Sara Boettiger and Brian D. Wright

Open Source in Biotechnology: Open Questions

Innovations Case Discussion: CAMBIA-BiOS

The case narrative by Richard Jefferson in this issue of *Innovations* shows how the rate and direction of progress in biology is constrained by available tools; a novel tool can set the field on a new and more productive course, but only if creative scientists are free to use it. The history of ß-glucuronidase (GUS) reporter genes illustrates the great impact a technology can have when it is novel, useful, and globally available on reasonable terms. Now Jefferson's energy is directed at restoring biotechnologists' global freedom to innovate, by "inventing around" essential, but proprietarily owned, research tools, and trying to ensure that the new alternatives remain freely available for use and improvement.

A key part of his program is the development of BiOS, an institutional innovation that applies aspects of the open source software model to biotechnology. Although the jury is still out on the effectiveness and sustainability of BiOS, Jefferson's detailed account provides a good foundation for initial analysis. Perhaps more important than his discussion of the BiOS model itself, however, is Jefferson's articulation of the intellectual property problems faced by innovators in biotechnology who want to see their efforts make a difference to end-users globally. What he has to say demands the attention of the many lawyers and economists who see no problems with intellectual property protection in biotechnology.

Open source is currently one among several approaches designed to encourage broad based participation in research in biotechnology in the face of the restrictions imposed by intellectual property rights on key enabling technologies.[1] Open source in biology is a work in progress, highly experimental and controversial. This essay seeks to reach beyond the rhetoric of openness and transparency, to consider some of the challenges that confront the BiOS project, and some of the oppor-

Sara Boettiger is Director of Strategic Planning and Development at PIPRA (The Public Intellectual Property Resource for Agriculture, <www.pipra.org>). Brian Wright is professor of Agricultural and Resource Economics, University of California, Berkeley, and member, Giannini Foundation.

tunities that might be created in biotechnology in general, and agricultural biotechnology in particular, by open source innovation.

A DIFFERENT PATH

The GUS reporter gene and subsequent innovations, (and especially Jefferson's publication with almost 4,000 citations) are achievements for which many a professor would contemplate homicide. This narrative has a familiar ring to those who like to read the lives of the academic super-heroes. Outstanding student meets creative mentors on the cutting edge, encounters the right research problem in the wrong field, and ports the solution to the right application just when it is needed. The accomplishment is widely celebrated and the just patent reward is claimed.

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But at this point Jefferson begins to steer his career away from the conventional, exhibiting reckless disregard of academic disciplinary boundaries and fiscal prudence. Many of those GUS citations, some might have noticed, were generated by his own efforts to disseminate the reporter gene technology far and wide in useful kits which enabled disenfranchised scientists in obscure corners of the world to do more effective plant breeding. Eschewing the single-minded pursuit of further publications and attainment of tenure, Jefferson turned to champion an international community of scientists, entrepreneurs, and farmers and their capacity to embrace the emerging scientific opportunities offered by biotechnology. Against the backdrop of such auspicious scientific potential, the constraints imposed by lack of resources and encroaching patent claims caught his attention. Had he followed Adam Smith's recognition of the key role of specialization in innovation and the social merits of selfish pursuing profit maximization, Richard Jefferson's career would have taken a very different, and less interesting, path.

Because he has played on both sides of the patent game in a rapidly evolving commercial field, he has had the opportunity to observe how patents can restrict, or even kill, promising technologies, and stifle the formation of startup firms that generate the flow of innovations to the end users. While most lawyers and economists were still debating whether access to technology and freedom-to-operate problems even existed, Jefferson designed CAMBIA and, in turn, BiOS to tackle those problems. His experience has earned him notable credibility in this debate.

OPEN SOURCE: FROM SOFTWARE TO BIOLOGY

The merits of open source (OS) in software, though still debated, are widely acknowledged. Some advocates of OS software, from its beginnings, have promoted its development with mystical zeal. But, over time, its success as a production model has garnered the respect of hard-headed lawyers and businessmen. OS has proved to be an efficient, thus far sustainable, and competitive system for development of some software applications, delivering high quality products, with faster development time, at a fraction of the cost of firm-based production models.

