1238). The main rationale was that in a legally defined space in which sharing is unimpeded by IPRs, farmers can continue to apply their local knowledge, in equitable cooperation; and public researchers can continue with scientific plant breeding in the face of global challenges. The open source idea was considered promising, both as a defense against IPRs and as a potentially successful commercial model leading to sustainably funded projects.

The extent to which open source models can be applied to agriculture is subject to debate. An open source model in the agricultural sector would be based on the idea that farmers are both users and developers of both plant varieties and the related information, knowledge and technology. New plant varieties and related technology developed using a participatory process could be made available to farmers and plant breeders with a GPL-styled license with the same viral effect: any subsequent modifications must be openly accessible under the GPL terms, on a contractual promise that there would be no downstream restrictions on the rights of others to experiment, innovate, share or exchange the plant genetic resources. An application of the model would entail an inclusive user community of farmers, plant breeders and researchers through which information and technology may be exchange freely via decentralized commons-based peer-production networks (Aoki 2009). Aoki optimistically argues that such a model would lead to increased capacity of users, rather than creating passive consumers of technologically advanced but legally inaccessible crop technology systems. It would also enable farmers to continue developing plant varieties adapted to particular local situations, and thus prevent genetic erosion. In addition to creating a system allowing for open exchange of knowledge and innovation, the motivations for using an open source model in the agricultural context are further linked to addressing global challenges, including food security, conservation of agricultural biodiversity, farmers' livelihoods and rural development.

An exploration of the structural similarities and differences between the software and agricultural sectors would be useful in illuminating the steps and conditions required for the application of open source principles in agriculture. It would also inform the assessment of the two case studies presented below.

Both sectors can be characterized as knowledge-intensive. At the same time, while agriculture-related knowledge is certainly dynamic, adapting to both environmental conditions and technological advances, information technologies are developing at an extremely rapid pace. The new information technologies are constantly redefining knowledge communities (Ostrom and Hess 2007), including the agriculture-related ones. The reach of these technologies however is not universal. It can be argued that it depends on a series of capacity-, funding-, and education-related conditions. Progress in information technologies impacts directly a University agricultural research facility in the Netherlands, while it may never reach a farmers' cooperative in Sri Lanka.

Similarly, the pace of production and the nature of communities involved in knowledge creation are different. Software developers live online and a community of users and contributors test their products instantly (Jefferson 2006). In contrast, experiments in life sciences take much longer and may be costly, while both formal research and development in agriculture and farmers' innovation may take several years before yielding results. Communities involved in agricultural innovation vary greatly: traditional farming communities contribute to the conservation of agricultural biodiversity by insisting on using traditional varieties to fit local conditions; while scientific breeding takes place in national and international agricultural research centers by specialized groups of scientists. Exchange of knowledge is a characteristic of both these agriculture-related communities. In the case of traditional farming communities however, cooperation and knowledge exchange is a much more localized phenomenon, in contrast to scientific breeders who are, in general, closer to technological innovation and more equipped to use it. This brings the scientific breeders' community closer to the software developers. This is also due to developments in bioinformatics, which make possible the understanding and sharing of biological data.

As described throughout this article, a principal common trend in both sectors refers to the impact of IPRs and the degree of corporate dominance. Farmers' varieties and knowledge are constantly misappropriated and eventually commodified, leading to loss of knowledge and livelihoods and shrinkage of the public domain. The knowledge and work of software developers employed by corporations are similarly exploited, as any potentially useful creation belongs to the corporation. This was indeed the main reason behind the attempts to apply the open source model in agricultural research and development.

4.1. The Open Source Seed Initiative

The idea for the Open Source Seed Initiative (OSSI) emerged from two meetings held in the US in April 2010 and May 2011, which were attended by a small number of public and private plant breeders, farmers, and NGOs' and indigenous groups' representatives. The idea was to encourage and reward the sharing rather than the restriction of germplasm; revitalize public plant breeding; and integrate the skills and capacities of farmer breeders with those of plant scientists. A key tool for achieving these goals was the development of open source licenses, which are modeled on legal arrangements successfully deployed in the software realm, and that preserve the right to use material for breeding and the right of farmers to save and replant seed (Kloppenburg 2014).

