Industrial and Corporate Change, Volume 15, Number 6, pp. 919–935
doi:10.1093/icc/dtl030
Advance Access published November 3, 2006

Information and intellectual property: the global challenges

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Looking back to the seminal papers by Richard R. Nelson, "The simple economics of basic scientific research," and Kenneth Arrow, "Economic welfare and the allocation of resources for invention," this article claims that in the last fifty years, there has been a paradigm change in our understanding of the economics of research and invention. The article argues that there are innovations within the process of innovation itself, and in particular in the instruments of promoting invention and innovation—the exclusive intellectual property rights granted to single economic actors for individual innovations—with, as a result, the emergence of various forms of collaborative innovation in different domains. The article concludes that the implications for the contribution of invention and innovation for global growth and development are significant.

1. Introduction

Like "golden weddings," there are also "golden papers": seminal papers which appear to be characterized by their uniqueness in having raised issues which fifty years after they have been written look as relevant as they probably did fifty years ago. Richard Nelson's (1959) paper on "The simple economics of basic scientific research" and Kenneth Arrow's (1962) paper on "Economic welfare and the allocation of resources for invention" clearly belong to this category of golden papers.

There appear two useful approaches to look at what such "golden papers" have contributed to current debates in the economics and more broadly the policymaking profession. The first one focuses on the way such papers have been an inspiration for further elaborations of ideas and concepts, sometimes by the authors themselves, but more generally by many subsequent generations of scholars[1] who have followed and

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[1]One of us has even had the pleasure to be once co-author with Richard Nelson (Nelson and Soete, 1988) and once editor of a book with a contribution from Ken Arrow (Silverberg and Soete, 1995).

build upon these seminal papers. When reading back both the Nelson and Arrow papers, it is truly surprising how many embryonic concepts and ideas were already present in those early papers. Many of the core concepts which are today at the center of the economics of invention and industrial research and development (R&D) innovation can be found back in both the Nelson and Arrow papers. Given space we only list a few:

1. The particular role and importance of applied research for scientific breakthroughs and the ensuing reasons for firms to invest in basic science. In his 1959 paper, Nelson wrote: "a firm producing a wide range of products resting on a broad technological base may well find it profitable to support research toward the basic-science end of the spectrum. A broad technological base insures that, whatever direction the path of research may take, the results are likely to be of value to the sponsoring firm. It is for this reason that firms which support research toward the basic-science end of the spectrum are firms that have their fingers in many pies" (p. 302). A similar point made also by Arrow in his 1962 paper: "The only way, within the private enterprise system, to minimize this problem [discrimination against investment in inventive and research activities] is the conduct of research by large corporations with many projects going on, each small in scale compared with the net revenue of the corporation." The point has been made subsequently much more explicitly by Nathan Rosenberg (1990b) in his celebrated "Why do firms do basic research (with their own money)?"
2. In his 1959 paper, Nelson lay the foundations of what in a much more elaborated way became known as the "business stealing effect" in Philippe Aghion and Peter Howitt's 1992 celebrated Econometrica article, "A model of growth through creative destruction." Nelson wrote: "If competing firms develop a patentable product first, or develop a competing product, these firms will in effect steal from the research sponsoring firm, through price and product competition, a large share of the social utility created by research" (p. 303), highlighting the particular role of industrial cooperative laboratories to offset such "stealing" tendencies. In Nelson's words: "these laboratories are motivated by the fact that most of the firms will gain from the results of relatively basic research in certain fields whether or not they pay for it; hence little research will be undertaken in the absence of co-operation" (p.303), a point made subsequently by many scholars on technology and R&D policy such as Paul Romer (1993) in his plea for self-organizing industry investment boards.
3. And as last quotation, let us cite the concluding paragraph on public policy on basic research in the 1959 Nelson paper. "The current US policies of letting huge applied research projects with universities should either be considered or complemented with other policies designed to prevent the increased applied-research burden from drawing university facilities and scientists away from basic research" (p.306). Replacing United States with European Union (EU), it is as if the quote was written by the most recent paper of Dosi *et al.* (forthcoming) in their critique of the current EU R&D support policies.