In OS, self-selected volunteers develop ideas that might make their own lives a little easier. For example, they remove bugs encountered in their idiosyncratic work environments (Bessen 2005), some of which could only be detected by a centralized research authority with great difficulty and expense. This activity is known as user innovation Von Hippel (2005). Often, they share their results with others, and enjoy the resulting peer acknowledgement of their contributions. But none of this started with software. Not by a long shot.

The first modern economist, Adam Smith, described the phenomenon in 1776.

> A great part of the machines … in those manufactures in which labor is most subdivided, were originally the inventions of common workmen, who, … employed in some very simple operation, naturally turned their thoughts towards finding out easier and readier methods of performing it. Whoever has been much accustomed to visit such manufactures must frequently have been shown very pretty machines, which were the inventions of such workmen in order to facilitate and quicken their particular part of the work.

Note the lack of any hint of monetary awards for the inventions, and the assumed willingness of the employers to share them with all comers. Long before Smith, farmers were solving biological problems without thought of monetary award, and sharing their inventions with their peers. Open source agriculture is more a restoration than a revolution.

To agricultural scientists, OS offers a promise of a return to the scientific environment of decades past, where materials and ideas were exchanged with greater fluidity, and today's preoccupation with intellectual property rights that was absent. But BiOS' wet lab plant biotechnology constitutes a young field very different from that of software production, or traditional plant breeding before the twin revolutions in biotechnology and intellectual property rights. Jefferson's initiative accordingly provides an interesting lens through which to examine the prospects for the open source model in novel terrain.[2]

The shift from copyright to patent law, and the complex and expensive regulatory regime, profoundly affect the prospects for open, distributed innovation and the creation of protected commons of easily accessible technology in plant biotechnology. The appropriate architecture for an OS model in biotechnology, like the appropriate design of any innovation, is hard to predict *ex ante*. The fate of BiOS, as a practical implementation of the model, will be highly instructive.

Patent vs. Copyright Law

Free access to technologies in the OS model fundamentally depends on the protection of those technologies from encroaching IP claims. This is accomplished through an open source license in which the right to use the technology is exchanged for the promise not to privately appropriate it. In software, the strategy designed to create a protected commons of accessible technologies involves the dominant IP form, copyright, as the key legal instrument in the open source. In biology, the dominant form of intellectual property protection is not copyright but patents. Several characteristics of patent law pose serious challenges to the translation of the OS software model to biotechnology.[3]

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Whereas copyright attaches instantaneously and with zero cost to new software code, obtaining patent protection ("patent prosecution") for an innovation in biotechnology costs tens of thousands of dollars, and entails months if not years of back and forth between the applicant and the patent office. The traditional OS model depends on the collaborative contributions of programmers who engage in the project for any number of well-researched motives (reputation, fun, improved skills, connection to community, etc.), but if their innovations were to be protected by patents, and the cost of patenting were shared by all research collaborators, the community of contributors would likely collapse.

Given that the cost of the patent system discourages the patenting of every iterative improvement to open sourced biotechnologies, it would be necessary to make informed bets as to what *ought* to be patented in order to achieve a cost-effective degree of protection for the growing commons of the project. Remaining technologies might be defensively published. The Single Nucleotide Polymorphism (SNP) consortium[4] provides an example of effectively combining defensive publishing and defensive patenting to reach a similar goal of sustained open access, but without the complication of maintaining access to "improvements" of key enabling technologies.

A priori decisions must also be made regarding *where* to patent. One strength of the OS model in software is its ability to cross national boundaries, gaining from the talents of a truly international set of developers.[5] While copyright lends itself to virtually costless international coverage,[6] patents are national in scope. Applying for patent protection worldwide can be prohibitively expensive; even filing in a handful of wealthy countries can cost hundreds of thousands of dollars in fees and associated expenses.