The initiative's basic aims included: a germplasm licensing framework with no breeding restrictions on the germplasm released through its auspices other than that derivatives must also be released with the same license; a well-supported public and community plant breeding sector; a plurality of sources from which farmers and breeders can obtain seed; participatory plant breeding through integration of the skills of farmers with those of plant scientists; and respect for the rights and sovereignty of indigenous communities over their seeds and genetic resources (Kloppenburg 2014, 1239).

Arrangements proceeded on the basis of two open source licenses, with the accompanying copyleft requirements: one was "free," with the only restriction that licensees may not restrict the freedom of others to use the seed in whatever way they wish; and the other was "royalty-bearing," allowing collection of royalties on the seed but not restricting usage in any other way. These two licenses aimed to accommodate two tendencies manifest within the Initiative: one supporting completely free access to seed and rejecting any commodification of life forms, coming mainly from farmers from the South; and one interested in some returns or rewards through royalties, coming mainly from breeders in the North, who looked for revenues to maintain their programmes, in view also of the declining level in state support.

This schism between farmers and breeders reflects not only the different needs between two societal sectors, but also the difference between still existing subsistence-based agricultural economies of the South and market-based economies of the North. In an increasingly hostile international legal context dominated by corporate IPRs, it also reflected cultural predispositions against an agricultural initiative born in the North.

While the initiative is still very young, which places it still in the necessary phase of experimentation and makes any assessment premature, some of the challenges are discussed in the (limited) literature; in addition, some general remarks can be made. As Kloppenburg notes, one of the immediate difficulties was a technical legal one. The initiative struggled over repurposing contract law and drafting copyleft licenses that would be maximally defensible in court, resulting in "seven pages in language that none but an attorney can understand" (Kloppenburg 2014, 1240). The need for such license to accompany every package of seed sold or exchanged resulted in inflexibilities, and a failure to virally propagate, negating the most powerful feature of the open source approach.

Notwithstanding the undisputable difficulties of repurposing contract law, Kloppenburg's remark indicates a weakness of the initiative that may be critical in differentiating open source agricultural initiatives from open source software. In the case of software, online collaborating communities *preexisted* when the idea of open software emerged as a defense against IPRs. Agricultural communities certainly exist, but they rarely unite such heterogeneous groups with different immediate needs, such as public and private breeders, farmers and indigenous peoples' representatives. Farmer and indigenous communities in particular are usually location-specific. In this context, OSSI seemed to be built on a somehow artificial community, created specifically in order to oppose IPRs and share seed.

Communities are certainly a dynamic concept and are often built around specific resources or needs. However, it can be argued that a novel community based on new collaborations requires a longer experimentation stage in order to first build trust among its members and second develop its own cooperative management strategies. Particularly when it seeks to address complex, globally important problems such as biodiversity conservation and food security, linked to long histories of colonial and neo-colonial domination (Aoki 1998), addressing equity- and redistribution-related concerns (Ostrom and Hess 2007), including through building the differentiated capacities of the community members, can be particularly important. Such governance approaches may delay operation and might impact efficiency, they may however be instrumental for the long-term sustainability of the project.

4.2. The Cambia BiOS Framework

Another case study exploring open source tools in the agricultural research setting, albeit in a narrower framework, is the Cambia initiative. Focusing solely on the researcher, and not questioning use of modern biotechnology methods in plant breeding, Cambia is described on its website as “an independent non-profit institute creating new technologies, tools and paradigms to promote change and enable innovation”. At its inception, Cambia used patent revenues to create a sustainable funding base, applying at the same time a tiered licensing system, with the fees depending on the ability of each client to pay. To deal with the transaction costs of negotiating licenses, Cambia proceeded with three interdependent activities: the BiOS Framework, which creates licensing tools making use of open source strategies; the Patent Lens, a platform to investigate patent rights and inform practitioners and policymakers; and Cambia’s own research, aiming to create and distribute key enabling technologies (Jefferson 2006).

