INCENTIVES FOR KNOWLEDGE PRODUCTION WITH MANY PRODUCERS

ESRC Centre for Business Research, University of Cambridge
Working Paper No. 292

By

Bronwyn H. Hall
University of California at Berkeley and NBER
Department of Economics
549 Evans Hall
University of California at Berkeley
Berkeley, CA 94720-3880.
(visiting ESRC Centre for Business Research, 2004)
Email: bhhall@econ.berkeley.edu

September 2004

This Working Paper forms part of the CBR Research Programme on Enterprise and SMEs

Abstract
In this paper, I briefly review the motivations for inventive behavior and describe two common incentive systems that harness and encourage such behavior. This review of well-trodden ground is performed only so that the implications of the rise of the networked knowledge economy for the effectiveness of these incentive systems can be noted. Some theoretical results on the operation and stability of the two incentive systems for the production of knowledge are presented with a discussion of how they might apply in the networked economy. The paper concludes with suggestions on open research questions.

JEL Codes: O340, L860, L230

Keywords: intellectual property; knowledge economy; incentives; open science

Acknowledgements
Parts of this paper are drawn from work joint with Alfonso Gambardella, Sant'anna School of Advanced Studies, Pisa.

Incentives for Knowledge Production with Many Producers

Presentation to the European Commission/U.S. National Science Foundation/Organization for Economic Cooperation and Development Conference on Networks of Knowledge: Research and Policy for the Knowledge-Based Economy Brussels, June 7, 2004

The starting point for thinking about economic policy for the knowledge economy is that the production of information and knowledge is characterized by relatively high fixed costs and low marginal costs. In addition, such production is highly cumulative (uses prior output as input or is subject to continuous enhancement over time) and usually has somewhat uncertain useful application. Therefore, social and possibly even private welfare can often be increased by the provision of new knowledge to large numbers of individuals at a low price. Wide access increases the productivity of the knowledge both as an input to future knowledge creation, and as the basis for the production of new goods and services. The central problem becomes the design of incentive systems that both reward inventors/knowledge producers and encourage dissemination of their output.

The basic ideas in the opening paragraph above have been familiar to economists and other scholars for a long time (e.g., Nelson (1959), Arrow (1962), Scotchmer (1991), etc.), but their importance has increased with the advent of the internet and other computer networking methods used in the production of research, often over long distances. The principal effect of the increase in computer networking and internet use is that it lowers the marginal cost of distributing codified knowledge to the point where it is essentially zero. This in turn has the potential to reduce incentives for production of such knowledge or to increase the demands of the producers for protection of their property rights to the knowledge.

In this paper, I briefly review the motivation for inventive behavior and describe the two incentive systems that harness and encourage such behavior. This review of well-trodden ground is performed only so that the effects on these systems of the rise of the networked knowledge economy can be noted. Some theoretical results on the operation and stability of the two incentive systems for the production of knowledge are presented with a discussion of how they might apply in the networked economy. The paper concludes with suggestions on open research questions.

1 Two (or three) worlds of invention

If we wish to think about policy towards knowledge production, we must first ask what motivates the producers of knowledge. Key factors that have been identified in the literature are curiosity and a taste for science, money, the desire for fame and reputation, and as a secondary goal, promotion or tenure (Stephan 1996). The latter two goals are usually achieved via *priority* in publication, that is, being the first to get a discovery into print. Although monetary income is clearly a partial motivation in the search for reputation and promotion, considerable evidence exists that for researchers in universities and public research organizations with some level of guaranteed income the first motive, intellectual curiosity, is of overriding importance (e.g., Isabelle 2004). For this type of researcher, the desire for financial rewards is often driven by the desire to fund their own scientific research (Lee 2000) rather than by consumption *per se*. Scientists' motivations also are colored by the culture in which they are embedded, with traditional norms giving way to a more market-oriented view among some younger scientists today (Isabelle 2004, Owen-Smith and Powell 2001).

