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The Economic Logic of "Open Science" and the Balance between Private Property Rights and the Public Domain in Scientific Data and Information: A Primer

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SUMMARY

The progress of scientific and technological knowledge is a cumulative process, one that depends in the long-run on the rapid and widespread disclosure of new findings, so that they may be rapidly discarded if unreliable, or confirmed and brought into fruitful conjunction with other bodies of reliable knowledge. "Open science" institutions provide an alternative to the intellectual property approach to dealing with difficult problems in the allocation of resources for the production and distribution of information. As a mode of generating reliable knowledge, "open science" depends upon a specific non-market reward system to solve a number of resource allocation problems that have their origins in the particular characteristics of information as an economic good. There are features of the collegiate reputational reward system -- conventionally associated with open science practice in the academy and public research institutes – that create conflicts been the ostensible norms of 'cooperation' and the incentives for non-cooperative, rivalrous behavior on the part of individuals and research units who race to establish "priority." These sources of inefficiency notwithstanding, open science is properly regarded as uniquely well suited to the goal of maximising the rate of growth of the stock of reliable knowledge.

High access charges imposed by holders of monopoly rights in intellectual property have overall consequences for the conduct of science that are particularly damaging to programs of exploratory research which are recognized to be vital for the long-term progress of knowledge-driven economies. Like non-cooperative behaviors among researchers in regard to the sharing of access to raw data-steams and information, and systematic under-provision the documentation and annotation required to create reliably accurate and up-to-date public database resources, lack of restraint in privatizing the public domain in data and information can significantly degrade the effectiveness of the entire research system. Considered at the macro-level, open science and commercially oriented R&D based upon proprietary information constitute complementary sub-systems. The public policy problem, consequently, is to keep the two sub-systems in proper balance by public funding of "open science" research, and by checking excessive incursions of claims to private property rights over material that would otherwise remain in the public domain of scientific data and information.

1. Information, and the Public Goods Problem in Research

Acknowledging the peculiar character of information as an economic commodity is a necessary point of departure in grasping the basic propositions that have been established by modern economic analyses of knowledge-producing (research) activities of all kinds.

1.1 Data, information and knowledge as economic goods

An idea is a thing of remarkable expansiveness, being capable of spreading rapidly from mind to mind without lessening its meaning and significance for those into whose possession it comes. In that quality, ideas are more akin to fire than to coal. Thomas Jefferson, writing in 1813 remarked upon this attribute, which permits the same knowledge to be jointly used by many individuals at once: "He who receives an idea from me, receives instruction himself without lessening mine; as he who lights his taper at mine receives light without darkening me...." (see David 1993, on Jefferson's observations in this connection).

Modern economists have followed Nelson (1959) and Arrow (1962) in recasting this insight and pointing out that the potential value of an idea to any individual buyer generally would not match its value to the social multitude, since the latter would be the *sum* of the incremental benefits which the members of society derived from their use of the idea. The individual benefits conveyed, however, will not readily be revealed in a willingness to pay on the part of everyone who would gain thereby; once a new bit of knowledge is revealed by its discoverer(s), some benefits will instantly "spill over" to others who are therefore able to share in its possession – at little incremental cost. Why should they then offer to bear any of the initial costs that were incurred in bringing the original thought to fruition?

Commodities that have the property of "expansibility," permitting them to be used simultaneously for the benefit of a number of agents, are sometimes described as being "non-rival" in use. This characteristic is a form of non-convexity, or an extreme form of decreasing marginal costs as the scale of use is increased: although the cost of the first instance of use of new knowledge may be large, in that it includes the cost of its generation, further instances of its use impose at most a negligibly small incremental cost. It sometimes is noticed that this formulation ignores the cost of training potential users to be able to grasp the information and know what to do with it. But while it is correct to point out that there can be fixed costs of access to the information, these do not vitiate the proposition that re-use of the information will neither deplete it nor impose further costs. It may well be costly to teach someone how to read the table of the elements, or the rules of the differential calculus. Nevertheless, any number of individuals thus instructed can go on using that knowledge without imposing further costs either on themselves or upon others.

A second peculiar property of ideas which has to be underscored here is that it is difficult, and generally costly to retain exclusive possession of them whilst putting them to use. Of course, it is possible to keep a piece of information or a new idea secret. The production of results not achievable otherwise, however, discloses something about the existence of a method for doing so. Quite understandably, scientific and technical results obtained by methods that cannot or will not be disclosed are felt to be less dependable on that account; their production is deemed to be more in the nature of magical performances than as contributions to the body of reliable knowledge. Even the offer of a general explanation of the basis for achieving a particular, observable result may be sufficient to jeopardize the exclusivity of its possession, because the knowledge that something can be done is itself an important step toward discovering how it may be done.

1. 2 Public Goods and the "Appropriability Problem"

The dual properties of non-rival usage and costly exclusion of others from possession define what a "pure public good." The term "public good" does not imply that such commodities cannot be privately supplied, nor does it mean that a government agency should or must produce it. Nevertheless, it follows from the nature of pure public goods that *competitive* market processes will not do an efficient job of allocating resources for their production and distribution, simply because where such markets work well they do so because the incremental costs and benefits of using a commodity are assigned to the users. In the case of public goods, such assignments are not automatic and they are especially difficult to arrange under conditions of competition.

One may see the essence of the problem posed by the public goods characteristics of knowledge by asking: How can ideas be traded in markets of the kind envisaged by disciples of Adam Smith, except by having aspects of their nature and significance disclosed before the transactions were consummated? Rational buyers of ideas, no less than buyers of coal, and of fish and chips, first would want to know something about what it is that they will be getting for their money. Even were the prospective deal to fall through, it is to be expected that the potential purchaser would enjoy (without paying) some benefits from what economists refer to as "transactional spill-overs." The latter are not without considerable value, because there may be significant commercial advantages from the acquisition of even rather general information about the nature of a discovery, or an invention -- especially one that a reputable seller has thought it worthwhile to bring to the attention of people engaged in a particular line of business.