Patent Lens aims to respond to the obscurity and massive complexity of the patent landscape highlighted above. It includes one of the world’s most comprehensive full-text searchable databases of patents, cost-free and open to anyone. It is intended as a public platform to enable many actors to investigate and share analysis of relevant IP issues, and to foster community involvement in overseeing and guiding the patent system (Jefferson 2006). In that regard, it is a valuable tool in the defensive protection against both misappropriation of genetic resources and traditional knowledge previously in the public domain, and IP litigation, as well as positive support to innovation.

The BiOS framework is directly inspired by the changes in ICTs brought about by FOSS. The basic characteristic of the BiOS license is that no fee is charged for use of a “basket” of patented technologies covered. In exchange for full commercial rights to the Cambia technologies offered, licensees are required to comply with three copyleft-inspired conditions: they shall share with all BiOS licensees any improvements to the core technologies as defined, for which they seek any IP protection; they agree not to assert over other BiOS licensees their own or third-party rights that may dominate the defined technologies; and they agree to share with the public any and all information about the biosafety of the defined technologies (Jefferson 2006, 30).

Adenle et al highlight the usefulness of the BiOS initiative for agricultural development, noting that it “has been at the forefront of promoting open source for sharing biological innovation” (Adenle et al 2012, 263). For example, scientists at Cornell University in collaboration with the Hawaiian Papaya Growers Cooperative used Cambia open source research tools to fight a papaya virus. According to their view however, the BiOS license is not flexible enough. Adenle et al propose an open source agricultural biotechnology framework, according to which flexible licencing policies are central in projects involving open source applications in agriculture, to allow for maximum freedom of choice for users/innovators. The framework also includes a series of structural conditions to address the circumstances of developing countries, such as provision of training, resources and facilities, and supporting legislation, in addition to collaborative networks. According to this proposal however, open source applications seem to be placed at the governments' basket of tools for top-down agricultural development, partly stripped from its political connotations and origin in horizontal communities of users.

In any case, depending on the national legal context, regulatory approval would be necessary for any open source biotechnological application subject to a biosafety risk assessment. Open source biotechnology may be addressing obstacles to innovation in an increasingly proprietary field, but takes a neutral position with regard to the impact of innovation and the thesis that scientific progress should benefit humanity as a whole, with emphasis on those most in need. Scientific and technological progress does not mean that benefits are shared fairly, or that they will reach the most vulnerable groups of society; nor does it mean that all technologies are well-suited for all societal contexts. For scientific progress to contribute to the advancement of broader aims, such as human development, the impacts of different paths and choices for progress must be assessed; and scientific progress cannot be conceived independently of the views of the intended beneficiaries, the society at large, who need to be part of the choices made (Tsioumani 2014).

5. Conclusions

While the economic success of the open source model in software development is unquestionable, the debate is still open on its potential to encourage both open and socially valuable innovation, in response to politically charged global challenges such as food security, rural development and conservation of biological diversity.

Jack Kloppenburg, one of the founders of the Open Source Seed Initiative, offered some valuable insights in his assessment of the experience. Apart from highlighting the practical challenges of drafting workable licenses that create a "legally enforceable mandate for sharing" and afford reasonable protection against IP litigation, he also noted the model's differentiated appeal depending on geo-social location. He remarked that at least in the seed context, there is distrust in the South of an initiative that first originates from the North and second depends on formal licenses. Use or not of genetic engineering tools and methods was also a fault line among participants in the initiative (Kloppenburg 2014), which indicates that a wealth of political, ethical and regulatory issues relevant for agricultural production needs to be addressed and resolved in a specific societal context, before related technologies are managed one way or another.

His assessment points to some critical lessons for agriculture-related communities that wish to experiment with open source. First, given the history and complexity of the matter, experimentation and community-building may take significant time and effort, particularly if the members come from different backgrounds. Second, choices related to agricultural research and development are politically and culturally charged. A community may take a different path than another, and this largely depends to their political predispositions and sociocultural context. Opting for an open source model does not automatically make any technology "good." In addition, it should be acknowledged that, for a large part of smallholder farmers, open source tools would seem just like another foreign idea developed by academics from the North. Building trust would not be easy.

