Property Rights and Entrepreneurship in Science

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ABSTRACT. This paper examines the evolving relationship in science between the reward structure and entrepreneurial activity. We draw a distinction between two types of property rights. Basic science is fostered by a mechanism of reputational rights; technological advances – and the products and processes they produce – are fostered by a mechanism of proprietary rights. The two forms of property rights differ markedly in terms of the incentives they provide to share information in a timely fashion. We argue that because of a host of factors university-based scientists in certain fields are more likely to "privatize" knowledge today than in the past, trading reputational rights for proprietary rights. Events in the life sciences serve as a case study. A discussion of how privatization affects basic science follows. Although the evidence is far from complete, we conclude that the movement towards privatization may be more beneficial to product development and the scientists engaged in the activity than to basic science.

I. Introduction

Research scientists at universities are an important source of innovation-generating knowledge (Jaffe, 1989; Acs *et al.*, 1992, 1994). The incentive for the profit sector to seek out these knowledge sources is, perhaps, obvious. Less obvious is the incentive for university-based scientists to seek ways of transferring knowledge from the public to the private domain. In this paper we examine factors leading scientists (and their universities) to seek out contacts with the profit sector. We argue that a confluence of factors make scientists in certain fields considerably more likely to "privatize" knowledge today than in the past. This trend has done much to stimulate the growth of new products and in the process enrich some scientists. The effects on basic science are less clear.

The plan of this paper is as follows. Section II discusses the reward structure in science. Section III argues that two distinct types of property rights have developed to foster research creativity. Section IV explores some of the factors making scientists willing and able to transfer knowledge from the public to the private domain. Events in the life sciences serve as the case study presented in Section V. Section VI asks whether the "privatization" of knowledge harms basic science. Discussion and conclusions follow in Section VII.

II. The reward structure of science

Scientists engage in research because of a love of the puzzle, an interest in reputation, and an awareness that monetary rewards await the successful. These incentives are summarized in Table I and detailed in Stephan and Levin (1992). The importance of the puzzle is discussed extensively by Kuhn (1970) and summarized by Hagstrom (1965, p. 16): "Research is in many ways a kind of game, a puzzle-solving operation in which the solution of the puzzle is its own reward". The philosopher of science David Hull (1988, p. 305) describes scientists as being innately curious and suggests that science is "play behavior carried to adulthood".

The psychological rewards resulting from research are generally considered not sufficient to motivate scientists to persist in their quest for knowledge. In a series of publications, Merton (1957, 1961, 1969) and such other sociologists as

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TABLE I
Summary of traditional incentive structure in science

Incentive	Unusual economic function	Author	Evidence
Love of puzzle		Hagstrom (1965); Hull (1988); Kuhn (1970)	Interviews; anecdotal; salary does not appear commensurate with training
Interest in priority	Goes a long way toward solving the public good issue by encouraging scientists to share information quickly	Merton (1957, 1961, 1969); Cole and Cole (1973); Dasgupta and David (1987); Ziman (1968); Zuckerman (1977)	Author order debated; rush to publish; practices of editors; history of science; interviews; priority is basis for awarding large prizes
Financial		Diamond (1986); Dasgupta and David (1987); Tuckman (1976); Tuckman and Leahy (1975)	Studies relating salary to publications and citations; interviews; anecdotal evidence; size and prevalence of prizes in science

Zuckerman (1977) and Cole and Cole (1973) who have extended his work have demonstrated that recognition is a key factor leading scientists to do research and have emphasized how this taste for recognition is nurtured through the socialization process.[1]