This leads to the conclusion that the findings of scientific research, being new knowledge, would be seriously undervalued were they sold directly through perfectly competitive markets. Some degree of exclusivity of possession of the economic benefits derived from ideas is therefore necessary if the creators of new knowledge are to derive any profit from their activities under a capitalist market system. Intellectual property rights serve this end in the form of patent and copyright monopolies. But imposing restrictions on the uses to which ideas may be put also saddles society with the inefficiencies that arise when monopolies are tolerated; a point harped upon by economists ever since Adam Smith. In addition, as will be seen below, access charges that holders of intellectual property are fee to impose on its users, and the secrecy practices that business companies embrace to protect their investments in the R&D process when it aims at securing proprietary control of new information, are a further source of inefficiencies in society's utilization of existing bodies of knowledge.

2. The Economic Logic of Open Science

For the purposes of this basic exposition, the institutional conditions of primary interest are those that sharply distinguish the sphere of 'open science' supported by public funding and the patronage of private foundations, on the one hand, from both the organized conduct of scientific research under for commercial profit under 'proprietary rules,' and the production and procurement of defence-related scientific and engineering knowledge under conditions of restricted access to information about basic findings and their actual and potential applications.

2.1 Ethos, norms and institutions of 'the Republic of Science'

The formal institutions of modern science are one's with which academic economists already are thoroughly familiar, for, it is a striking phenomenon in the sociology of science that there is high degree of mimetic professional organization across the various fields of academic endeavor. Whether in the social sciences, or the natural sciences, or the humanities for that matter, most fields have their professional academies and learned societies, journal refereeing procedures, public and private foundation grant programs, peer-panels for merit review of funding applications, organized competitions, prizes and public awards. Within the sciences proper, however, there are recognized norms and conventions that constitute a clearly delineated ethos to which members of the academic research community generally are disposed to publicly subscribe, whether or not their individual behaviors conform literally to its strictures. The norms of 'the Republic of Science' that have famously articulated by Robert Merton (1973: esp. Ch. 13) sometimes are summarized under the mnemonic CUDOS: communalism, universalism, disinterestedness, originality, scepticism. (See Ziman 1994, p. 177).

The 'communal' ethos emphasizes the cooperative character of inquiry, stressing that the accumulation of reliable knowledge is a social, rather than an individual program; however much individuals may strive to contribute to it, the production of knowledge which is 'reliable' is fundamentally a social process. Therefore, the precise nature and import of the new knowledge ought not to be of such immediate personal interest to the researcher as to impede its availability or detract from its reliability in the hands of co-workers in the field. Research agendas, as well as findings ought therefor to be under the control of personally (or corporately) disinterested agents. The force of the universalist norm is to allow entry into scientific work and discourse to be open to all persons of 'competence', regardless of their personal and ascriptive attributes. A second aspect of 'openness' concerns the disposition of knowledge: the full disclosure of findings, and methods, form a key aspect of the cooperative, communal program of inquiry. Disclosure serves the ethos legitimating, and, indeed prescribing skepticism, for it is that which creates an expectation that all claims to have contributed to the stock of reliable knowledge will be subjected to trials of verification, without insult to the claimant. The 'originality' of such intellectual contributions is the touchstone for the acknowledgement of individual claims, upon which collegiate reputations and the material and non-pecuniary rewards attached to such peer evaluations are based.

An essential, differentiating feature of the institutional complex associated with modern science thus is found in its public, collective character, and its commitment to the *ethos* of cooperative inquiry and to free sharing of knowledge. Like other social norms, of course, these are not perfectly descriptive of the behaviors of individuals who identify themselves with the institutions; indeed, not even of those who would publicly espouse their commitment to "openness" and scientific cooperation. It is evident that as is the case with public goods more generally, the temptation to "free-ride" on the cooperative actions of others creates tensions within the system. Consequentially, the fact that it has withstood those strains points to the existence of some positive, functional value that it conveys to a substantial number of the scientists working in the "public/academic" research sector, and to the particular benefits that society as a whole has been able to derive through public patronage of this mode of pursuing knowledge.

2.2 A functionalist rationale for the norms and institutions of Open Science

While for most of us the idea of science as the pursuit of "public knowledge" may seem a natural, indeed a 'primitive' conceptualization, it is actually a social contrivance; and by historical standards, a comparatively recent innovation at that, having taken form only as recently as the sixteenth and seventeenth centuries. (See David 1998a, 1998b for further discussion of the historical origins of open science.) Although economists have only lately begun to analyze the workings of the institutional complex that characterizes "modern science," it has not been difficult to reveal a functionalist rationale: it centers on the proposition that greater economic and social utility derives from behaviors reinforced by the ideology of the open pursuit of knowledge and the norms of cooperation among scientists (see Dasgupta and David 1987, 1994; David 2001). That analysis also demonstrates the "incentive compatibility" between the norm of disclosure and the existence of a collegiate reputation-based reward system grounded upon validated claims to *priority* in discovery or invention.

The core of this rationale is the greater efficacy of open inquiry and complete disclosure as a basis for the cooperative, cumulative generation of predictably reliable additions to the stock of knowledge. In brief, "openness" abets rapid validation of findings, and reduces excess duplication of research efforts. Wide sharing of information puts knowledge into the hands of those who can put to to uses requiring expertise, imagination and material facilities not possessed by the original discoverers and inventors. This enlarges the domain of complementary among additions to the stock of reliable knowledge, and promotes beneficial 'spill-overs' among distinct research programs.

As important as it is to emphasize these societal benefits of the cooperative mode for the advancement of science, it is equally significant to appreciate that the norms of information disclosure -- applied both to "findings" and to the methods whereby research results have been obtained – have a second functional role. They are not an extraneous ethical precept of the open science system, but figure in the mechanism that induces individual scientific effort. The open science reward system typically is a two-part affair, in which researchers are offered both a fixed form of compensation and the possibility of some variable, results-related rewards. The fixed part of the compensation package, e.g., a basic stipend or salary, tied to teaching in the case of academic research institutions, provides individual researchers a measure of protection against the large inherent uncertainties surrounding the process of exploratory science. The variable component of the reward is based upon expert evaluation of the scientific significance of the individual's contribution(s) to the stock of knowledge. This involves both the appraisals by peers of the meaning and significance of the putative "contribution," and acceptance of the individual's claim to "moral possession" of the finding, on the grounds of having priority in its discovery or invention. The latter is particularly important, as it connects the incentives for disclosure of findings under the collegiate reputational reward system of open science with the social efficiency of sharing new information.