Furthermore, it is dubious whether the open source model takes into account the underlying global inequities regarding distribution of assets and possibilities, which is critical for addressing global problems such as food security. Effective use of open systems requires preexisting infrastructures, knowledge and skills (Louafi and Welch 2014; Aoki 2009) and the largely differing circumstances between North and South render some (individuals and collectivities) better able than others to exploit it. Consequently, open source systems do not seem to solve the equity issues often associated with IPRs. As Louafi and Welch note (2014), open systems would need to develop institutions that redistribute the benefits derived from use to a wide range of actors, in order to integrate equity considerations in addressing global challenges.

The philosophical background of the open source movement is based on the belief that humanity, across history, can operate as a "collective brain," meaning that any produced knowledge does not belong to its creator but to humanity at large. In practice though, by not rejecting the idea of property, including intellectual property, but rather attempting to manage it differently, it creates its own enclosures.

That said, we understand that we do not operate in a historical vacuum, we are not naïve. Discussing absolutely free creation (of anything) within capitalist conditions would be like handing in Native Americans to armed pioneers of the colonial times. The open source movement does integrate a critique against intellectual property; and it is valuable for proposing a "crack" to individual property more generally, by creating for instance highly popular software programmes that are competitive to corporate-owned ones, by proving that "it can be done!" It has been successful in reintroducing in the public debate an "ethos of sharing" (Kloppenburg 2014), in creating networks that are based on values and not on profit, and in creating positive, autonomous spaces to that regard, thus marking a shift from continuous defensive actions.

As free software advocates note, free does not mean gratis but it stands for libre; It stands for "free" as in "free speech" and not as in "free beer" (Free Software Foundation 2000). However, the freedom to share knowledge is in direct conflict with a political and economic system that is increasingly transforming knowledge to a commodity. Failing to acknowledge that, the free software movement has been partly alienated by the rest of the movements for social change. It has either been consumed by open source advocates detached from the demands for more freedom, or it has cornered itself fighting a legal battle instead of a social one. At the end, rather than limiting the debate on open source systems versus IPRs, issues related to production and management of knowledge are to be addressed in a broader context, as part of the larger political debate on knowledge appropriation, access to information and socially acceptable technologies.

References

Adenle, Ademola, Sowe, Sulayman, Parayil, Govindan, Aginam, Obijiofor. 2012. Analysis of Open Source Biotechnology in Developing Countries: An Emerging Framework for Sustainable Agriculture. In *Technology in Society* 34: 256–269.

Andersen, Regine. 2005. *The History of Farmers' Rights. A Guide to Central Documents and Literature*. Lysaker: Fridtjof Nansen Institute.

Aoki, Keith. 2009. 'Free Seeds, not Free Beer': Participatory plant breeding, open source seeds, and acknowledging user innovation in agriculture. *Fordham Law Review* 77: 2276–2310.

Aoki, Keith. 1998. Neocolonialism, Anticommons Property, and Biopiracy in the (Not-So-Brave) New World Order of International Intellectual Property Protection. *Indiana Journal of Global Legal Studies* 6: 11–38.

Benkler, Yochai. 1999. Free as the Air to Common Use: First amendment constraints on enclosure of the public domain. *NYU Law Review* 74: 354–446.

Black Duck Software. 2015. Top 20 Open Source Licenses. Accessed June 15, 2015. https://www.blackducksoftware.com/resources/data/top-20-open source-licenses

Boldrin, Michele and Levine, David K. 2005. Against Intellectual Monopoly. Accessed June 15, 2015. http://levine.sscnet.ucla.edu/general/intellectual/against.htm

Boyle, James. 2003. The second enclosure movement and the construction of the public domain. *Law and Contemporary Problems* 66: 33-74.

Bowman v. Monsanto Co, 133 S.Ct. 1761 (2013) [US Supreme Court]. Accessed June 15, 2015. https://en.wikipedia.org/wiki/Bowman_v._Monsanto_Co.

CAMBIA, Patent Lens. Can IP rights protect plants?. Accessed June 10, 2015. http://www.bios.net/daisy/patentlens/1234.html.

CBD Decision V/5. Agricultural Biological Diversity: review of phase I of the programme of work and adoption of a multi-year work programme. Accessed September 10, 2015. https://www.cbd.int/decision/cop/?id=7147.