In patents, as in copyright, the utility of the protection gained from intellectual property rights depends on the ability to enforce. All the expenditures and effort involved in patent prosecution are in vain unless the OS commons has the credible financial capacity to sue infringers and finance the necessary litigation through to a decision, if necessary. In patents this capacity does not come cheap; each lawsuit in the United States costs millions of dollars. It is not clear whether the issue of enforcement is less serious in OS software, which is itself a pioneering commons institution, and, as such, still a work in progress.

One practical distinction between software and plant biotechnology in this regard is that infringers may have less incentive to fight to the end if they can, at low cost to themselves, cease infringing by substituting lines of new code in a relatively short time period. In plant biotechnology, however, an accused infringer is likely to have less attractive alternatives to legal warfare; switching to a non-infringing technology may forfeit an investment of years of development, back-crossing and regulatory testing because patented technology is often locked into the genome of a novel plant variety.

In light of these constraints, BiOS, for effective management to achieve unfettered access to crucial technologies, needs to be able to make centralized decisions about patenting and publishing, and to have the financial capacity to enforce its rights. Centralized decisions are not foreign to the traditional open source model; despite claims of democratic innovation by OS protagonists, the system most often depends on a hierarchy of reviewers ensuring quality control and assigning credit.[7] But even with this hierarchy, the OS quality control process lends itself to, and indeed finds strength in, its openness and immediacy. To our knowledge, BiOS and other OS biology initiatives have not addressed the issues of confidentiality, delays and capital requirements associated with extension of the OS model to patentable biotechnologies.

Open Access to End-Products

Beyond the challenges posed by the shift from copyright to patent law, further constraints to the translation of the open source model into applied biotechnology arise from fundamental differences in the characteristics of product commercialization paths. In the life sciences a significant amount of capital is often necessary to move inventions through development, field testing, manufacturing, and distribution. OS software, on the other hand, has no expensive regulatory hurdles to traverse and can be replicated and distributed at zero marginal cost.

If the goal is open access to an end-product, not to a research tool (as in BiOS), then widespread delivery of the product may depend on engaging capital to get it from the lab out into the hands of consumers. The ability to leverage patent rights can, in some cases, play a critical role. If the product has both commercial and humanitarian markets (consider, for example, an AIDS vaccine), the patent owner may license the patent rights to a company for use in the lucrative developed country market in exchange for the company's promise to manufacture and deliver the product into developing country markets at a reasonable price. This logic is not new, of course. Product development public private partnerships (PDP's), among others, have demonstrated how to leverage intellectual property rights, segmenting the market in their licensing agreements in order to achieve the ultimate goals of delivering biomedical innovations to poor and underserved populations where there are very limited commercial markets. It is in cases like these that open source licenses may *hinder* the product's commercialization by precluding the engagement of private capital. An understanding of this dynamic is in part what drove the BiOS model to focus on enabling technologies, preserving the potential for patent rights on application-level technologies.

The polio vaccine provides a historical example that seems to contradict the cautions above. It is often cited as a case where the choice not to patent resulted in a major public health success. Jonas Salk famously stated: "Who owns my polio vaccine? The people! Could you patent the sun?" It's true that Salk did not patent his work and open access was achieved, by almost anyone's standard, as the polio vaccine represents one of history's great public health success stories.

The polio vaccine was delivered through an extraordinary collaboration between individual volunteers and a public charity, the National Foundation for Infantile Paralysis (now known as the March of Dimes), founded by Franklin Delano Roosevelt. Salk's work was funded by the National Foundation. The field trials were the biggest peace-time mobilization of volunteers in U.S. history. Nearly two million school children, called the "Polio Pioneers," and thousands of health-care workers and lay people volunteered to take part in or assist with the vaccine field trials. The results of the trials were analyzed at the University of Michigan. Millions of Americans participated by raising funds in their communities. The National Foundation for Infantile Paralysis even funded the manufacture of the vaccines by subsidizing the production of nine million dollars worth of vaccines.