One can fairly reasonably monitor minimal levels of input of effort into research activities (turning up in the lab, attending scientific meetings, etc.), or the performance of associated duties such as giving lectures, supervising students, and so on. But beyond that, the assessment of individual performance on the basis of inputs is quite inadequate, and incentives offered for new discoveries and inventions must perforce be based upon observable "outputs" – results. The core of the problem here is that the outputs that one wants to reward are intangible and unique – in the sense of being novel. The repetition of someone else's finding is not entirely devoid of social utility, for it may contribute to assessment of the reliability of the scientific assertions in question. But, although you would want to pay a second miner for the ton of coal he brought to the surface more-or-less the same amount that the preceding ton of coal earned for its producer, this is not the case for the second research paper that repeated exactly what was reported in its predecessor. To be rewarded for a novel idea, research technique, or experimental result, one must be seen to have been in the vanguard of its creators. It is the prospect of gaining such rewards – whether in reputational standing and the esteem of colleagues, enhanced access to research resources, formal organizational recognition through promotions accompanied by higher salary, accession to positions of authority and influence within professional bodies and public institutions, the award of prizes and honors – that serves to induce races to establish "priority," and hence to secure rapid disclosure of "significant" findings.

Because the evaluation of significance will rest largely with the researchers scientific peers, this incentive mechanism performs the further function of directing his or her research efforts towards goals that are more likely to win wider appreciation precisely because it will advance the work of others in the scientific community. What this means is that the incentives created for disclosure under the regime of open science are linked with the orientation of problem choice and the formation of collective research portfolios that are biased toward "research spillovers," rather than "product-design spillovers" in the sphere of commercial innovation.

3. Open Science and Proprietary Research: Regime Complementarities and System Balance

The advantages to society of treating new findings as "public goods" in order to promote the faster growth of the stock of knowledge, are to be contrasted with the requirements of secrecy for the purposes of extracting material benefits from possession of information that can be privately held as intellectual property. This point can be formulated in the following overly stark, unqualified way. Science (*qua* social organization) is about maximizing the rate of growth of the stock of knowledge, for which purposes public knowledge and hence patronage or public subsidization of scientists is required, because citizens of the Republic of Science are cannot capture any of the social surplus value their work will yield if they freely share all the knowledge they obtain. By contrast, the Regime of Technology (*qua* social organization) is geared to maximizing wealth stocks, corresponding to the current and future flows of pure "economic rents (private profits) from existing data, information and knowledge, and therefore requires the control of knowledge through secrecy, or exclusive possession of the right to its commercial exploitation. The conditions that are well suited to appropriate value from possession of the rights to exploit new knowledge, however, are not those that favor rapid growth in the stocks of reliable knowledge.

This functional juxtaposition suggests a logical argument for the existence and perpetuation of institutional and cultural *separations* between the communities researchers forming 'the Republic of Science' and those engaged in proprietary scientific pursuits within 'the Realm of Technology': the two distinctive organizational regimes serve different and potentially complementary societal purposes. Indeed, neither system alone can perform effectively over the long run as the two of them coupled together, since their special capabilities and limitations are complementary. Maintaining them in a productive balance, therefore, is the central task towards which informed science and technology policies must be directed.

It follows from this logic that such policies need to attend to the delineation of intellectual property rights and protections of the public domain in scientific data and information as the respective codified knowledge infrastructures of the dual regimes, and to the maintenance of balance between them. To do so will be easier if there is a clearer understanding of the ways in which public expenditures for the support of open science serve to enhance the value of commercially-oriented R&D as a socially productive and privately profitable form of investment. Such an understanding on the part of representatives of the academic science communities is just as important as it is for government policy-makers, intellectual property lawyers, and business managers.

3.1 Application-oriented payoffs from open, exploratory research: the uncertain lure

When scientists are asked to demonstrate the usefulness of research that is exploratory in character and undertaken to discover new phenomena, or explain fundamental properties of physical systems, the first line of response often is to point to discoveries and inventions generated by such research projects that turned out to be of more or less immediate economic value. Indeed, many important advances in instrumentation, and generic techniques, such as PCR and the use of restriction enzymes in "gene-splicing" may be offered in illustration of this claim. These by-products of the open-ended search for basic scientific understanding also might be viewed as contributing to the "knowledge infrastructure" required for efficient R&D that is deliberately directed towards results that would be exploitable as commercial innovations.

The experience of the twentieth century also testifies to the many contributions of practical value that trace their origins to large, government-funded research projects which were focused upon the development of new enabling technologies for public-mission agencies. Consider just a few recent examples from the enormous and diverse range that could be instanced in this connection: airline reservation systems, packet switching for high-speed telephone traffic, the Internet communication protocols, the Global Positioning System, and computer simulation methods for visualization of molecular structures -- which has been transforming the business of designing new pharmaceutical products -- and much else besides.

Occasionally, such new additions to the stock of scientific knowledge are immediately commercializable and yield major economic payoffs that, even though few and far between, they are potent enough to raise the average social rate of return on basic, academic research well above the corresponding private rate of return earned on industrial R&D investment. Inasmuch as the high incremental social rate of return in cases like those just mentioned derives from the wide and rapid diffusion of knowledge that provide new "research tools," the open dissemination, validation and unobstructed elaboration of these discoveries and inventions is itself directly responsible for the magnitude of the "spillover" benefits they convey.

The skeptical economist's response to recitations of this kind, however, is to ask whether a more directed search for the solutions to the applied problems in question would not have been less costly. Would that approach not be more expedient than waiting for serendipitous commercially valuable results to emerge from costly research programs that were conducted by scientists with quite different purposes in mind? This is a telling point, at least rhetorically, simply because the theme of such "spin-off" stories is their utter unpredictability. To argue that these "gifts from Athena" are in some sense "free," requires that the research program to which they were incidental was worth undertaking for its own sake, so that whatever else might be yielded as by-products was a net addition to the benefits derived. Yet, the reason those examples are being cited is the existence of skepticism as to whether the knowledge that was being sought by exploratory, basic science was worth the cost of the public support it required. Perhaps this is why the many examples of this kind that scientists have brought forward seem never enough to satisfy the questioners.