The second approach focuses on the way in which two seminal papers did provide a clear benchmark to assess our progress in thinking about this field. What was fifty years ago most strikingly absent from those papers relative to our present understanding of the subject? And what does this tell us about the way our thinking has progressed?

The two most striking features appear from our perspective:

1. *Innovation* as a concept seems by and large absent from both papers. Both papers describe in essence a supply-dominated world of basic and applied science, invention and industrial research, and information. It is also a world of large firms, with broad underlying technological bases and which have at their disposal large industrial research laboratories and a world of universities where basic science is being carried out. There is nothing on small, entrepreneurial science-based enterprises; Schumpeter is completely absent and so is also the notion of "creative destruction" in the cumulative process of technological advance.
2. *International aspects*, with the exception of Ken Arrow's reference to the Soviet Union where "the reward for invention would be completely separated from any charge to the users of the information" (p.617), are also completely absent. There is no attention to any of the implications of the insights provided or the policies proposed for the rest of the world. Undoubtedly this is a reflection of the times: the importance of domestic US policy challenges with respect to science policy in the late 1950s early 1960s with the Soviet Union Sputnik challenge, the Cold War, and so on.

It is to those two aspects of what we would claim represents today a paradigm change in our understanding of the economics of research and invention that we turn in this article. They lead us to argue that there are innovations within the process of innovation itself, and in particular in the instruments of promoting invention and innovation—the exclusive intellectual property rights granted to single economic actors for individual innovations—with, as a result, the emergence of various forms of collaborative innovation in different domains. As we argue in the conclusions, the implications for the contribution of invention and innovation for global growth and development are significant. But before we arrive at such conclusions, we start from the second point above: the one probably least subject to debate—the global implications of invention and industrial research.

2. "Research without borders": the global implications

Economically, the last fifty years since Nelson and Arrow wrote their seminal papers, the world has witnessed an unparalleled growth and transformation. Economic development has undoubtedly been spurred by the opening up and ensuing expansion of world trade and the dramatic reduction in barriers to capital movements, but it would only be fair to say that either in conjunction with such liberalization or separate from it, the growth externalities of knowledge have had undoubtedly a lot to do with the rapid post-war growth. First, under the form of catching up of the European countries and Japan—the thirty glorious years (as the French economic historian Jean Fourastier used to refer to this period)—and subsequently of the newly industrializing South East Asian economies. The third phase set in motion in the late 90s with the world integration of large emerging economies such as Brazil, Russia, India, and China (the BRIC)—compared by Richard Freeman (2005) with a doubling of the world labor force—could be said to be still in full swing requiring a much longer period of global adjustment.

Innovation and the shifts in global demand play today, in other words, a crucial role in the policy debates about science and technology (S&T). The largest part of worldwide growth and development has undoubtedly been associated with acceleration in the diffusion of technological change and worldwide access to codified information. The role of information and communication technologies has been instrumental here as has been that of more capital- and organizational-embedded forms of technology transfer such as foreign direct investment which is today as a percentage of gross domestic product (GDP) a decimal point greater than what it was fifty years ago and no longer limited to the Organization for Economic Cooperation and Development (OECD) world. By contrast, labor markets and with it the knowledge embodied in skills and human capital have barely globalized, with the exception of the mobile top tail of scientists, engineers, managers, actors, football players, or other creative talent. As Dosi and Castaldi (2002) note: "Persistently national labour markets have gone together with high and persistent asymmetries in the skills in the population."