The story of the polio vaccine is, indeed, an inspirational illustration of a nation mobilizing its resources to address a public health crisis. But it was developed with ample funding and without a thicket of potentially blocking patents. Remember, too, that vaccines are currently under-supplied globally. The Salk model has not been sustained. A major source of vaccines for tropical diseases is the U.S. government, which funds the necessary research to protect soldiers who might one day fight in tropical lands; any gains that accrue to locals in such countries are more or less incidental. Where there is still some doubt as to whether private sector resources may need to be engaged, the option to use IP rights as a tool to achieve the goals of open access may be valuable.

The larger point is that different IP management tools fit different circumstances. There are many instances where publishing and *not* patenting is the path to ensuring open access. Yet another important strategy, widely praised as judicious, is exemplified by the broad and non-exclusive licensing strategy implemented for the key Cohen-Boyer patents. Effective IP management plans require flexibility and knowledgeable professionals. They should be designed to support particular goals, and depend on the characteristics of a technology and surrounding circumstances as they unfold. Open source mechanisms, though, are not flexible; in terms of IP, the fate of a new invention is mandated ahead of time. This can mean missed opportunities.

Inter-operability and Parallels to Linux

The burgeoning of the OS model in software and its ability to generate serious rivals to commercial products in some market segments was dependent, in part, on two critical elements. First, the contribution of a kernel by Linus Torvalds in 1991 enabled Linux to become a complete, functional alternative to proprietary operating systems, and subsequently the flagship for OS success. Second, the creation of a set of OS licenses with different degrees of virality, allowed OS code to be used in combination with proprietary software, thereby broadening the range of business applications that could integrate OS code. The original OS license, the GNU General Public License (GPL), has a viral quality which mandates that products incorporating the original code also become additions to the commons and must be licensed under the same GPL terms. In response to needs for an OS license where interoperability brought fewer restrictions, other licenses were developed[8] which allowed OS code to be incorporated into proprietary commercial products. The range of degrees of virality among licenses reflects a trade-off. More viral licenses promote greater growth in the protected commons of code, but at a cost of reducing the range of applications for the code. Less viral licenses still can work to preserve the commons of code, but lean more toward the direction of a static commons which does not grow as quickly.

It is natural to look to OS in software to find a model for the protected commons of technology that BiOS seeks to create. Jefferson rightly identifies the need for a complete platform of enabling technologies, tools for plant genetic transformation, as an important element of OS application for agricultural biotechnology. Along with Jefferson, the press has highlighted parallels between his Transbacter™ technology, designed to work around existing, proprietarily-owned, plant transformation methods that form a crucial bottleneck in agricultural biotechnology, and the kernel of what we now know as Linux. The analogy, though, is premature, for two reasons. First, Torvald's kernel was the lynchpin to the system—with it a truly self-sufficient operating system was born. Transbacter™, though, removes only one of two current bottlenecks. There is yet another technology that remains a critical impediment to operability.[9] Second, Transbacter™ is a young technology. Its utility for plant breeders is not yet established.[10]

In any case, because of the territorial nature of patents, these bottlenecks of proprietarily owned enabling technologies exist for the most part in only a few countries (including the United States). The key patents creating the bottlenecks in the U.S. were either never issued, or have expired in many other countries. While it is true that products exported back into territories where these patent bottlenecks exist will have problems, there are many countries without these patents in which researchers can use a full set of technologies in the public domain with impunity, and with no need to consider BiOS license terms. There are other, non-IP, reasons why this is not done; access to materials, biosafety issues, liability and stewardship issues, and a weakness in scientific capacity can be more serious impediments than foreign patents in hindering progress in plant biotechnology in developing countries.

However, the path pioneered by BiOS could become a route to freedom to operate for poor countries in the future. The full effects of the global spread of patenting fostered by the TRIPS Agreement of the World Trade Organization, and even more onerous bilateral agreements, are now coming to bear on agricultural researchers in developing countries. As their scientific capacities develop, the full force of patent claims might well become a serious obstacle.

Because BiOS does not currently provide a complete and viable alternative platform, interoperability concerns are not just important, but essential. Researchers have no alternative to using technologies licensed under the BiOS terms in conjunction with patented technologies owned by others. Unfortunately the BiOS license mandates encumbrances that "infect" key complementary enabling technologies. Owners of patents on such technologies might well find these encumbrances unacceptable.