Several scholars (e.g., David, Merton, etc.) have described the two regimes that allocate resources for the creation of new knowledge: one is the system of granting intellectual property rights, as exemplified by modern patent and copyright systems, the other is the "open science" regime, as often found in the realm of "pure" scientific research and sometimes in realm of commercial technological innovation, often in infant industries (Allen 1983; Nuvolari 2001). Today we also see this system to a certain extent in the production of free and open source software. The first system assigns clear property rights to newly created knowledge that allow the exclusion of others from using that knowledge, as well as the trading and licensing of the knowledge. As is well-known, such a system provides powerful incentives for the creation of knowledge, at the cost of creating temporary monopolies that will tend to restrict output and raise price. Additionally, in such systems, the transaction costs of combining pieces of knowledge or building on another's knowledge may be rather high, and in some cases achieving first or even second best incentives via *ex post* licensing impossible (Scotchmer 1991). The use of other firms' knowledge output will often require payment or reciprocal cross-licensing, which means negotiation costs have to be incurred. Finally, obtaining IP rights usually requires publication, but only of codified knowledge, and trade secrecy protection is often used in addition.

The second set of institutional arrangements, sometimes referred to as the norms governing the "Republic of Science," generates incentives and rewards indirectly: the creation of new knowledge is rewarded by increased reputation, further access to research resources, and possible subsequent financial returns in the form of increased salary, prizes, and the like (Merton 1957, 1968). This system relies to some extent on the fact that individuals often invent or create for nonpecuniary reasons like curiosity. Dissemination of research results and knowledge is achieved at relatively low cost, because assigning the "moral rights" to the first publisher of an addition to the body of knowledge gives creators an incentive to disseminate rapidly and broadly. Therefore, in this system the use of others' output is encouraged and relatively cheap, with the cost being appropriate citation and possibly some reciprocity in sharing knowledge. But it is evident that this system cannot capture the same level of private economic returns for the creation of knowledge. Inventors must either donate their work or receive compensation as clients of public or private patrons.[1]

I have written elsewhere about the tension that arises when these two systems come up against each other (Hall 2004). For example, it is common for the difference in norms and lack of understanding of the potential partner's needs and goals to produce breakdowns in negotiations between industry and academe. These breakdowns can have an economic as well as cultural cause, as shown by Anton and Yao (2002) in a study of contracting under asymmetric information about the value of the knowledge to be exchanged. In addition there is the simple fact that both systems rely on reciprocal behavior between both parties to a knowledge exchange, so that contracting between participants in the two difference systems becomes subject to misunderstanding or worse. This is illustrated by the reaction of the genomic industry in the U.S. when asked to take out licenses to university-generated technology: once the university starts acting like a private sector firm, there is a temptation to start charging them for the use of the outputs of industry research, and consequent negative effects on researchers who still believed themselves part of the "open science" regime.

Before leaving this topic, notice should be taken of an important variation of the "open science" regime for the sharing of knowledge production outputs, one which has existed many times in the development of industry throughout history: the free exchange and spillover of knowledge via personnel contact and movement, as well as reverse engineering, without resort to intellectual property protection. I will call this system the CI regime, for collective invention. Examples include the collective invention in the steel and iron industry described by Allen (1983), the development of the semiconductor industry in Silicon Valley (Hall and Ziedonis 2001), and the silk industry in Lyons during the *ancien regime* that was described by Foray and Hilaire-Perez (2004). In these environments, most of which are geographically localized innovation areas with social as well as business relationships that build trust (or at least knowledge of whom to trust), the incentive system for the production *and exchange* of knowledge is somewhat different than in either of the other two systems.

The first and most obvious difference is that the production of "research" in the industry setting is supported not by public or private patronage but by commercial firms that finance it by the sale of end products that incorporate their discovery. Because rewards come from the sale of products rather than information itself, as they do in the conventional IP-based system, the sharing of information about incremental innovations is motivated by different considerations than in the case of the OS regime. Although priority is not per se valuable except in the sense that it may confer lead time for production, shared knowledge, especially about incremental improvements to a complex product, is perceived to be useful and essential for the progress of the entire industry including the firm that shares the knowledge. When an industry is advancing and growing rapidly, the desire to exclude competitors from the marketplace is not as strong as when an industry reaches maturity. An implication is that this form of free exchange of knowledge tends to break down, or is unstable over time, as has happened in many of the historical examples. In the next section of the paper I report on some models that try to capture this idea and give conditions where the academic or industry-based OS regime might break down.

2 Stability of incentive system equilibria

Gambardella and Hall (2003, 2004) explore the conditions under which these different systems of knowledge generation and sharing develop, and when they might be expected to break down. That is, what sets the boundary lines between the domains in which these two regimes, one of freely shared knowledge and one of proprietary knowledge, are found, and how stable is that boundary to external forces or the behavior of individual actors? To do this, we use two simple models, one of collective invention in the commercial arena, and one of "open science," both of which are based on the basic insight in Olson (1971). We show that the only way to get a stable equilibrium with individuals operating under "open sharing" rules is when there is coordination among individuals. Otherwise, the sharing (cooperative) equilibrium tends to break down because some individuals find it in their interest to defect. We also give conditions under which there are more or fewer individuals contributing to the good.