In short, while information and communication technology (ICT) enable easier diffusion of information, the global knowledge market (if there is such a thing) and with it global access to knowledge—and in particular in its creation—remains highly unequal. There remains a continuing concentration of innovative activities, which are matched by persistent international differences in the share of resources devoted to science and technological efforts. Yet, today it is no longer the direct impact of the transfer of industrial technologies on economic development which is at the center of the debate but rather the broader organizational, economic, and social embedding of such technologies in a development environment, the way they unleash or block particular specific development and growth opportunities which is at the center of the S&T policy debate. That process is in all likelihood much more complex in a developing country context than in a developed country.

As has become recognized in the endogenous growth literature,[2] the innovation policy challenge with its characteristic Schumpeter mark 1 versus mark 2 features is

[2]This view of the philosophy and aims of innovation policies differing amongst countries according to their level of development, reminiscent of many of the arguments of the old infant industry type arguments has now become popular in the endogenous growth literature. See Aghion and Howitt (forthcoming).

closely associated with levels of development. In the high-income, developed country context, the innovation policy challenge seems increasingly directed toward questions about the sustainability of processes of "creative destruction" within environments that give increasingly premiums to insiders, to security and risk aversiveness, and to the maintenance of income and wealth. In an emerging, developing country context, by contrast, the challenge appears directed toward the more traditional, "backing winners," industrial S&T policies bringing also to the forefront the importance of engineering and design skills and accumulating "experience" in particular. Finally, there are those poor countries characterized by "disarticulated" knowledge systems, well described by many development economists in the area of S&T (Bell, 1984; Sagasti, 2004) and where the endogenous innovation policy challenge is probably most complex of all.

3. From industrial R&D to innovation

The national industrial S&T system has been well described in many of Richard Nelson's subsequent detailed descriptions of the United States national system of innovation. It has brought to the forefront the crucial role of core institutions: the university and private industrial R&D, and the importance of experimental development work, design, and engineering experience. What became characteristics of this industrial technology production method were, as many of the Sussex more sectorally focused innovation studies from Christopher Freeman, Keith Pavitt, and Giovanni Dosi have demonstrated in detail, the activity of industrial R&D, its scientific content, and the extent of professional specialization accompanying it. It is this sort of professional work which became and still is recorded in official, internationally harmonized R&D statistics. As was actually already acknowledged in the early days of defining what was to become the Frascati Manual (OECD, 1981) definition of "R&D," the industrial R&D statistics were first and foremost a reflection of the professionalization of R&D activities. In many manufacturing firms, the "technical" or "engineering" departments or "OR" sections contributed far more to the technical improvement of an existing process than the formal R&D department, more narrowly defined. But, the emergence of the particular R&D function was what came to be most closely identified with the emergence and growth of the industrial society (Mowery, 1983).

As historians have argued, this industrial research "revolution" was not just a question of change in scale. It also involved a fundamental change in the relationship between society on the one hand and technology and science on the other (Mokyr, forthcoming). The expression "technology," with its connotation of a more formal and systematic body of learning, only came into general use when the techniques of production reached a stage of complexity, where traditional methods no longer sufficed. The older, more primitive arts and crafts technologies continued to exist side by side with the new "technology." But, the way in which more scientific techniques would be used in producing, distributing, and transporting goods led to a gradual shift in the ordering of industries alongside their "technology" intensity. Thus, typical for most Western industrial societies of the twentieth century, there were now high-technology intensive industries having as major sectoral characteristic the heavy, own, sector-internal R&D investments and low-technology intensive, more craft technique-based industries, with very little own R&D efforts. And although in many policy debates, industrial dynamism became as a result somewhat naively associated with just the dominance in a country's industrial structure of the presence of high-technology intensive sectors, the more sophisticated sectoral studies on the particular features of inter-sectoral technology flows, from Pavitt (1984) to Malerba (2004), brought back to the forefront many of the unmeasured, indirect sources of technical progress in the analysis.