The discovery and invention of commercially valuable products and processes are seen from the viewpoint of "the new economics of science" to be among the rarer among the predictably "useful" results that flow from the conduct of exploratory, open science. Without denying that "pure" research sometimes yields immediate applications around which profitable businesses spring up, it can be argued that those direct fruits of knowledge are not where the quantitatively important economic payoffs from the open conduct of basic scientific inquiry are to be found.

3.2 Micro-level Complementarities between Exploratory Science and Proprietary R&D

Much more critical over the long run than "spin-offs" from exploratory science programs are their cumulative indirect effects *in raising the rate of return on private investment proprietary R&D* performed by business firms. Among those indirect consequences, attention should be directed not only to "informational spillovers" that lend themselves readily to commercialization, but to a range of complementary "externalities" that are generated for the private sector by publicly funded activities in the sphere of open science, where research and training are tightly coupled.

Resources are limited, to be sure, and in that sense research conducted in one field and in one organizational mode is being performed at the expense of other kinds of R&D. But what is missed by attending exclusively to the competition forced by budget constraints, is an appreciation of the ways in which exploratory science and academic engineering research activities support commercially-oriented and mission-directed research that generates new production technologies and products.

First among the sources of this complementary relationship, is the intellectual assistance that fundamental scientific knowledge (even that deriving from contributions made long ago) provides to applied researchers -- whether in the public or in the private sector. From the expanding knowledge base it is possible to derive time- and cost-saving guidance as to how best to proceed in searching for ways to achieve some pre-specified technical objectives. Sometimes this takes the form of reasonably reliable guidance as to where to look first, and much of the time the knowledge base provides valuable instructions as to where it will be *useless* to look. How else does the venture capitalist know not to spend time talking with the inventor who has a wonderful new idea for a perpetual motion machine?

One effect this has is to raise the expected rates of return, and reduce the riskiness of investing in applied R&D. Gerald Holton, Harvard's physicist and historian of science, recently has remarked that if intellectual property laws required all photoelectric devices to display a label describing their origins, "it would list prominently: ‘Einstein, Annalen der Physik 17(1905), pp.132-148.’" Such credits to Einstein also would have to be placed on many other practical devices, including all lasers.

The central point that must be emphasized here is that, over the long-run, the fundamental knowledge and practical techniques developed in the pursuit of basic science serves to keep applied R&D as profitable an investment for the firms in many industries as it has proved to be, especially, during the past half-century (see David, Mowery and Steinmueller 1992). In this role, modern science continues in the tradition of the precious if sometimes imprecise maps that guided parties of exploration in earlier eras of discovery, and in that of the geological surveys that are still of such value to prospectors searching for buried mineral wealth.

That is not the end of the matter, for a second and no less important source of the complementary relationship between basic and applied research is the nexus between university research and training, on the one hand, and on the other the linkage of the profitability of corporate R&D to the quality of the young researchers that are available for employment. Seen from this angle, government funding of open exploratory science in the universities today is subsidizing the R&D performed by the private business sector. Properly equipped research universities have turned out to be the sites of choice for training the most creative and most competent young scientists and engineers, as many a corporate director of research well knows. This is why graduates and postdoctoral students in those fields are sent or find their own way to university labs in the U.S., and still to some in the U.K. It explains why businesses participate (and sponsor) "industrial affiliates" programs at research universities.

3.3 The “Tacit Dimension” and Knowledge Transfers via the Circulation of Researchers

A further point deserving emphasis in this connection is that a great deal of the scientific expertise available to a society at any point in time remains *tacit,* rather than being fully available in codified form and accessible in archival publications. It is embodied in the craft-knowledge of the researchers, about such things as the procedures for culturing specific cell lines, or building a new kind of laser that has yet to become a standard part of laboratory repertoire. This is research knowledge, much of it very "technological" in nature -- in that it pertains to how phenomena have been generated and observed in particular, localized experimental contexts -- which is embodied in people. Under sufficiently strong incentives it would be possible to express more of this knowledge in forms that would make it easier to transmit, and eventually that is likely to happen. But, being possessed by individuals who have an interest in capturing some of the value of the expertise they have acquired, this tacit knowledge is transmitted typically through personal consultations, demonstrations and the actual transfer of people (see Cowan, David and Foray 2000, for further treatment of the economics of tacitness and codification of knowledge). .

The circulation of post-doctoral students among university research laboratories, between universities and specialized research institutes, and no less importantly, the movement of newly trained researchers from the academy into industrial research organizations, is therefore an important aspect of "technology transfer" -- diffusing the latest techniques of science and engineering research. The incentive structure in the case of this mode of transfer is a very powerful one for assuring that the knowledge will be successfully translated into practice in the new location; for the individuals involved are unlikely to be rewarded if they are not able to enhance the research capabilities of the organization into which they move.

A similarly potent incentive structure may exist also when a fundamental research project sends its personnel to work with an industrial supplier from whom critical components for an experimental apparatus are being procured. Insuring that the vendor acquires the technical competence to produce reliable equipment within the budget specifications is directly aligned with the interests of both the research project, and the business enterprise. Quite obviously, the effectiveness of this particular form of user-supplier interaction is likely to vary directly with the commercial value of the procurement contracts and the expected duration and continuity of the research program.

For this reason, "big science" projects or long-running public research programs may offer particular advantages for the collaborative mode of technology transfers, just as major industrial producers -- such as the large automotive companies in Japan -- are seen to be able to set manufacturing standards and provide the necessary technical expertise to enable their suppliers to meet them. By contrast, the transfer of technology through the vehicle of licensing intellectual property is, in the case of process technologies, far more subject to tensions and deficiencies arising from the absence of complete alignment in the interest of the involved individuals and organizations. But, as has been seen, the latter is only one among the economic drawbacks of depending upon the use of intellectual property to transfer knowledge from non-profit research organizations to firms in the private sector.

3.4 Won't the Private Sector Sponsor Academic, "Open Science" Style Research?

Business firms do indeed cooperate with academic research units, and in some cases they undertake on their own to support "basic research" laboratories whose employed scientists and engineers are permitted, and even encouraged to rapidly submit results for publication in scientific and technical journals. Large, R&D-intensive companies also adopt strategies of liberally licensing the use of some among their patented discoveries and inventions. Their motives in adopting such policies include the desire to developing a capability to monitor progress at the frontiers of science, the hope of being able to pick up early information concerning emerging potential lines of research with commercial innovation potential, being better positioned to penetrate the secrets of their rivals' technological practices, and recruiting talented young scientists whose career-goals are likely to be advanced by the exposure that can be afforded to them by publication and active participation in an open science community. Even some small and medium-size firms sometimes opt to freely disclose inventions that are patentable. (This may be done as a means of establishing the new knowledge within the body of "prior art," and thereby, without incurring the expenses of obtaining and defending a patent, effectively precluding others from securing property rights that would inhibit the firm from exploiting the knowledge for its own production operations.)