Clues concerning the importance of reputation to scientists are apparent from a variety of behaviors. The author order on articles is not haphazardly arrived at but usually carefully negotiated. Scientists read footnotes to see if they were thanked in someone else's work. Nowhere is the importance of reputation to scientists more apparent than when it comes to issues concerning priority of discovery. Science is not just a game played for one's enjoyment. It is a game played to win. And, as Jerry Gaston (1971) has pointed out, unlike many other competitions, it does not award second and third prizes. It is a winner-take-all situation where priority is the prize (Dasgupta and David, 1987). Claims are staked by writing scholarly articles and submitting them for publication in a timely manner. In extreme cases the contest can be so intense that the time between writing and submission is collapsed into a period as short as a day. It is reported, for example, that in the race for superconductivity, scientists at Bellcore had someone drive their manuscript to *Physical Review Letters* rather than put it in the overnight delivery queue, thereby insuring that they would be one more step ahead in the battle for priority (Hazen, 1988).

Puzzle-solving and an interest in recognition are not the only motivating forces for doing science. Like other economic agents, scientists are not disinterested in money. When Henry Rosovsky (1990, p. 242), the former dean of the Faculty of Arts and Sciences at Harvard, asked one of Harvard's most eminent scientists the source of his scientific inspiration, the reply ("which came without the slightest hesitation") was "Money and flattery". Similar comments by others,[2] as well as the phenomenal amount of attention given to compensation issues at U.S. research universities, suggest that Rosovosky's experience was not atypical.

Because the winner-take-all nature of the race places most of the risks on the shoulders of the scientist, it is not surprising that compensation of university-based scientists can be thought of as being structured in two parts: a guaranteed portion paid regardless of the individual's success in research and a priority-based portion reflective of the value of the winner's contribution to science. While this clearly oversimplifies the compensation structure in science, the role played by counts of publications and citations in determining raises and promotions at universities is evident from the work of Hamermesh *et al.* (1982), Diamond (1986), Tuckman (1976) and Tuckman and Leahy (1975). The life-cycle effects of such a compensation system for research have been modeled by Diamond (1984) and Levin and Stephan (1991). Outside the university, priority-based financial rewards are present in the form of prize money and speaking and consulting fees, which can be quite sizeable.

III. Property rights

Basic scientific research has properties of a public good (Arrow, 1962; Dasgupta and David, 1987; Johnson, 1972). Knowledge is not depleted when shared with others, and once it is made public it is difficult to exclude others from its use. Furthermore, the incremental cost of an additional user is virtually zero, and, unlike other public goods, not only is the stock of knowledge not diminished by more extensive use, but it may be enlarged.[3]

Recognition of the public nature of knowledge by non-economists is not new. Thomas Jefferson (1904) wrote that an idea has the peculiar characteristic that "... no one possesses the less, because every other possesses the whole of it. 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". The public nature of science is an important theme in much of the work of the physicist and science policy analyst John Ziman (1968). The sociologist Robert Merton (1988) also recognized this public aspect of science when he wrote that ". . . a fund of knowledge is not diminished through exceedingly intensive use by members of the scientific collectivity – indeed, it is presumably augmented. . . .".

The conventional wisdom in economics is that the producer of a public good cannot appropriate the benefits derived by users. This logic, however, applies to a reward structure which functions through the market. The argument fails if the reward system relies on reputation since reputation provides a mechanism for capturing the externalities involved. In fact, the more a scientist's work is used, the larger is the scientist's reputation, and the larger are the resulting financial rewards.[4]

It is important to stress that it is the *public* nature of knowledge that *facilitates* the building of reputations in science.[5] The fastest way for a scientist to establish a reputation among peers is to "share" knowledge by placing ideas in print. Others then use the knowledge that the scientist has developed, citing the scientist's work, and thereby "advertising" the work to the scientific community. The process is encouraged by a user fee which approaches zero. Moreover, as long as financial rewards are a consequence of reputation, the promise of monetary rewards acts to stimulate the production of basic knowledge and drives scientists to share information rapidly in order to build reputations and hence capture the financial resources bestowed on the eminent.