4. Collaborative ownership as an innovation in innovation

In the 1990s another significant shift in the understanding of the relationships between research, innovation, and socioeconomic development occurred. The perception of the nature of innovation process changed significantly. Innovation capability became seen less in terms of the ability to discover new technological principles but more in terms of the ability to exploit systematically the effects produced by new combinations and use of pieces in the existing stock of knowledge (David and Foray, 2002). The new model, closely associated with the emergence of numerous knowledge "service" activities, implied more routine use of a technological base allowing for innovation without the need for particular leaps in S&T, sometimes referred to as "innovation without research." It requires a systematic access to the state-of-the-art technologies, whereby industries introduce procedures for the dissemination of information regarding the stock of technologies available, so that individual innovators can draw much more directly upon the work of other innovators. This mode of knowledge generation—based on the recombination and reuse of known practices—raises more information-search problems and is more directly confronted with the problems of impediments to accessing the existing stock of information that are created by intellectual property right laws.

This shift in the nature of the innovation process seems to imply a more complex, socially distributed structure of knowledge production activities, involving a much greater diversity of organizations having as explicit goal knowledge production. The old industrial system typical of Nelson's golden paper was based on a relatively simple dichotomy between knowledge generation and deliberate learning (R&D laboratories, engineering, and design experience) and activities of production and consumption where the motivation for acting was not to acquire new knowledge but rather to produce or use effective outputs. The collapse (or partial collapse) of this dichotomy leads to a proliferation of new places having the explicit goal of producing knowledge and undertaking deliberate research activities, which may not be readily observable but nevertheless essential to sustain innovative activities in a global environment.

In short, traditional R&D-based technological progress, still very much dominant in many industrial sectors ranging from the chemical and pharmaceutical industries to motor vehicles, semiconductors, and electronic consumer goods, has been characterized by the S&T system's ability to organize technological improvements along clear agreed-upon criteria and a continuous ability to evaluate progress. At the same time, a crucial part of the engineering research consisted, as Richard Nelson put it, "of the ability to hold in place": to replicate at a larger industrial scale and to imitate experiments carried out in the research laboratory environment. As a result, it involved first and foremost a cumulative process of technological progress: a continuous learning from natural and deliberate experiments.

The more recent mode of technological progress described above and more associated with the knowledge paradigm and the service economy, with as an extreme form the attempts at ICT-based efficiency improvements in, for example, the financial and insurance sectors, the wholesale and retail sectors, health, education, government services, business management and administration, is much more based on flexibility and confronted with intrinsic difficulties in replication. Learning from previous experiences or from other sectors is difficult and sometimes even misleading. Evaluation is difficult because of changing external environments: over time, among sectors, and across locations. It will often be impossible to separate out specific context variables from real causes and effects. Technological progress will, in other words, be much more of the trial and error base yet without as in the life sciences providing "hard" data, which can be scientifically analyzed and interpreted. The result is that technological progress will be less predictable, more uncertain, and ultimately more closely associated with entrepreneurial risk taking.

If this first shift in one's understanding of innovation involved removing the dichotomy between R&D and production, a second shift has been occurring more recently, removing (partially) the distinction between production—as a locus for innovation—and consumption. The notion of user-driven innovation has been used to explain the rise of open-source software as well as some other sectors, such as sports equipment by Von Hippel (2004). Such innovation reduces risks for individual entrepreneurs, as the risk of developing an unsuccessful technology is spread across the many user–producers who contribute and perhaps implement their own ideas.

More broadly, blurring the distinction between production and consumption allows one to understand the increasing importance of collaboration among multiple producer–consumers, with incremental innovation contributed by several producers resulting in a single end product. The more complex the interaction is among contributors, the more sophisticated can be the innovation, as resources and skills can be matched to the needs with lower search and transaction costs. This may require adjustments in attitudes to ownership and the control of rights. This form of collaborative ownership and production (Ghosh, 2005) can be found in several domains beyond software and is strikingly similar to Allen's notion of collective invention (Allen, 1983). It is to a more detailed description of some of those features that we turn now focusing in particular on software and the emergence of open-source software.