Yet, in regard to the issue of whether market incentives fail to elicit private sector funding of exploratory R&D conducted in the "open science" mode, the relevant question for society is one that is quantitative, not qualitative. One cannot adequately answer the question "Will there be enough business-motivated support for open science?" merely by saying, "There will be some." Economists do not claim that without public patronage scientific and technical research would entirely cease to be conducted under conditions approximating those of the "open science" system. Rather, their analysis holds that there will not be *enough* investment in that style of inquiry, that is to say, not as much as would be carried out were individual businesses able to anticipate capturing all the benefits of such knowledge-producing investments – as is the case for society as a whole.

Moreover, business support for academic-style R&D – as distinguished from industrial contracting for university based, applications oriented research with intellectual property rights assigned to the sponsoring firms – is more likely to commend itself as a long-term strategy. Consequently, it is likely to be sensitive to commercial pressures to shift research resources towards advancing existing product development, and improving existing processes, rather than searching for future technological options. This implies that exploratory lines of inquiry funded in this way are vulnerable to wasteful disruptions. Large commercial organizations that are less prone to becoming asset-constrained, and of course the public sector, therefore are better able to take on the job of monitoring what is happening on the international science and technology frontiers. Considerations of these kinds are important in addressing the issue of how to find the optimal balance for the national research effort between secrecy and disclosure of scientific and engineering information, as well in trying to adjust the mix in the national research portfolio of exploratory open science style programs and proprietary, applications-driven R&D projects.

4. Property and the Pursuit of Knowledge

4.1 Intellectual property rights and the norms of disclosure

The past two decades have witnessed growing efforts to assert and enforce intellectual property rights over scientific and technological knowledge through the use of patents, copyrights, and other, more novel forms of legal protection. (The latter include the special legislation introduced in the US in 1980 to extend copyright protection to the "mask work" for photo-lithographic reproduction of very large microelectronic circuits on silicon wafer, and the European Union's protection of databases by new national statutes implementing an EC Directive issued in 1996.) These developments have coincided with two other trends that, similarly, have tended to expand the sphere of private control over access to knowledge, at the expense of the public knowledge domain.

One trend has been the rising tide of patenting activity by universities, especially in the areas of biotechnology, pharmaceuticals, medical devices and software. This movement started in the US, where it received impetus under the 1980 Bayh-Dole Act (1980) that permitted patent applications to be filed for discoveries and inventions issuing from research projects that were funded by the federal government, but is has since spread internationally, being reinforced by the efforts in other countries to foster closer research collaboration between universities and public research institutes, on the one hand, and private industry on the other. The other trend has seen a concerted effort by all parties to secure copyright protection for the electronic reproduction and distribution of information, in part to exploit the opportunities created by electronic publishing, and in part to protect existing copyright assets from the competition that would be posed by very cheap reproduction of information in digital form over electronic networks.

During the past two decades a renewal of enthusiasm for expanding and strengthening private property rights over information has given rise to a rather paradoxical situation. Technological conditions resulting from the convergent progress in digital computing and computer-mediated telecommunications have greatly reduce the costs of data capture and transmission, as well as of information processing, storage and retrieval. These developments are working to give individuals – and especially researchers – unprecedentedly rapid and unfettered access to new knowledge. At the same time, and for reasons that are not entirely independent, the proliferation of intellectual property rights and measures to protect these is tending to inhibit access to such information in areas (basic research in general, and most strikingly in the life sciences, and computer software) where new knowledge had remained largely in the public domain (see David 2000 on the connection between the technological and the institutional trends).

Thus, it may be said that a good bit of intellectual ingenuity and entrepreneurial energy is being directed towards the goal of neutralizing the achievements of information scientists and engineers by creating new legally sanctioned monopolies of the use of information -- thereby creating artificial scarcities in fields where abundance naturally prevails and access to that abundance is becoming increasingly ubiquitous. The consequent imposition of data and information access charges above the marginal costs of producing and distributing information results in a double of burden of economic inefficiency when it falls upon researchers who use those information-goods as inputs in the production of more information and knowledge. The first-order effect is the curtailment of the use of the information, or the increased cost of using it to produce conventional commodities and services, and hence the loss of utility derived from such products by consumers. A second round of inefficiency is incurred by the inhibition of further research, which otherwise would be the source of more public goods in the form of new knowledge.

To understand the full irony of this situation, on has simply to return to the point of departure in this discussion: the observation that knowledge is not like any other kind of good, and certainly does not resemble conventional commodities of the sort that are widely traded in markets. Intellectual property cannot be placed on an equal footing with physical property, for the simple reason that knowledge and information possess a specific characteristic that economists refer to as "non-rival in use": the same idea and its expression may be used repeatedly, and concurrently by many people, without being thereby "depleted." This contrasts with the properties of ordinary "commodities" that are consumed: if Marie eats the last slice of cake in the kitchen, that piece cannot also be consumed by Camille; whereas, both girls may read the same novel either simultaneously or sequentially, and in so doing they will not have rendered the story any the less available for others to enjoy.

The allocation of property rights in the case of information-goods does not attempt to confer a right of exclusive possession, as do property laws governing tangible goods such as land. Indeed, to claim a right of possession one must be able to describe the thing that is owned, but no sooner do you describe your idea to another person than their mind comes into (non-exclusive) possession of it; only by keeping the information secret can you possess it exclusively.

What the creation and assigning intellectual property rights does, then is to convey a monopoly right to the beneficial economic exploitation of an idea (in the case of patent rights) or of a particular expression of an idea (in the case of copyright) that has been disclosed, rather than being kept secret. This device allows the organisation of market exchanges of "exploitation rights," which, by assigning pecuniary value to commercially exploitable ideas, creates economic incentives for people to go on creating new ones, as well as finding new applications for old ones. By tending to allocate these rights to those who are prepared to pay the most for them, the workings of intellectual property markets also tends to prevent ideas from remaining in the exclusive (secret) possession of discoverers and inventors who might be quite uninterested in seeing their creations used to satisfy the wants and needs of other members of society.