It can also be argued that contrary to conventional wisdom of economists that a public good will be underproduced, there are indications that occasionally "overproduction" occurs in science in the sense that from a societal point of view "too many" scientists enter specific contests. The literature is replete with case studies of fights for priority when two or more scientists make similar discoveries within a short period of time.[6] The presence of multiples, to use Merton's terminology, is due in part to the free access scientists have to public knowledge (Dasgupta and Maskin, 1987); in part to the winner-take-all nature of contests which, under many conditions, have been shown to attract a greater than socially optimal number of participants (Frank and Cook, 1991); and in part to the fact that the uncertainty associated with discovery leads scientists to choose research portfolios that are correlated (Dasgupta and Maskin, 1987).

Basic science only has an economic impact if knowledge transfer occurs.[7] Because the goal of applied research is to produce a product to be marketed, the incentives to engage in research and development require a means of guaranteeing exclusivity for a period of time. *Proprietary rights* are one means of encouraging rent-seeking activity. They come in a variety of forms that include patents, copyrights, trade secrets, and licenses, and they provide the producer some period of time in which to reap the economic benefits before competitors can enter the fray.[8]

Two distinct types of property rights have thus developed to foster research and development. Basic science has been fostered by a mechanism of *reputational rights*; technological advances – and the products and processes they produce – have been fostered by a mechanism of *proprietary rights*.[9] While both are forms of *property rights*, they differ markedly in terms of the incentives to share information, particularly to share information in a *timely fashion*. On the one hand, the quest for reputation requires scientists to share information quickly, since only by sharing can the scientist establish priority of discovery. Proprietary rights, on the other hand, discourage the rapid spread of information, since they are designed to provide a means for capturing directly the economic rents attached to a new product and/or technology. And, while some forms of proprietary rights require the sharing of knowledge in recognition of the public nature of knowledge (e.g., the patent process), the incentives to divulge the information *quickly* are not present and the bureaucracy of the system further slows the process.

The distinction is so crucial that some would argue that the two types of property rights, and the implications they hold for disclosure, differentiate science from technology. "If one joins the science club, one's discoveries and inventions must be completely disclosed, whereas in the technology club such findings must not be fully revealed to the rest of the membership" (Dasgupta and David, 1987, p. 528). To quote John Ziman: "The alchemist kept the secret of transmutation, to make a private hoard of gold; the scientist, in a sense, publishes the secret in return for a million pennies of recognition from those who use his technique" (Ziman, 1968, p. 95).[10]

The distinction, however, should not be overdrawn. Scientists in business and industry publish and sometimes in exceedingly prestigious journals (Hicks, 1994). There are a variety of reasons why firms interested in establishing proprietary rights engage in disclosure. Nelson (1989), for example, notes that the reputation of the lab affects the ability of the company to hire new scientists and engineers. Stephan (1994) examines the role that publications play in signaling capital markets. Hicks explores a number of other factors leading companies to decide to opt for disclosure through publication. She also points out that the crucial element in this process is the company's ability to *screen* the material that is published, thereby insuring that its proprietary interests are maintained.[11] It is also important to realize that while the generic knowledge associated with technology is a public good (Nelson, 1992), techniques can often only be transferred at considerable cost (Pavitt, 1987; Rosenberg, 1976, 1982). This private aspect of technology is a major reason why property rights are not a necessary condition for successful research and development (Nelson, 1992).

IV. The move by university-based scientists to privatize knowledge

Due to a confluence of factors, some university-based scientists involved in basic research now have the opportunity, disposition, and incentive to become involved in product development and entrepreneurial activity. One factor is a technologically-based "time collapse" which has markedly shortened the period between discovery and application in some fields of science. Another factor is the willingness of venture capitalists and the public to support small high-tech companies long before the companies can bring products to market (Florida and Kenney, 1988; Stephan, 1994). Key decisions made by U.S. federal granting agencies and the courts, as well as the emergence of an entrepreneurial spirit, have also fostered increased interest among academic scientists in establishing proprietary rights over their discoveries.