5. Of software and steam engines

Open-source software is the most obvious instance of such collaborative ownership and production. It has previously been argued that such collaboration in the production of non-rival information goods in particular takes place in the form of implicit exchanges or the "cooking-pot market" (Ghosh, 1998): the one-time cost involved in the creation of a single intellectual work (or the making of a single contribution to a larger work) is provided in exchange for access to a diversity of works created by others (or contributions by others to the larger work). Key to this notion of exchange is the elimination of a producer–consumer barrier, the elimination of any distinction between an inventor and the user of the invention. Such a distinction is inherent in a model that rewards inventors through the allocation of exclusive rights attached to their invention. While theoretically rewarding inventors, it also creates barriers to collaborative production by making it harder for others to incrementally innovate, as others are assumed to be mainly *consumers* rather than *possible producers.*

Without inventors' exclusive rights to a product, all consumers are potentially producers of improved versions of the product. This is what happens in the cooking-pot market, where, to take the example of open-source software, the creator of a piece of software does not retain exclusive rights[3] but allows others to improve upon it. The person with the best skills or understanding of needs can innovate; innovation is no longer limited to the original creator of a work. This implies the (near) elimination of search costs involved in identifying the best skills and resources to improve a work, as well as the elimination of transaction costs that would be required under an exclusive rights and royalty-licensing regime.

A historical example of how such collaboration can work in other domains is provided by Nuvolari (2005), who draws explicit links between the model of open-source software production and the development of the Cornish pumping engine. He notes that the steam engine patented by Watt was sold extensively among Cornwall mines, which accounted for between 28% and 80% of Boulton & Watt's business in the first half of their patents lifetime,[4] from 1769 to the mid 1780s. The Cornish businesses did not like the Boulton & Watt royalty model and challenged the patent for its broadness (it covered all engines using steam as a "working substance"; this allowed Watt to block advances in engine technology by other inventors). They lost and were forced to continue paying royalties till the end of the patent in 1800, at which time "steam engine orders to Boulton & Watt from Cornish mines ceased completely."

Shortly afterwards, Nuvolari notes that Cornish businesses collectively started publishing a monthly journal, *Lean's Engine Reporter,* reporting the technical characteristics,

[3]In fact, all creators and contributors to open source initially hold copyright over their work but allow others to modify it through the use of innovative copyright licenses that waive most copyrights.

[4]The patent's life was extended by an Act of Parliament to 31 years, thanks to Boulton and Watt's lobbying, which shows that businesses that benefit from IPRs have long had an influence over lawmaking more than their benefit to society would justify.

operating procedures, and performance of each engine built—the engines' "source code," as it were—leading to collaborative improvements based upon the knowledge that was now public. Nuvolari shows that "the practice of information sharing resulted in a marked acceleration in the rate of technical advance," and this had an effect on the innovation culture much as the success of open source has an effect on the behavior of its participants. Richard Trevithick did not patent his 1812 engine. Another Cornish inventor, Arthur Woolf, patented one major invention which found no purchase among Cornish businesses used to "open-source" sharing; he chose not to patent his next invention.

Cornwall was a major source of innovation in steam engines, and Nuvolari shows that although it had a significant share of all UK patents filed from 1698 to 1812, in its period of "open-source" innovation during the publication of *Lean's Engine Reporter*, when the Cornish pumping engine was actually developed, the county's share of national patents was almost zero.

The cases of steam engines and software, while very different in terms of modes of production, consumption, and pace of innovation, have one thing in common: an awareness among participants in the market that innovation can be driven by widespread access to the ability to replicate and improve, in explicit contrast to the restricting of this ability by exclusive rights awarded to individual innovators.