In Gambardella and Hall (2003), we present two models, one for the collective invention case, and one that applies to the open scientific research setting when IP is available. The collective invention model hypothesizes that the joint output of a set of user-innovators is used to produce a good of variable quality that is sold in the market by an oligopolist facing downward sloping demand. The user-innovators care about the quality of the final good as well as about their own income, but the relative importance of these two factors varies across them, so they are heterogeneous. Each one chooses whether to operate under OS rules and charge marginal cost for their output or to take out a patent and charge the monopoly price. Clearly they weigh their effect on the quality of the output against the increase in income from a higher price in making this decision. We show that unless they can be coordinated by a lead user-innovator or a set of norms, it is individually rational to deviate to IP, at least as the number of them becomes greater than a very few. It is also true that the benefit from deviation becomes stronger as the market size increases. This may provide at least a partial explanation of the observation that free knowledge sharing seems to be more prevalent in immature industries.[2]

Our model of open science versus privatization assumes that a body of scientific knowledge in a particular area will be supplied jointly by scientists supported by government grants and by scientists financed by the market, who have the option of taking out patents and selling their knowledge output to competitive firms at a monopoly price. We call the first group the OS sector and the second group the IP sector. Examples might be production of information about a particular gene sequence and its use, or the production of a scientific database from a variety of inputs. Note that the scientists operating under IP may not be in the private sector, but could represent university researchers working through a technology transfer office. In our model all scientists are assumed to have a taste for scientific output (the body of knowledge) *per se* and also for income, but the relative tradeoff between the two is heterogeneous across scientists. This seems to us to capture the true state of affairs fairly well.

The government that supports scientific research faces a budget constraint and allocates funds to those who wish to work under OS while maximizing scientific output. We show that without coordination and as the number of scientists in the area increases beyond a very small number, the only stable equilibrium is one where all the scientists work under IP rules. This is because an individual scientist who deviates from OS to IP receives a discrete jump in income, but only reduces public scientific output (for which he has a taste) by an infinitesimal amount. Therefore, some of form of coordination, social norm, or willingness to imitate the behavior of “lead researchers” or conform to the expectations of university or research organization administrations is needed to enforce an equilibrium with scientists working under OS rules. But, of course, this is exactly what the norms of the “Republic of Science” provide.

We model the existence of social norms or leaders in the community by assuming that deviation from OS to IP occurs only when a measurably large group of scientists leave together. With this kind of coordination, we find that an interior equilibrium with some scientists working under OS and some under IP will usually exist. We also show that the share of scientists working under OS will decrease if the demand for research output from the downstream firms increases, the government reduces its budget for scientific research, or fewer scientists coordinate when they change regimes. All three of these factors appear to be at work at various times and places in the recent past, so it is perhaps not surprising that we have observed more attention paid to securing intellectual property rights on the part of university researchers.

Gambardella and Hall (2004) extend the above model to show that a mechanism that can work to enforce the OS equilibrium and increase the diffusion of knowledge in a setting like the one above is a type of viral or copyleft licensing at zero cost, where the licensor is also required to license his output to others at zero cost if its production uses the licensed knowledge input. In effect, this mechanism resembles the General Public License (GPL) used in open source software. As we indicate below, an unresolved question is how to achieve sufficient production of certain auxiliary services and support when such a license is in place. In our paper, we provide empirical evidence that shows the widespread privatization of an incidental output of applied economic research, econometric software, largely because the production of such software is not part of the research output that is rewarded under the norms of “open science” and because researchers in the field demand a set of services that cannot be supported using public funds.

Several conclusions have emerged from the observation and modeling of two stylized ways of sharing and protecting knowledge production:

1. The OS model works best when there are common norms and the community is relatively small, or focused on a common goal, such as the advancement of science or the growth of a new industry.
2. Larger and more profitable markets are likely to lead to defection from OS to IP, and once that has happened it is difficult to go back. That is, IP tends to be an absorbing state.[3]
3. Finally, the OS model relies to some extent either on public financing or on tolerance or even active encouragement by industrial firms of leakage and spillovers from the efforts of their employees.