Traditionally in science there has been a substantial delay between basic research and its market fruits. In many areas of science the delay has been of such magnitude that several generations of scientists are born, work, and die before the transition is made. Examples in physics abound, particularly in nuclear and particle physics.[12] Even in the life sciences the delay in the past has been substantial. It took thirty-two years, for example, to move from basic research to a marketable product for the first pacemaker.[13]

A common theme in science today is that in certain fields a "time collapse" is occurring, dramatically shortening the lag between basic discovery and application (Panem, 1984).[14] Nowhere is this more obvious than in the field of genetics, where the "fundamental experiments with recombinant-DNA techniques were performed between 1971 and 1973; the first insulin gene was cloned in 1977; and the first genetically engineered insulin was approved for sale by the Food and Drug Administration (FDA) in late 1982" (Panem, 1984). This example is ten years old. More recently, Epogen, a drug designed to treat anemia, was introduced into the market within months of isolating the gene that triggers a human protein crucial to the production of red blood cells (Waldholz and Stout, 1992). Other biogenetically engineered products on the market as of this writing include drugs to treat dwarfism in children, multiple sclerosis, and heart attacks as well as a vaccine for hepatitis B. Many other products are in the process of clinical tests, including drugs to kill cancer cells without destroying normal cells and to prevent blood clots that can cause strokes and heart attacks (Burrill and Lee, 1993; Stipp and Gupta, 1992).[15]

While this time collapse is most pronounced in the life sciences, it has also occurred in the field of solid state-condensed matter physics. Transistors, invented in 1947, were used in pocket radios and hearing aids in the early 1950s. By the 1960s, semiconductor diodes and transistors had replaced vacuum tubes in most electronic equipment.[16] Lasers, conceived in 1958, were used in laboratory equipment in the 1960s and by the late 1970s were used in a wide number of commercial applications. In both instances the breakthroughs occurred before applications had been conceived. Indeed, the laser was referred to as "a solution looking for a problem".[17] There are already many ideas concerning the use of superconductors. Consequently, much of the rush in this area of solid state is due to the backlog of products that can be made if a suitable superconductor can be produced. The field of neuroscience is also poised for a time collapse and is being propelled forward in part by the great financial gain that awaits the parties that find treatments for disorders such as Alzheimer's, Parkinson's Disease, and drug dependency.

The time collapse occurring in these fields is not only technological. A financial time collapse is also occurring in some fields, as investors willingly advance capital to basic researchers long before a product can possibly reach the market. There are two dimensions to this collapse. First, as Florida and Kenney (1988) document, venture capitalists play a significant role in financing innovations in the high technology areas of semiconductors, personal computers, biotechnology, CAD-CAM, software, and artificial intelligence. But it is not only the venture capitalists who have brought money to the table long before a product is available to the public. The strong market for initial public offerings in small high-tech companies in the late 1980s and early 1990s shows that the public is also willing to advance large sums of money to companies (and their consulting scientists) long before a product is fully developed. According to Ernst and Young (Burrill and Lee, 1992), 46 initial public offerings in biotechnology companies were filed in the twelve-month period from July of 1991 to July of 1992, raising $1.4 billion. It is not uncommon for these prospectuses to include a statement such as "The company expects to incur substantial and increasing operating losses for at least the next several years", or "The company believes that an application to a regulatory agency is more than a year away".