Even in terms of reward and business models, there are similarities—there is a clear parallel between software as a cost rather than profit center in today's economy and the steam engine as a cost center for mining businesses, which earned profits from mining not engine building. Similarly, the case of mining entrepreneurs awarding prizes for desired innovations that would be made publicly available recall the open-source software "bounties" from the South African businessman Mark Shuttleworth[5] and prizes for public healthcare proposed by Hubbard and Love (2005).

In the case of steam engines, certainly, the pace of technical innovation through this "open-source" process of collaborative ownership[6] was higher than the "proprietary" approach that preceded and followed it. In the case of software, it is perhaps too early to tell, but clearly the software and mode of collaboration has received enormous support from businesses.

6. New arrangements for innovation

The collaborative forms of ownership and production described above do not need to have any formal arrangements between contributors. In the case of the Cornish

[5]Now provided also by others such as Google and public markets such as, Open Source Bounties, http://www.opensourcexperts.com/bountylist.html.

[6]Nuvolari notes that contemporary literature referred to "Cornish" engines, acknowledging the collaborative character of their development.

miners, there was mainly social pressure resulting from recognition of the value of collaboration, combined with some resentment toward patenting because of earlier experiences with the Boulton & Watts business model.

However, collaborative production does raise questions of rational expectations and free riding. Participants are likely to contribute if they can reasonably expect matching contributions from others. Such contribution may be negatively affected if too many are seen to free ride. This should be qualified: creators of non-rival knowledge and information goods may realize that "free riding" in terms of consumption of such goods is not purely negative unlike the "tragedy of the commons" involving grazing grounds (Hardin, 1968). Creators of knowledge goods realize that readers or users can be valuable in themselves (Ghosh, 1995), and indeed the size of the user base is the common criterion for valuations among venture capitalists in new Internet businesses (Francisco, 2006).

Frameworks, formal or informal, may thus be helpful for the existence of collaborative ownership, from its inception in a particular domain of production to its successful operation. In a Hobbsean world, implicit in many economic models, people are reluctant to collaborate with others, because they assume that they will be taken unfair advantage of. Exclusive appropriation of production and its distribution under careful control is seen as the natural remedy. However, as real world examples from open source to steam engines to bioinformatics (below) show, there may be many things that help collaboration that are not always explicit, which provide an environment of preference for contribution to the commons rather than exclusive appropriation.

There are, first, the expectations of participants. If they find themselves in an environment where collaboration "just happens"—in particular, where contribution rather than exclusive appropriation is somehow rewarded—then they are likely to assume that their own contributions will also be rewarded. There may be many reasons why collaboration is taking place to begin with, but these are not necessarily analyzed by new participants. Thus, the reasons for previous participants' preference for contribution over exclusive appropriation may be diffuse and even, for some, irrational, but need not affect the behavior of new participants [see Ghosh *et al.* (2002) for an empirical exploration of the motivation of open-source developers].

The environment that shapes expectations is underpinned by social norms that have formed within communities of collaboration. Open source arose out of the norms developed in two closely related communities: that of software developers (especially academics) in the 1970s and mid 1980s (Levy, 1984; Himanen, 2001) and that of on-line communities of the late 1980s and 1990s (Turkle, 1995). The latter in particular was notable for providing an environment for the development of pseudolegal rules and social norms that defined behavior in several on-line communities.

Many descriptions of the free software community, and other collaborative but non-monetary production on the Internet, borrow the notion of "gift giving" that (hypothetically) occurs in "tribal" societies (Barbrook, 1998). An assumption is that free software production is similar to supposedly primitive forms of interaction involving the generous contribution of gifts with no expectation of returns—altruism in the sense that economists use the term.

There are indeed similarities between collaborative production and non-monetary exchange in tribal societies and collaborative ownership in the digital economy, notably free software: both are based on the self-interested participation of individuals and communities linked by a complex web of rights and obligations. In particular, there are numerous counter-examples to the simplistic intellectual property right (IPR) model of exclusive appropriation, which recognizes only individual (rights based) and collective (public domain) ownership of works. Certain communities of Papua New Guinea exhibit the *imagined collective* (Strathern, 2005) that represents not true collective ownership (where everyone is the joint owner of a single work) as much as multiple authorship or multiple ownership, where each "owner" lays claim to a certain definable but inseparable part of a collectively owned whole.