3 Research questions

In this paper I have tried to provide a framework for thinking about different modes of knowledge sharing and their consequences for the incentives to produce knowledge, one which is admittedly rather simplified relative to the complexity of arrangements in place in various arenas. In my view this framework is as valid for the networked economy as it is for the traditional knowledge economy. What may have changed in the present day are the costs of diffusing knowledge relative to the cost of producing it and the cohesion of the communities that produce it. The second implies that breakdown of systems with free trading of knowledge are more likely to occur.

The effects of the change to the relative costs of diffusing knowledge are more complex. One implication is that social welfare is likely to be enhanced by more diffusion at zero price (online journals that are freely accessible, etc.). However, there is still the problem of paying for the complementary inputs to the diffusion process, such as cyberinfrastructure, software, maintenance, customer service, and so forth. None of these activities normally yield returns in the "open science" system in the form of priority, so they will be underprovided in that system. Some of them, such as cyberinfrastructure, will probably be provided by government funding. But how much, and should any of the investment be charged to users?

A central question for research and policy is the question of how the different regimes for knowledge sharing interact and what happens when they come up against each other? For example, suppose that a member of the open science community decides to privatize some of his or her knowledge by licensing it exclusively to a commercial firm? Will this cause that particular area of research to slow down (because researchers no longer have access to certain results costlessly) or to speed up (because commercial demand for research in that area increases)? Is there really a present day danger that the absorbing state of IP will take over scientific research? On this subject we have the survey results of Walsh et al (2003) for the biotechnology industry. They find that recent increases in the patenting of research tools in the United States has not impeded pharmaceutical industry or university research, at least not yet. They do find that there have been delays and sometimes restrictions in obtaining access to patented research tools, and cases of research redirection (as in Lerner 1995). They also find widespread use of "working solutions" such as taking out licenses, inventing around patents, infringement (often informally invoking a research exemption), developing and using public tools, and challenging patents in court. However, the survey was conducted prior to the Madey decision, which effectively removes the research exemption defense, so more work in this area is needed.

Another area for future research would look at the changing incentives faced by researchers operating under the traditional norms of science as research becomes highly collaborative and linked across a network. As implied by the models I have reviewed, larger communities that are not geographically localized will find it more difficult to sustain a cooperative equilibrium if IP protection is available. In addition, the Mertonian reward system is based very strongly on identifying the knowledge producer who is "first" but this becomes considerably more difficult when there are large number of such producers located in very different systems. There are important differences between, for example, the U.S. and continental European reward systems with respect to job tenure, with U.S. researchers usually working for 7 to 10 years post-degree before being assured of a permanent job, and European researchers commonly receiving tenure shortly after they are hired. Do such differences make collaboration problematic because the participants are facing different reward structures?

The models presented earlier capture a phenomenon that has frequently been observed in practice, which is the tendency for the introduction or strengthening of IP rights in some area to lead to privatization of invention output. But they leave a number of question unanswered. First, none of our models explicitly incorporates the reward system of Mertonian science. Although they do allow for a generic taste for science on the part of the researcher or quality on the part of the innovator, his rewards are not directly linked to his productivity. Doing so would complicate the analysis and make it easier to achieve interior solutions, although the basic results would survive.

Second, our models currently contain no welfare analysis; we do not know yet under which conditions the cooperative knowledge sharing equilibrium yields higher output at lower cost than the IP regime. The former keeps costs lower and allows more spillovers, but incentives may be too low-powered to encourage production of certain essential inputs (such as supporting software or customer service). The latter has powerful incentives but may tend to constrain output. This problem is of course general, and similar to the questions in antitrust, but the particularities of its application to the production of scientific research and its auxiliary output deserve further study.

Finally, the models do not yet tell us how to get a combination of outputs created by different knowledge sharing systems supplied at the right level for society. This is the central question for a modern networked research endeavor.

Notes

[1] We can subsume both cases as instances of "patronage"---self patronage of the donated efforts is a special case of this. See David (1993) and Dasgupta and David (1994).

[2] There are of course many other things going on as the industry develops, such as shakeout and consolidation, as well as vertical disintegration, that may also encourage the development of the use of IPRs.

[3] Although see Nuvolari (2004) for an apparent example where the presence of strongly enforced patents in the steam engine industry (Watt's) led to a development of a collective invention model in Cornwall for steam-driven pumping engines that used a different technology.

References

Allen, Robert C. 1983. "Collective Invention," *Journal of Economic Behavior and Organization* 4 (1): 1-24.