Another potential economic problem that is addressed by instituting a system of intellectual property rights is the threat of unfair competition -- particularly the misappropriation of the benefits of someone else's expenditure of effort – which might otherwise destroy the provision of information-goods as a commercially viable activity. The nub of the problem here is that the cost of making a particular information good available to a second, third, or thousandth user are not significantly greater than those of making it available to the first one. When Théo listens to a piece of music, modern reproduction and transmission technologies will permit Quentin, Manon and millions of others to listen to the same piece without generating significant additional costs. The costs of the first copy of a compact disk (CD) are very great, compared to the cost of "burning" a second, third or millionth copy of that CD. Ever since the Gutenberg revolution, the technical advances that have lowered the costs of reproducing "encoded" material (text, images, sounds) also has permitted "pirates" to appropriate the contents of the first copy without bearing the expense of its development. Unchecked, this form of unfair condition could render unprofitable the investment entailed in obtaining that critical first copy.

Producers of ideas, texts, and other creative works (including graphic images and music) are subject to economic constraints, even when they do not invariably respond to variation in the incentives offered by the market. If they had no rights enabling them to derive income from the publication of their works, they might create less, and quite possibly be compelled to spend their time doing something entirely different but more lucrative. So, there is an important economic rationale for establishing intellectual property rights. A strong case also can be made for protecting such rights by the grant of patents and copyrights, especially as that way of providing market incentives for certain kinds of creative effort leaves the valuation of the intellectual production to be determined *ex post*, by the willingness of users to pay; it thereby avoids having society try to place a value on the creative work *ex ante* – as would be required under alternative incentive schemes, such as offering prospective authors and inventors prizes, or awarding individual procurement contracts for specified works.

4.2 Property institutions, transactions costs and access to information

But, the solution of establishing a monopoly right to exploit that "first copy" (the idea protected by the patent or the text protected by copyright), alas, turns out not to be a perfect one. The monopolist will raise the price of every copy above the negligible costs of its reproduction, and, as a result, there will be some potential users of the information good who will be excluded from enjoying it. The latter represents a waste of resources, referred to by economists as the "dead-weight burden of monopoly": some people's desires will remain unsatisfied even though they could have been fulfilled at virtually no additional cost. Economists as a rule abhor "waste," or "economic inefficiency," but they believe in and rather like the power of market incentives. Not surprisingly, then, the subject of intellectual property policies has proved vexatious for the economics profession, as it presents numerous situations in which the effort to limit unfair competition and preserve incentives for innovation demonstrably results in a socially inefficient allocation of resources.

There is not much empirical evidence as to how altering the legal conditions and terms of intellectual property rights translates into change in the overall strength of economic incentives for the producers, or about the effectiveness of bigger incentives in eliciting creative results; nor is it a straightforward matter to determine the way in which holders of a particular form of intellectual property right would choose to exploit it, and the consequent magnitude of the resultant social losses in economic welfare ("the dead-weight burden"). Without reliable quantitative evidence of that kind, obviously, it is hard to decide in which direction to alter the prevailing policy regime in order to move towards the notional optimum for any particular market.

The difficulties of arriving at "scientific closure" on such matters, combined with conflicts of economic interests over the distribution of the benefits of new knowledge, quite understandably, have sustained a long history of intense debate in this area. In each era of history new developments affecting the generation, or the distribution of knowledge, give rise to a revival of these fundamental questions in new guises. Today, the "hot issues" arise from questions concerning the desirability of (a) curtailing patent monopolists' rights by letting governments impose compulsory licensing of the local manufacture of certain pharmaceutical products, or of some medical devices; (b) providing those engaged in non-commercial scientific research and teaching with automatic "fair use" exemptions from the force of intellectual law; (c) permitting purchasers of copyright protected CD's to freely share music tracks with others by means of peer-to-peer distribution over the Internet.

There is no easy general solution to this class of economic problems, and useful answers to the basic questions raised (are new rights that would better address the new circumstances required, and, if so, what form should they take?) will vary from one case, area or situation to the next. Most economic and legal analysis favours protecting broad classes of intellectual works, rather than very specific forms that are more likely to be rendered economically obsolete. But having flexible legal concepts that are meant to be applied in novel situations creates added uncertainties for innovators. There is likely to be a protracted period of waiting, and struggling to have the courts settle upon an interpretation of the law that is sufficiently predictable in its specific applications to provide a reliable guide for commercial decision-making.

Another general principle that finds widely expressed approval is that of harmonising intellectual property rights institutions internationally, so that arbitrary, inherited legal differences among national entities do not interpose barriers to the utilisation of the global knowledge base in science and technology. The catch in this, however, is that harmonisation rarely is a neutral procedure. Representatives of polities usually are loathe to cede property rights which their constituents already possess, and, consequently, programs of "harmonisation" turn out to impart an unwarranted global bias towards expanding the range of property rights that will be recognised and raising the strength of the protections afforded.

A more tenable broad policy position on this contested terrain may be derived from the recognition that the generation of further knowledge is among the major important uses of new knowledge, and, at the same time, there are enormous uncertainties surrounding the nature and timing of the subsequent advances that will stem from any particular breakthrough. This is especially true of fields where new discoveries and inventions tend more readily to recombine in a multiplicity of ways that generate further novelties. A reasonably clear policy implication follows from this, and from the additional observation that although we will seldom be able to predict the details and future social value attaching the *sequelae* of a specific advance in knowledge, it is far more certain that there will be a greater flow of entailed discoveries if the knowledge upon which they rest remains more accessible and widely distributed. Therefore, rather than concentrating on raising the inducements to make "hard-to-predict" fundamental breakthroughs, it will be better to design intellectual property regimes in ways that permit non-collusive pooling and cross licensing. As a practical matter, this consideration generally would call for raising the novelty requirements for patents, awarding protection for narrower claims, requiring renewals with increasing fees, and other, related measures. All of these steps would encourage entry into the process of generating further knowledge by utilising the breakthroughs that have occurred and been adequately disclosed (see David and Foray, 1995).