This is not gifting. Nor is it exclusive appropriation. This form of ownership lies somewhere between individual appropriation (individual works map to individual authors) and the commons (the entire work maps collectively to the entire set of authors). Whether Papuan Tambarans described by Leach (2005) or the source code of the Linux Kernel, the core of the most successful open-source software system, individual contributions have no value independent of the context of the whole (collaboratively produced) work of which they form a part. Yet, individual contributions can be clearly identified. In the case of the Linux Kernel (Ghosh and David, 2003), each individual line of source code is "owned" by its individual creator (thanks to copyright law, which makes explicitly claiming ownership unnecessary) and also identifiably associated with its creator (thanks to the version-control tools used to enable collaborative development of Linux). Under copyright law, the Linux is not *collectively* owned by any means; no single group owns the copyright to the entire work. Indeed, as discussed in a later section, this distribution of ownership is a major guarantee of the sustained "freeness" of Linux, as there is no single—individual or collective—owner able, for example, to sell the rights to a commercial entity for exclusive appropriation. Contrast this with a scientific paper where all joint authors collectively own the entire paper.

The Linux Kernel is not, however, in the public domain or even in a commons—each individual contribution can be associated with its individual contributor who, in terms of copyright law, owns it. However, the individual and individually owned contributions only make sense, and have any value at all, in the context of the combined whole, which is, hence, *multiply* owned.

This is possible in open-source software, thanks partly to social norms similar to those of the Cornish engineers—awareness of the benefits of collaboration and a certain antipathy toward proprietary forms of development (Ghosh *et al.*, 2002). But what ensures the success and sustainability of open source is the legal infrastructure behind much of it.[7] This is exemplified by the GNU General Public License or GPL,[8] a copyright license that ensures reciprocity: users are free to modify and share software contributions but only under the same terms. This ensures that improvements to software remain available to previous contributors (providing them an incentive to make the initial contributions in the first place) and to future contributors (ensuring sustainability of innovation in the software). This results in innovation taking place, not in the public domain but in a "protected commons" (Aigrain, 2002).

Other sectors of industry have picked up on this arrangement of semi-voluntary reciprocity to create a protected commons, for example, in the area of genomics. The ENSEMBL project (Hubbard *et al.*, 2002) is a public database of human genome sequences with annotation. Human genome sequences are identified by various researchers, publicly and privately funded, but are not very useful without annotation placing them in context and identifying their purpose. Those who identify a sequence may not be interested (or have resources) to annotate or further exploit a given sequence. There is a clear problem of high search costs to match those with the need to work on a sequence to those who have identified or explained the sequence. Thus, participants agree to make annotations and other contributions public. Needless to say, the system runs on sophisticated software developed as open source.

The single-nucleotide polymorphism (SNP) consortium "was established in 1999 as a collaboration of several companies and institutions to produce a public resource of single nucleotide polymorphisms (SNPs) in the human genome. The initial goal was to discover 300 000 SNPs in two years, but the final results exceeded this, as 1.4 million SNPs had been released into the public domain at the end of 2001" (Thorisson and Stein, 2003). It is funded by contributing firms, including most of the major pharmaceutical firms and several major software developers[9]. Firms commit to make their contributions publicly available, recognizing that it is easier to build private developments upon a jointly developed public resource rather than to duplicate efforts. More closely related to open-source software in terms of its incentives structure is the HapMap project (International HapMap Consortium, 2003), a successor to the Human Genome Project that aims to identify common patterns of variation within the genome. HapMap imposes reciprocal requirements in the form of a protected commons for research in progress; however, once the project is finally completed, results will be released to the public domain with no reciprocity requirements.