Correa, Carlos. 1999. Access to Plant Genetic Resources and Intellectual Property Rights. CGRFA Background Study paper no 8. Rome: FAO

Correa, Carlos. 2000. Options for the Implementation of Farmers' Rights at the National Level. Geneva: South Centre.

Chiarolla, Claudio. 2012. *Intellectual Property, Agriculture and Global Food Security*. Cheltenham Glos: Edward Elgar.
Chiarolla, Claudio, Louafi, Selim, and Schloen, Marie. 2013. An Analysis of the Relationship between the Nagoya Protocol and Instruments related to Genetic Resources for Food and Agriculture and Farmers' Rights. In Morgera, Elisa, Buck, Matthias, and Tsioumani, Elsa (eds). *The 2010 Nagoya Protocol on Access and Benefit-sharing in Perspective: Implications for International Law and Implementation Challenges*. Leiden: Martinus Nijhoff: 83.
Commission on Intellectual Property Rights. 2002. *Integrating Intellectual Property Rights and Development Policy*. London: CIPR.
Cringely, Robert X. 2005. Interview with Brewster Kahle. Accessed June 15, 2015. http://www.pbs.org/cringely/nerdtv/shows/#4
ETC Group. 2010. Capturing Climate Genes. Accessed June 11 2015. http://www.etcgroup.org/content/gene-giants-stockpile-patents-%E2%80%9Cclimate-ready%E2%80%9D-crops-bid-become-biomassters-0.
Farmers' Rights Project. 2009. India's Protection of Plant Varieties and Farmers' Rights Act. Accessed September 20, 2015. http://www.farmersrights.org/bestpractices/success_seed_1.html.
Flink, James J. 1977. The Car Culture. Boston: MIT Press.
Fogel, Karl. 2015. Producing Open Source Software. Accessed June 15, 2015. http://producingoss.com/en/patents.html
Free Software Foundation. 2000. What is free software? Accessed June 15, 2015. https://www.gnu.org/philosophy/free-sw.html.
Garrett, Hardin. 1968. The Tragedy of the Commons. *Science* 162(3859): 1243–1248.
Halewood, Michael, López Noriega, Isabel, and Louafi, Selim. 2013. The Global Crop Commons and Access and Benefit-Sharing Laws. In Halewood, Michael, López Noriega, Isabel, and Louafi, Selim (eds). *Crop Genetic Resources as a Global Commons. Challenges in International Law and Governance*. Oxon: Routledge. 1.
Heller, Michael. 1998. The Tragedy of the Anticommons: Property in the Transition from Marx to Markets. *Harvard Law Review* 111 (3): 621–688.
Heller, Michael, and Eisenberg, Rebecca. 1998. Can Patents Deter Innovation? The Anticommons in Biomedical Research. *Science* 280 (5364): 698–701.
Hess, Charlotte, and Ostrom, Elinor. 2007. Introduction: An Overview of the Knowledge Commons. In Hess, Charlotte, and Ostrom, Elinor (eds). *Understanding Knowledge as a Commons: From Theory to Practice*. Cambridge MA: MIT Press. 3.
Hope, Janet Elizabeth. 2004. *Open Source Biotechnology*. PhD Thesis. Accessed June 10, 2015. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=755244.
IDC. 2015. Android and iOS Sqeeze the Competition. Accessed June 15, 2015. http://www.idc.com/getdoc.jsp?containerId=prUS25450615
Jefferson, Richard. 2006. Science as Social Enterprise. The CAMBIA BiOS Initiative. *Innovations* Fall 2006: 13–44.
Kloppenburg, Jack. 2014. Re-purposing the Master's Tools: The open source seed initiative and the struggle for seed sovereignty. *The Journal of Peasant Studies* 41 (6): 1225–1246.
Louafi, Selim and Welch, Eric. 2014. Open Systems versus Strong Intellectual Property Rights: disentangling the debate on open access for meeting global challenges in life science. In Grosclaude, JY Tubiana, L and Pachauri, RK (eds). *A Planet for Life 2014: Innovation for Sustainable Development* New Delhi: Teri Press: 145–160.
Monsanto Canada Inc. v. Percy Schmeiser [2004] 1 S.C.R. 902, 2004 SCC 34 [Supreme Court of Canada]. Accessed 15 June, 2015. https://en.wikipedia.org/wiki/Monsanto_Canada_Inc_v_Schmeiser
Moody, Glyn. 2015. Open Source Has Won, But It Isn't Finished. Accessed June 15, 2015. http://www.computerworlduk.com/blogs/open-enterprise/open source-has-won-3592314/
Netcraft. 2014. October 2014 Web Server Survey. http://news.netcraft.com/archives/2014/10/10/october-2014-web-server-survey.html
Office of the High Commissioner for Human Rights. 16 October 2014. Family farmers produce over 70% of the world's food, their rights cannot be ignored. Press Release. Accessed June 11, 2015. http://www.ohchr.org/SP/NewsEvents/Pages/DisplayNews.aspx?NewsID=15172&LangID=E.
Open Source Initiative. 2012. History of the OSI. Accessed June 15, 2015. http://opensource.org/history.