Anton, James J. and Dennis A. Yao. 2002. "The Sale of Ideas: Strategic Disclosure, Property Rights, and Contracting," *Review of Economic Studies* 67 (4): 585- 607.

Arrow, Kenneth. 1962. "Economic Welfare and the Allocation of Resources for Invention," in R. R. Nelson (ed.), *The Rate and Direction of Inventive Activity*. Princeton, NJ, Princeton University Press: 609-625.

Carayol, Nicolas. 2004. "Academic Incentives and Research Organization for Patenting at a Large French University," Paper presented at the Third EPIP Workshop, Pisa, Italy, April 2/3.

Dasgupta, Partha, and Paul A. David. 1994. "Toward a New Economics of Science," *Research Policy* 23: 487-521.

David, Paul A. 1993. "On the three P's…. Procurement, Property, and Patronage," ABCDE, *World Bank Review*.

Foray, Dominique and Liliane Hilaire-Perez. 2004. "The Economics of Open Technology: Collective Organization and Individual Claims in the 'Fabrique Lyonnaise' During the Old Regime," in C. Antonelli, D. Foray, B. H. Hall and W. E. Steinmueller (eds.), *Essays in Honor of Paul A. David*.

Gambardella, Alfonso, and Bronwyn H. Hall. 2003. "On the Stability of Intellectual Property Regimes: IP Protection versus Open Source/Open Science," Sant'anna School of Advanced Studies and University of California at Berkeley. Manuscript.

Gambardella, Alfonso, and Bronwyn H. Hall. 2004. "Proprietary vs. Public Domain Licensing of Software and Research Products," Paper presented at the Third EPIP Workshop, Pisa, Italy, April 2/3.

Hall, Bronwyn H. 2004. "On Copyright and Patent Protection for Software and Databases: A Tale of Two Worlds," in O. Granstrand (ed.), *Economics, Law, and Intellectual Property*, Amsterdam: Kluwer Publishing Company.

Hall, Bronwyn H., and Rosemarie Ham Ziedonis. 2001. "The Determinants of Patenting in the U.S. Semiconductor Industry, 1980-1994," *Rand Journal of Economics* 32: 101-128.

Isabelle, Marc. 2004. “They invent (not patent) like they breathe: what are their incentives to do so? Short tales and lessons from researchers in a public research organisation,” Paper presented at the Third EPIP Workshop, Pisa, Italy, April 2/3.

Lee, Yong S. 2000. “The Sustainability of University-Industry Research Collaboration,” *Journal of Technology Transfer* 25 (2): 111-133.

Lerner, Josh. 1995. "Patenting in the Shadow of Competitors," *Journal of Law and Economics* 38(2): 463-496.

Merton, Robert K. 1957. “Priorities in Scientific Discovery: A Chapter in the Sociology of Science,” *American Sociological Review* 22(6): 635–59.

———. 1968. “The Matthew Effect in Science,” *Science* 159(3810, Jan. 5): 56–63.

Nelson, Richard R. 1959. “The Simple Economics of Basic Scientific Research,” *Journal of Political Economy* 77: 297-306.

Nuvolari, Alessandro. 2004. “The Anatomy of Collective Invention Processes: A Study of Early Nineteenth Century Steam Engineering,” Paper presented at the Third EPIP Workshop, Pisa, Italy, April 2/3.

__________. 2001. “Collective Invention during the British Industrial Revolution: The Case of the Cornish Pumping Engine,” DRUID, Copenhagen Business School Working Paper 01-05.

Olson, Mancur. 1971. *Logic of Collective Action: Public Goods and the Theory of Groups*. Cambridge, MA: Harvard University Press.

Open Source Software Foundation, http://www.opensource.org/licenses/

Owen-Smith, Jason and Walter W. Powell. 2001. “To Patent or Not: Faculty Decisions and Institutional Success at Technology Transfer,” *Journal of Technology Transfer* 26 (1/2): 99-114.

Scotchmer, Suzanne. 1991. “Standing on the Shoulders of Giants: Cumulative Research and the Patent Law,” *Journal of Economic Perspectives* 5: 29-41.

Stephan, Paula E. 1996. “The Economics of Science,” *Journal of Economic Literature* XXXIV: 1199-1235.

Walsh, John P., Ashish Arora and Wesley M. Cohen. 2003. “Effects of Research Tool Patenting and Licensing on Biomedical Innovation,” in W. M. Cohen and S. A. Merrill (eds.), *Patents in the Knowledge-Based Economy*. Washington, D.C.: National Academies Press: 285-340.