The import of this is to strictly limit the scope of grants of monopoly rights over research tools and techniques, curtailing the freedom of the rights-holders levy whatever "tax" they wished upon others who might use such inventions and discoveries in order to generate still further additions to the knowledge base. Collective knowledge enhancement is thwarted when discoveries cannot be freely commented upon, tested by replication, elaborated upon and recombined by others. Putting this in other words, intellectual property regimes designed to make it easier for many to "see farther by standing on the shoulders of giants" would appear likely to be more fruitful than a strategy which render those shoulders less easily mounted by others, in the hope that this would stimulate the growth of more, and taller "giants."

The extension of monopoly rights over the application of particular research tools in the life sciences -- techniques such as PCR (polymerase chain reaction) and monoclonal antibodies, new bioinformatic databases and search engines, as well as generic information about the structure of genetic material and the way that these govern the production of proteins – is coming to be seen as especially problematic. The issuing of such patents may indeed be responsible for stimulating more commercially oriented R&D investment by pharmaceutical companies, and others who look forward to selling them access to new information. Yet, intellectual property protection in this sphere is likely to impose heavy dynamic welfare losses on society. It will do by impeding access to existing information, or by increasing the wastage of resources in functionally duplicative research aimed at avoiding patent licensing charges. This raises the cost not simply of research directed toward producing a specific new product (e.g., diagnostic test kits for a particular class of genetically transmitted conditions), but, also of exploratory research that may enable the future creation of many applications, including those that still are undreamed of. To use the evocative phrasing of a leading European scientist, cooperatively assembled bioinformatic databases are permitting researchers to make important discoveries in the course of "unplanned journeys through information space.” If that space becomes filled by a thicket of property rights, then those voyages of discovery will become more troublesome and more expensive to undertake, unanticipated discoveries will become less frequent, and the rate of expansion of the knowledge base is likely to slow.

Popular wisdom maintains that “good fences make good neighbours”. This may apply in the case of two farmers with adjacent fields – one growing crops and the other grazing cattle – or gold diggers excavating neighbouring concessions. But unlike land, forage or other kinds of exhaustible resources, knowledge is not depleted by use for consumption; data-sets are not subject to being “over-grazed”, but instead are likely to be enriched and rendered more accurate the more that researchers are allowed to comb through them (David, 2001).

The issues just examined are entangled with other, difficult problems concerning the institutional (as distinct from the technological) determinants of human beings ability to enhance their “capabilities” by finding and making use of existing repositories of knowledge and sources of information (Foray and Kazancigil, 1999). They involve special problems of access to scientific and technological knowledge relevant to developing countries, and raise complex issues of what it implies for resource allocation to insist that every individual in a society has a right to benefit from the collective advance of human knowledge affecting such fundamental, capability enhancing conditions as health and education.

A delicate attempt at regaining a better balance between protection of the public domain of knowledge from further encroachments by the domain of private property rights, at least in regard to some sectors where services are recognised to profoundly effect human “well-being” (health, education). The notion of a universal right to health appears to have the “strength” to countervail against the national and international campaigns led by pharmaceutical companies to secure intellectual property owners the right to unregulated exploitation of their patents. But, one must not be deluded into supposing that appeals to principles of equity alone will be sufficient in deciding such contests in the area of political economy.

4.3 Some subtleties in gauging the effects of IPR protections on the conduct of science

Apart from a few anecdotes of the sort that already have been introduced in this discussion, a there any really systematic body of empirical material on which to base the warnings that are being sounded about the possible impact of IPR-fever on exploratory research, and academic science more generally? Should we not insist on policy action being “evidence-based? More specifically, how can we evaluate the potential for the enforcement of database rights to impede the exploitation of bioinformatic techniques, and scientific discoveries more generally? Heller and Eisenberg (1998) popularized the phrase “tragedy of the anticommons” in an article published in *Science*, suggesting that the great increase of patenting in the biomedical and in biotechnology area more generally might actually inhibit innovation, especially where inventions and discoveries required the assembling of an assortment of complementary bits of knowledge and research tools, each of which might be owned by distinct parties. The argument, basically, is that fragmented ownership rights invites opportunistic bargaining strategies (hold-outs, over-pricing), and so raises negotiation costs that projects which otherwise would be privately profitable, and possibly of great social value, would not be undertaken. But, Heller and Eisenberg (1998) did not substantiate the existence of a potent “anti-commons effect” by producing concrete instances of such losses.

Not surprisingly, the claim that granting greater protection to IPRs might adversely affect investment in the production of knowledge, by increasing the costs of collaborative projects among the property holders, has been received with skepticism in some quarters, and therefore has attracted the attention of empirically-minded economists. A recent study by Walsh, Arora and Cohen (2002) set out to look for evidence on the question of whether serious “Anti-commons effects” had materialized in the biotechnology sector, which is where Eisenberg and Heller’s article warned it was likely to appear. Their methodology was the survey of participants in business and academic research organizations, and the thrust of their “findings” was that while there were a few isolated instances of serious difficulties in working out the IPR arrangements among firms, and between firms and universities, their interviews disclosed nothing resembling a “tragedy.” Rather more serious reservations were sounded, however, regarding the impediments to research discoveries that might be caused by the patenting of fundamental research tools, an issue that Walsh, Arora and Cohen, treated as distinct from that of the “anti-commons” effect—even though Eisenberg (2001) evidently regards the two as closely related.

While this study was carefully carried out and reported in a balanced and qualified fashion, it gave little attention to the issue of what sort of indications might be elicited by interviews that would establish the existence of “anti-commons tragedies.” The interview protocols followed in questioning managers, lawyers and researchers in biotech and pharmaceutical companies, and also a much smaller number of university scientists (numbering 10 among the 70 interviews conducted) are not described in any detail by Walsh, Arora and Cohen (2002). In particular, the question of exactly what constitutes a “blockage” or “breakdown” to a biomedical research project is never specified. So, it is difficult to evaluate the responses that the study reports having elicited, but there clearly are potential problems in interpreting some of the reported testimony. (The same must be said with regard to the interview material from the NIH Working Group on Research Tools, discussed by Eisenberg (2001).