[7]About two-thirds of open-source software is licensed under the GPL or similarly "reciprocal" copyright licenses, such as the lesser LGPL or the Mozilla public license (MPL). The rest is licensed under "permissive" licenses that are similar to public domain copyright grants and rely only on social norms and economic incentives rather than legal controls to ensure contribution from software beneficiaries (see, e.g., statistics from one of the largest software repositories, Freshmeat, 2006).

[8]See Wikipedia's entry on the GPL, http://en.wikipedia.org/wiki/GPL.

[9]See the SNP consortium website for a current list of sponsors, http://snp.cshl.org/.

The examples above should demonstrate that there is a degree of innovation within the process of innovation itself, and thus the instruments of promoting it—exclusive rights granted to single economic actors for individual innovations—may not always be the most appropriate. Other arrangements for enabling collaborative innovation have been developed and are being applied in many domains; they may be useful to investigate further.

7. Conclusions: innovation and development

The implications of these new modes of technological progress for development are rather striking. First and foremost, they bring to the forefront the importance of endogenous innovation processes in developing country situations. In the old industrial S&T model, the focus within a context of development was quite naturally on technology transfer and imitation. Imitation as the opposite of innovation: allowing for a sudden and rapid catching up process being accompanied by a systematic copying or where necessary the adoption of appropriate technologies from developed countries. In the new mode, every innovation is to some extent unique with respect to its application. Reuse and recombinations of sometimes routine, sometimes novel pieces of knowledge might be of particular importance. International access to knowledge is essential though and so are recombination skills.

If one looks at the common feature described previously for various examples of collaborative innovation, the most important enabling feature is *access*. Access is not required to knowledge alone but to the tools and (legal) ability to replicate and improve upon knowledge. Thus, it is not access to knowledge as passive consumers, which is often discussed and fitted well with the old model of R&D distinct from producers distinct from consumers. In the old model, developing countries are often treated as consumers who do not have the ability to innovate, perhaps because of the lack of technical skills, and must therefore passively consume products of developed countries (with subsidies, if required), or if they are more industrially advanced they may imitate production methods developed elsewhere. Apart from being patronizing, this view does not fit with the new mode of technological progress for development, for two reasons.

First, empirical research has shown (Ghosh and Glott, 2005) that in the case of software, open collaboration provided by access to modifiable technology may not be problematic due to a lack of skills; rather, it leads to the development of technical, business, and legal skills. Such skills are often better than those learnt in formal courses, and proven participation in open-source development may compensate for the lack of formal degrees. These results were supported by employers surveyed. This shows that although access to knowledge may build skills through passive absorption (e.g., through textbooks), access to technology in a form that can be shared and modified without entry barriers (as with open-source software) can build advanced skills, compensate for the absence of formal training, and generate increased employment.

Second, the premise of the new mode of technology development is that lowering entry barriers for the modification of technology reduces search costs, allowing participants in the market of producer–consumers to more efficiently to allocate skills and other resources to needs for improvement. This leads to more efficient and perhaps faster technical innovation, with the entrepreneurial risks of innovation spread widely. Thus, providing access to technology need not be seen as charity or aid for developing countries but as enlarging the resource base of potential innovators.

Although access to knowledge as a passive process is politically framed within the language of development aid, access to technology as a way of providing the right and ability of participation is analogous to the arguments favoring free trade:[10] developing countries can then be seen as providing a resource of potential innovators rather than merely using existing innovations from the developed world.

The consequences of this shift can be significant, not only for development itself but also for the debate concerning migration affecting the developed world today. If it becomes easier for people from developing countries to reproduce, improve, and build upon innovations from the developed world, it may ease the "brain drain" of people whose only chance of exercising their potential as innovators is to emigrate.

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[10]In the case of exclusive rights protection for intellectual works, this analogy has often been made explicit: in 1851, *The Economist* criticized patents as a barrier to trade.

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