The United States government has also played a key role in fostering an interest in proprietary rights within the scientific community. There are several dimensions to this. First, a 1980 ruling by the Supreme Court brought not only microorganisms but also most, if not all, plant varieties within the scope of patent protection, thereby extending proprietary protection.[18] The Supreme Court ruling dramatically changed the law since patents traditionally were awarded to an invention or discovery only if it came from a "unique process, if it did not exist on its own in nature, and if it had an identifiable use" (Waldholz and Stout, 1992). Second, in the same year Congress passed the Patent and Trademark Amendment Act which enabled universities, non-profit institutions and small firms to own patents resulting from sponsored research (Weiner, 1986). Government funding agencies not only permit investigators to hold patents. In some instances they virtually require investigators to apply for patents. For example, part of the application process to the National Institutes of Health's Drug Discovery Program requires that "applicants provide plans to ensure such (patent) protection." (National Institutes of Health, 1994, p. 6).[19]

The government has also contributed, perhaps unknowingly, to an increased entrepreneurial attitude and aptitude among scientists. University-based scientists in the United States typically must support their research through grants. The amount of money required is substantial as scientists must fund not only graduate students and post docs, but also their laboratory equipment. In the late 1950s and early 1960s such grants were reasonably easy to obtain. In recent years, however, funding has become substantially more difficult to obtain as funding sources have grown at slower rates while the number of applicants and costs of research have increased dramatically. Where one in two proposals was funded in 1965 by the National Institutes of Health, today one in five is funded (Marshall, 1994).

As competition for grants has increased, U.S. scientists have had to become increasingly entrepreneurial. They have had to hone their writing skills, crafting proposals that often resemble business plans. They have become accustomed to diverting long hours away from their labs in an effort to seek (and renew) funding. And, they have had to seek alternative sources to government support.[20] The grantsmanship process has also meant that scientists have been forced to develop knowledge about budgets and the management of money. It is, therefore, not surprising that today's scientists are remarkably more receptive to the idea of product development than were scientists of an earlier era. The grantsmanship process has led them to think and function like entrepreneurs.[21]

V. The life sciences: A case study of privatization

Until the 1970s, research in biology proceeded in much the same way as it did in physics, earth sciences, or chemistry. Most basic research was done at universities and supported by the government. The primary rewards to basic research were puzzle, reputation, and the money that accompanied reputation. Professional "stature was achieved by thorough, rapid, and open dissemination of new findings and ideas. The advent of genetic engineering (in the 1970s) with its extraordinary commercial opportunities for biologists, along with increasing competition for federal research support, significantly changed the research environment" (Panem, 1984, p. 3). Scientists (and the universities where they worked) began to realize that they could capture financial rewards not only indirectly through reputation but also directly through the product market. They could design new drugs or create genetic treatments and could reap the financial rewards that came from their sales, or, to quote one molecular biologist, "do good science and make money" (Etzkowitz, 1983, p. 219). They would no longer have to wait for the rewards offered by deans; they could short-circuit the reward process. And universities, under financial siege, could look to patent royalties for revenues, hoping to offset some of the shortfalls that they had experienced in the 1980s and early 1990s. They could also seek alliances with industry.

A variety of ways have evolved for university-based scientists and their employing institutions to directly capture the monetary rewards of research in molecular biology (Etzkowitz and Peters, 1991; Feller, 1990). In many instances, scientists share patent royalties with their employing institutions. Stanford, a leader in licensing agreements, received in excess of $25.6 million from such arrangements as early as 1990 (Dickinson, 1991). While the percent of royalties received by the scientist-inventor in such arrangements varies across universities, it is generally substantial, averaging, according to one survey, 32 percent (Glazer, 1992).[22]

In other instances, universities sign contracts with firms to conduct research, accepting money in exchange for certain rights and privileges. Monsanto was early to develop this approach, giving Harvard $25 million in research funds. In the 1980s it created a similar arrangement with the medical school of Washington University in St. Louis. The terms of the Washington University agreement allow the university to retain patent rights "arising from any discovery made in the course of the research while the company will have first choice and the right to license these patents on an exclusive basis" (Etzkowitz, 1983, p. 219). Other companies followed suit. A study by Blumenthal *et al.* (1986b) indicates that industrial firms supported 16 to 24 percent of biotechnology research in institutions of higher education in the mid-1980s.[23]