Ostrom, Elinor, and Hess, Charlotte. 2007. A Framework for Analyzing the Knowledge Commons. In Hess, Charlotte, and Ostrom, Elinor (eds). *Understanding Knowledge as a Commons: From Theory to Practice*. Cambridge MA: MIT Press. 41.
Schweik, Charles. 2007. Free/Open-Source Software as a Framework for Establishing a Commons in Science. In Hess, Charlotte, and Ostrom, Elinor (eds). *Understanding Knowledge as a Commons: From Theory to Practice*. Cambridge MA: MIT Press. 277.
Stallman, Richard. 2004. Use Free Software. Accessed June 15, 2015. https://www.gnu.org/philosophy/use-free-software.html.
Stallman, Richard. 1985. The GNU Manifesto. Accessed June 15, 2015. https://www.gnu.org/gnu/manifesto.html.
Stallman, Richard. 2006. Did You Say "Intellectual Property"? It's a Seductive Mirage. Accessed June 15. http://www.gnu.org/philosophy/not-ipr.en.html
Tsioumani, Elsa. 2014. Exploring Benefit-Sharing from the Lab to the Land (Part I): Agricultural Research and Development in the Context of Conservation and Sustainable Use. Edinburgh School of Law Research Paper No. 2014/44. Accessed June 11, 2015. http://ssrn.com/abstract=2524337
UN Special Rapporteur on the Right to Food. 2009. Seed policies and the right to food: enhancing agrobiodiversity and encouraging innovation. Report presented to the UN General Assembly (64th session) (UN doc. A/64/170). Accessed June 11, 2015. http://www.srfood.org/images/stories/pdf/officialreports/20091021_report-ga64_seed-policies-and-the-right-to-food_en.pdf.
UN Special Rapporteur on the Right to Food. 2010. Agribusiness and the right to food. Report presented to the Human Rights Council (UN Doc A/HRC/13/33). Accessed June 11, 2015. http://www.srfood.org/images/stories/pdf/officialreports/20100305_a-hrc-13-33_agribusiness_en.pdf.
UPOV Mission Statement. Accessed June 10, 2015. http://www.upov.int/about/en/mission.html.
UPOV. August 24, 2015. International Union for the Protection of New Varieties of Plants. Accessed September 20, 2015. http://www.upov.int/edocs/pubdocs/en/upov_pub_437.pdf.
W3Techs. 2015. Usage of Operating Systems for Websites. Accessed 15 June, 2015. http://w3techs.com/technologies/overview/operating_system/all.
W3Techs. 2015b. Usage Statistics and Market Share of Unix for Websites. Accessed 15 June, 2015. http://w3techs.com/technologies/details/os-unix/all/all
Weber, Steven. 2004. The Success of Open Source. Cambridge, MA: Harvard University Press: 38–44.
WIPO Patentscope. 2010. Publication no. WO2010019838, Stress Tolerant Transgenic Crop Plants. Accessed September 15, 2015. https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2010019838&recNum=1&maxRec=&office=&prevFilter=&sortOption=&queryString=&tab=PCT+Biblio
Yamin, Farhana. 2003. Intellectual Property Rights, Biotechnology and Food Security. IDS Working Paper 203. Accessed June 15, 2015. www.ids.ac.uk/publication/intellectual-property-rights-biotechnology-and-food-security.

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