Suppose, for instance, a scientist creates a plant transformation vector (the research tool that enables a researcher to insert a gene into a plant's DNA), with a BiOS enabling technology as one of its many component technologies. Under the terms of the license, the entire vector system must be granted back to BiOS. The BiOS license, in its reservation of rights for the licensee to own application technologies (i.e. *not* enabling technologies), falls short of what is known in open source software licensing as "viral."[11] However, the BiOS license does have a viral quality to it that affects enabling technologies.

The terms of the BiOS license could mean that researchers become limited in the set of tools from which they choose. In a sense, the BiOS license could, counter-intuitively discourage, rather than encourage collaboration. To see this effect, imagine again the vector system referred to above where one component is a BiOS technology. The researcher would like to use another component that happens to be patented by a commercial firm. The commercial firm will not agree to the use of their technology knowing that the vector system, incorporating their technology will be available for free under the BiOS license. Therefore the researcher's choice of tools is effectively diminished by having chosen to use the BiOS technology; he has relinquished the ability to use certain tools because he has brought a technology into his lab under the terms of the BiOS license.

It is true that the BiOS license allows the licensee to refrain from granting back improvements if they are kept as trade secrets. (Not only can the licensees benefit from access to enabling technologies, and the improvements of others, but they can use trade secrecy, where feasible, to avoid making their own improvements available to other licensees.) The trade secrecy option is, however, unlikely to be a useful concession for universities, where disclosure is an important part of the culture and materials are regularly shared among researchers in a lab (or among labs) informally.[12]

In sum, creation of a transformation platform as a flagship application with freedom to operate has been the subject of much effort and creativity, but it is still a work in progress.

Is the BiOS Model Sustainable?

In order for BiOS to be a viable and replicable model, sustainability is essential. Richard Jefferson has generously seeded the model by placing his own patents under the BiOS license; the Rockefeller Foundation and IBM, among others, have provided financial or material support. The initiative aims to increase the commons with improvements to the existing technologies. But what about *new* technologies? The incentives for participating by signing the BiOS license are separate from the incentives needed to get people to donate new technology. Will the latter be forthcoming to BiOS as contributions from the private sector or public sector? Jefferson's own experience with BiOS is not encouraging on this point. Perhaps the BiOS approach will be sustained by replication, with each new collaboration initiated by a creative leader who sets the broad agenda. The key enabling technology for widespread adoption of the BiOS model might be a perfected BiOS license.

The culture of hackers that continues to fuel the advances of OS in software may not be replicable in the field of biology. But to the extent that it is, researchers in the public sector are likely to be crucial participants, especially in less developed economies where almost all agriculture-related research is public. In its present form, the BiOS license remains a poor contractual fit for universities (particularly those in the U.S.[13]). Some would argue that the goal of the BiOS model to provide for dissemination and access is already part of the university process. Universities publish, they collaborate, they share and exchange. Having learned from painful experiences akin to Jefferson's loss of access to a positive selection strategy, when universities license their technology they typically retain the right to publish, conduct research, and allow other universities/non-profits to do the same for research and educational purposes.

The reach of the BiOS grantback[14] goes beyond what is often found in licenses from the nonprofit sector, and could impose obligations that public sector scientists are not free to satisfy, since the rights to their inventions are often mediated by their employer institutions. This is a problem that arises when the OS approach is ported from the world of copyright to the world of patents. Universities have not wrested control of copyright on texts from the grasp of their academic authors, even if the work is produced on campus. By contrast, patents on inventions originating in U.S. university labs are assigned to the institution. It may be that a sustainable OS model in patentable biotechnologies will need to utilize a legal mechanism that is better-suited to the peculiarities of academic institutions.

Some Perspective

At this point, it is appropriate to put some perspective on the relevance of open source initiatives for global agriculture. To date, it is unlikely that massive numbers have died of hunger due to the current state of agricultural intellectual property rights. Subsidized by rich countries' agricultural policies, the world markets have offered basic foods at prices lower than ever recorded.