A more direct way for life scientists to engage in technology transfer is to start their own companies. Several notable examples come to mind, beginning with the founding of Genentech in 1976 and Biogen soon thereafter. In both instances, the companies were started by university researchers, including Phillip Sharp, currently the head of the biology department at Massachusetts Institute of Technology (Eisner, 1992). More recently, Eric Shooter, a Stanford neurobiologist, co-founded Regeneron, a company that raised in excess of $90 million when it went public in 1991. Paul Ts'o and Paul Miller, both of the Johns Hopkins School of Public Health, co-founded Genta, which also had a successful initial public offering in 1991; and Robert Bell of Duke University co-founded Sphinx. And these are but a few examples. In a study in process of initial public offerings (IPOs) in biotechnology, Stephan (1994) finds that approximately 43 percent of biotech-pharmaceutical firms that went public in the early 1990s had at least one founder who was university-based. Stephan and Everhart (1995) document that several of these founders realized substantial economic profit by exercising options and then selling a portion of their holdings. Scientists who are founders often do more than hold equity in, or receive consulting fees from, these firms. The firms may also sign exclusive licensing agreements with them, as in the case of the Genta agreement with Miller and Ts'o. In some instances scientists may even quit their university jobs to work full-time with the firm, as did Harvard's Walter Gilbert.[24]

It is not necessary for life scientists to start companies in order to garner financial rewards from the biotech industry. Many non-founders serve on the scientific advisory boards of these newly formed companies or have licensing agreements with the companies. Fifty-four of the fifty-six biotech firms that Audretsch and Stephan (forthcoming) study have scientific advisory boards (SABs) drawn heavily from the ranks of university faculty.[25] Stephan and Everhart (1995) find that 67% of the SABs compensate their members by providing stock options. Involvement of molecular biologists with biotech companies has become so commonplace that James Watson reportedly said that if the National Institutes of Health (NIH) made biotech stocks an issue, NIH would have a hard time finding a scientist to replace him as director of the Human Genome Project: "I don't know anyone who doesn't have stocks".[26]

These kinds of arrangements have succeeded in making some scientists millionaires and others millionaires on paper. Boyer, for example, became a multimillionaire after Genentech went public and he sold some stock (Etzkowitz, 1983). One scientific founder in the Stephan and Everhart study (1995) made $11,760,000 by exercising an option to buy 352,000 shares of stock on one day at a price of $11.00 and selling 199,334 shares the same day at $70 per share. Eighteen months after Immune Response went public, Jonas Salk's shares of record were worth $6.9 million. Within six months of the public offering of Immulogic, Malcolm Gefter's shares of record were worth $10.6 million.[27] Other examples could readily be given. Among the 445 university-based scientists that Audretsch and Stephan study, 39 held sufficiently large blocks of stock at the time of the public offering to require disclosure in the prospectus.

VI. Does privatization harm basic science?

The question arises as to whether "privatization" harms science. When reputation is the means for capturing rewards, scientists are quick to share information, since only by sharing does the work, in Merton's terms, become theirs. When entrepreneurial activity is the means for capturing the rewards of science, the incentives towards secrecy exist, at least until the product is marketed or a patent firmly established. Here we argue that there is some indication that secrecy and a decreased willingness to share information have become issues in the biological sciences.

In Panem's interviews concerning interferon, she found that scientists agreed that there was more collegiality and a greater flow of information in the early 1960s than in the early 1980s when she conducted her study. Part of this decrease in information-sharing stems from the fact that the field had become more crowded, and hence competition for positions and funding had increased. But part of it clearly stems from fear that openness leads to a loss of financial remuneration. Weiner (1986, p. 33) claims that "the exchange of scientific information has been restricted as universities and scientists have attempted to protect patentable research results".