To illustrate the methodological problem, let us suppose the procedure involved asking interviewees: “Have you experienced serious obstacles to research you have tried to undertake, due to conflicts arising over intellectual property rights – difficulties that prevented you from pursuing worthwhile projects?” The reported responses, by and large, would be consistent with the informants having replied: “Not really, we are quite able to do our thing.” One might wonder what the investigators thought they might be told. Would the heads of research departments say that their research performance was no longer as good as it once had been (no matter what the alleged cause)? The point here is a simple and familiar one: the way that interview questions are phrased is a delicate matter in such an inquiry.

In the case of the university biomedical researchers interviewed by Walsh, Arora and Cohen (2002), a typical response to the question of whether patenting of research tools was impeding their research seems to have been something along the lines: “Not really. We don’t pay attention to it, and the firms seem reluctant to enforce their patents against us.” Now it is quite correct that if property rights are granted people do not voluntarily comply with the intent of the law establishing those rights, and the right-holders do not enforce their legal claims, it cannot be said that there will be any effect of the statutory change. But, surely, to conclude that “there is no problem” in such a case is rather misleading. There is no “effect” because the “cause” has yet to happen. The proper conclusion is: We can’t say, what the effect of the IPR regime will be in this instance, except that when a cease and desist injunction is brought against one of these professors, and her university is charged with patent infringement and sued for damages (perhaps by another university that holds the patent on one of those research tools), it is going to be a big shock.

The problem of interpreting the evidence of the survey responses in other respects is a bit more subtle than was suggested by the previous remarks about possible reporting biases, arising from the framing of the questions. The "anti-commons" argument can be given a naive interpretation or one that is economically sophisticated, and correspondingly, the evidence can be read either naively or in a sophisticated manner. Let us start by consider the alternative styles of interpretation of the putative “Anti-Commons effect”:

1) *Naive:* parties to a potentially productive coalition will see only the value of cooperating for a common benefit, and will ignore the possible costs of contracting. So, if IPR has the effect of raising the parties valuation of their own contribution to the collective project, and makes it possible for them to deny others access to that contribution, the negotiation of cooperative agreements will be surprisingly difficult,

and frequently these will fail. One should be able to find records, or elicit testimony of such failures. Look for them in order to test the "anti-commons" hypothesis.

2*) Sophisticated*: A well-known essay by Ronald Coase, the Nobel Laureate in Economics, pointed out that the institutional arrangements that assigned property rights to some agents would only affect the efficiency of resource allocation among them if there were zero "costs of transacting," of arriving at a contract in which the gains from trade would be secured for the collectivity and distributed among them. Agents understanding this should consider ex ante the likely benefit of a contract for the exchange of assets (entitlement to rent streams), and the costs of negotiating such a contract. If they do this, they will take account of changes in institutions that alter the property rights of the parties, and the likely affect of this on the nature of the contracting process and its costs. So, a change in property rights that raises everyone's assessment of what they should get from the same cooperative project, would be perceived as raising the costs of contracting sufficiently to render it foolish to pursue some projects -- namely those at the lower marginal utility end of the ranking. Note that I use "utility" to cover both projects with lower expected rates of return, and those where there is higher intrinsic technical or commercial risk (in the sense of higher variance relative to the expected rate of return.)

Rational agents, therefore, will discard projects as being not worth serious consideration. If they are asked for examples of projects that were "blocked" or "abandoned" because of high transactions costs, they should not report any higher frequency of such events following the institutional change than they reported before. There might be an initial "learning" period in which mistakes were more frequent, but there is no reason why the equilibrium level of failed negotiations should be raised.

What the sophisticated view of the matter suggests is that to find the "effect" of the institutional change, one has to estimate what would happen in the counter-factual world: what projects that were not seriously considered, would have been considered. The foregoing line of thought might suggest that the nature of the projects that would be undertaken following the change in the IPR regime would be found to have shifted towards those with the following characteristics:

a) The distribution of initial property rights among the participating was already highly asymmetric and the relative disparity in bargaining power would not be materially changed by the altered property rights regime, so the estimated transaction costs wouldn't be significantly affected;

b) The private expected rate of return was higher than the norm for the previously undertaken projects, and so could justify the higher contracting costs of putting the collaboration together;

c) The risk-return ratios for the projects undertaken are found to have been lower than those among the projects previously undertaken.

In other words, an institutional change that raises the marginal costs of transactions of a particular kind need not actually increase the amount of resources consumed by such transactions; rather it may push resources into other channels, and leave a gap between the marginal rates of return that the realized projects in that area yield (gross of negotiation expenses) and the rates of return on other kinds of projects. That gap is a measure of the social burden of "royalty stacking", "blocking patents" etc.

Unfortunately, ideas are extremely heterogeneous. It is rare that the same options for exploration present themselves at successive points in time; in the world of research the dictum of Heraclitus hold – one cannot dip into precisely the same stream of ideas twice. Because the set of projects to create knowledge will not present themselves after the legal system protecting IPR changed will not be exactly the set that was available before, the gap of discarded opportunities can never be measured exactly. What one could do, in principle, is to examine the characteristics of the entire portfolio of research projects that were being undertaken before, and after the institutional innovation. Of course, it would be necessary in doing so to control for the influence of other temporally correlated changes that would affect those portfolio characteristics.

The hunt for evidence of a “tragedy” in the form of a lost opportunity is inextricably encumbered by the problem of documenting a counterfactual assertion of the form: if we had not do that, the world would now be different. In discussion of such propositions, rhetorical victories tend to go to the side that can shift the burden of proof to the shoulders of their opponents – simply because conclusive proof of a counterfactual assertion will be elusive. Thus, for those who see the system of IPR protection as fundamentally benign, the debating strategy is to demand that the critics show the social efficiency losses that they claim it is causing. But, why should that assignment of the burden of proof be accepted? Although in the case of ordinary, physically embodied commodities there is a theoretical presupposition that competitive markets and well-defined private property rights can support a socially optimal equilibrium in the allocation of resources, that presumption ceases to hold in the realm of information and knowledge.

5. Conclusion

The elision effected by the application of the metaphor of “property” to the domain of ideas has been fruitful in many regards. But there is a danger in permitting those who are enthusiastic for more and stronger IPR to employ this as rhetorical device as a way of avoiding the burden of proof. They should be asked to show that the moves already made in that direction have not been economically damaging; that further encroachments into the public domain of scientific data and information would not be still more harmful; that society would not benefit by adopting a policy that was just the opposite of the one they support.

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