Furthermore, almost all currently useful agricultural biotechnology has been available, without patent protection, to most developing countries, for all purposes except incorporation in exports to countries with relevant patents in force. It has not been widely adopted for basic food production, for two reasons. First, widespread opposition to genetic modification, for reasons of biosafety and public acceptance, has discouraged this type on innovation. (For example, as of 2006, South Africa was the only country in Africa where genetically engineered crops are grown commercially).[15]

At present, open source is a promising, but problematic, way to preserve some freedom to innovate in a world of patent thickets.

Second, the less developed countries, with a handful of notable exceptions including China, India, Brazil and Argentina, lack any real capacity to exploit the new technologies, because the substantial, sustained investments in education, research and facilities necessary to get the process under way have not been made.

Nevertheless this is the right time to be addressing patent problems in developing countries. The long downtrend in food prices has been interrupted, a reminder that the food yield increases behind recent declining price trends did not come automatically, but reflect sustained, large, largely public, investments in research. In the past year, the world has awakened from complacency about atmospheric carbon, on the one hand, and reliance on imported fuels, on the other, to support massive increases in ethanol production from crops. If these increases continue, large yield improvements in the productivity of crops will be needed to ensure that competition from gasoline consumers does not cause an increase in the numbers of the world's poor and hungry.

Considerable investments have already been made into researching the genetic modification of developing-country crops (for instance, biofortification, disease and pest resistance, and drought tolerance). These projects must consider constraints and opportunities associated with intellectual property rights in order to ensure the intended delivery of the products of their research into the hands of farmers. In its short history, there is already an accumulation of anecdotal evidence of agricultural biotechnology research projects being delayed, re-directed, or halted all together because of intellectual property rights problems (Wright and

Pardey 2006a, 2006b). A recent survey of agricultural biologists at U.S. Land Grant Universities reveals that they, as a group unusually familiar with patenting and the exchange of tools, believe that intellectual property rights, through their effects on transactions with their peers, are on balance hindering progress in their research areas (Lei et al., 2007).

There is, therefore, a sound argument that we cannot wait to find out how the global implementation of the TRIPS agreement, and subsequent bilateral negotiations on intellectual property rights, affect global innovation over the next quarter century. IPRs, among the many challenges in life sciences, require forethought. Decisions today about the ownership of and access to technologies (through patents and licenses) will affect the paths of research and development for decades ahead.

CONCLUSION

To develop BiOS, Jefferson has had to dedicate years of effort and ingenuity, calling on all his talents as scientist, entrepreneur, innovator, fund-raiser and cheerleader. To create a flagship application for BiOS, he and his colleagues have invented a novel technology for genetic transformation of plants, designed to be unencumbered by prior patent claims. To ensure its development follows the open source model, he has fashioned the BiOS license, porting the open source licensing concept from copyright to a more complex world of patent protection and biosafety regulation.

Given the magnitude of the task, it is no surprise that the development of BiOS as a sustainable institutional innovation is still a work in progress. But at this stage, the story merits a close reading. Jefferson has indisputable credibility as a witness to the multidimensional challenges of acquiring freedom to operate in agricultural biotechnology.

From a policy perspective, the major lesson is implicit. Almost the entire effort in creating BiOS constitutes expenditure of valuable, if not unique, resources that would be unnecessary, absent a patent system, or a system of efficient license agreements. This effort, then, constitutes a concrete example of the "excess burden" of the patent system, as it exists in developed countries, that is, its cost to innovators that does not get transferred to others as benefits, but is lost as economic waste.

The availability of global communication at virtually zero cost offers unprecedented opportunities for exploiting specialization and the division of labor in biotechnology research. Unfortunately, the recent revolution in patent protection, and constraints imposed by biosafety regulations, have had the opposite effect, forcing "in-house" aggregation of essential agricultural biotechnology innovation capabilities within a few vertically-integrated firms. As this has happened, the innovation race has slowed to a crawl.

Thus far, the prudent caution regarding biosafety, and the slowdown in biotechnology innovation, have had no serious effects on food consumption; past research investments, and rich-country food subsidies, have kept prices low and supplies high. Given the current surge in biofuels demand, and the continuing increase in world population, it would be foolhardy to assume that this situation will continue. At present, open source is a promising, but problematic, way to preserve some freedom to innovate in a world of patent thickets. Achievement of a less restrictive patent regime would allow the full creative potential of open source collaboration to be realized in ensuring an adequate supply of food for the years ahead.

We invite reader comments. Email <editors@innovationsjournal.net>.

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1. Other models include patent pooling, clearinghouse mechanisms, and humanitarian licensing.
2. It is not clear that biotechnology per se is less amenable to specialization and open source collaboration, absent biosafety and intellectual property constraints. The potential efficiencies of specialization and collaboration in synthetic biology are illustrated by the BioBricks initiative <http://www.biobricks.org/>. See Endy (2005).
3. In the interest of brevity, we discuss only highlights of several differences between patent and copyright law and their significance for the translation of the OS model are provided. In fact, differences in the legal systems have wide-ranging implications for OS that deserve more in-depth analysis.
4. Robert Cook-Deegan (2003) describes how a group of academic institutions and thirteen private firms formed a consortium to ensure the SNPs remained broadly accessible and were not privately appropriated. He writes: "The SNP Consortium did not just dump the data. They filed patent applications and then characterized the SNP markers enough so that they could be sure that nobody else could patent them. At that point, they would abandon the patent. It is a very sophisticated intellectual property strategy that in the end was intended to bolster the public domain. It requires coordination, lots of paperwork, and it costs money to file and process applications, but it appears to be an effective defensive patenting strategy."
5. Lancashire (2001) reports 33 different nationalities among Linux contributors.
6. There are two principal international copyright conventions: the Universal Copyright Convention (or UCC) and the Berne Convention. To protect copyright internationally the name of the author is required and (for the UCC) the year of publication and a © symbol.
7. Jill Coffin (2006) notes: "For [an open source project] to function…an organizational and political structure must support it. Hybrid, flexible political systems based upon meritocracy motivates participants, provide rewards in the absence of capital, and encourage a community-wide sense of project ownership. In addition to the bottom–up, peer–administered hierarchy described in the analysis of Wikipedia, the benevolent dictator and consistently active personnel keep the project alive and dialog open from above, so to speak…A transparent meritocratic structure also allows for smooth succession in administrative and leadership positions."
8. For instance the Berkeley Software Distribution (BSD) style licenses.
9. Generating genetically modified crops requires several indispensable technologies including those necessary to transfer foreign DNA into a plant cell, selection gene markers to distinguish genetically modified cells from untransformed cells, and marker-excision technologies to remove superfluous DNA after successful integration of the trait gene into the plant genome. This packet of core technologies is complemented with other research-specific technologies, which may also be protected by IP. Of the transgenic crop technologies, transformation and selectable markers may be considered "bottleneck" areas where the restricted access to the technologies can impede innovation.

10. Broothaerts et al. found that the transformation efficiency of non-*Agrobacterium* bacterial species ranged from less than 1% to almost 40% of that of *Agrobacterium*-mediated transformation, depending on the transformation assays and species used. (Gene Transfer to Plants by Diverse Species of Bacteria, Nature 433, 629-633 (10 February 2005)
11. The GPL (http://www.gnu.org/copyleft/gpl.html), requires in clause 2(b) that any works derived from the licensed software must also to be distributed under the GPL.
12. Another anomaly differentiating the commercial use of the BiOS license from academic has to do with federal funding and obligations that are common in university policy as a consequence of the adoption of the Bayh Dole Act.
13. PIPRA, The Public Intellectual Property Resource for Agriculture, www.pipra.org, has completed an in- depth analysis of the BiOS license from the perspective of a U.S. university as a potential licensee.
14. For a legal discussion of the BiOS license see Boettiger and Burk (2004).
15. See Eicher (2006).

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