One area that has been affected is the willingness to publish, or at least to publish quickly, since publication jeopardizes proprietary rights. This is clearly true for trade secrets, but it is also an issue for patents. In a letter to *Science*, a patent attorney stated (Johns, 1991): "The sad truth is that once publication has occurred without a patent filing date, U.S. and foreign patents are jeopardized and may be forever lost".[28] There is, of course, an irony here, since the patent process encourages disclosure and dissemination of information once a patent is sought. But, "patent first, publish later" is definitely a theme in science (Nelkin, 1984, p. 16).[29]

A survey by Blumenthal and his colleagues (1986a) found that faculty with industrial support were four times as likely as their colleagues to state that trade secrets resulted from their research and five times as likely to state that they had restrictive publication arrangements with a sponsor. Mackenzie *et al.* (1990, p. 77) suggest that, because of a particular decision regarding Hybritech, scientists "... who want to protect their conceptions from being appropriated as proprietary information may have to withhold their ideas from the public domain until they are fully formed and can be thoroughly articulated as, for example, 'obvious' rather than 'obvious to try'".

It is not always the scientists who make the decision to withhold information or to slow down the release of information when patents or trade secrets are involved. It can be their institutional partners, whether they be the university or industry. For example, the biologist Lap-Chee Tsui of Toronto, in an effort to isolate the gene involved in cystic fibrosis, shared probes with a company named Collaborative. Much to Tsui's chagrin, he found that at publication time Collaborative opted to limit the amount of information made available (Roberts, 1988). This is also an issue within the university community. According to university technology transfer officers, a concern expressed by many university scientists is that the university will ask them to withhold publication while a decision is made concerning whether to seek a patent (Dickinson, 1991).

The possibility of profit does more than slow the speed of publication. It also discourages scientists from sharing information (such as the name of a compound) with colleagues. Articles and editorials in the trade press speak of "creeping concealment" of research results at biotechnology conferences and report "tensions" and "reluctance to share data", and "an obsession with secrecy among graduate students who work in their professors' university and industrial laboratories" (Weiner, 1986, p. 42).[30] A principal investigator told us of a conversation he had with an undergraduate working in his lab on an NIH-sponsored drug discovery project. When he told her that for patent purposes she should not identify the compound, she reportedly responded, "Oh, I know that. In the lab I worked in last summer we didn't talk about anything!"

When the possibility of phenomenal commercial gain exists, the temptation may also exist to withhold information by dispensing misinformation. Robert Hazen (1988, pp. 58–59), notes a possible example in his chronicle of the race for discovering a high-temperature superconductor. He reports that Paul Chu's manuscript to *Physical Review Letters* contained two sets of errors. In every place the symbol Y, for the element yttrium, should have appeared, the symbol Yb, for the element ytterbium, appeared instead. The error was repeated two dozen times. Furthermore, the numerical coefficients in the chemical formula were given incorrectly. While it is entirely possible that these were accidents, given the stakes it is not implausible that they were intentional.[31]

VII. Discussion and conclusion

Several factors are leading scientists and the universities where they work to become increasingly involved in technology transfer. Among these are a "time collapse" that is shortening the period between discovery and practical application in certain fields, the availability of capital to finance technology transfer, a change in U.S. laws to encourage technology transfer and the development of an entrepreneurial spirit on the part of university scientists and their universities. The confluence of these events has done much to stimulate the growth of new products and, in the process, enrich some scientists.

Basic science is also affected by this process of privatization. Some of these effects are negative. According to Derek Bok, former President of Harvard, "the new-found concern with technology transfer is disturbing not only because it could alter the practice of science in the university but also because it threatens the central values and ideals of academic research" (Weiner, 1986, p. 41). Nelson (1989, p. 240) continues the theme: "To try to make universities more like industrial labs will tend to take attention away from their most important functions, which are to be a major source of new public technological knowledge and societies' most effective vehicle for making technological knowledge public".[32] As scientists become entrepreneurs, they cease to disclose information, thereby affecting the growth of public knowledge. They also bypass the well-developed review system that exists in science and the benefits of quality and consensus associated with it.

Despite these concerns, basic science can benefit in some instances from the movement towards privatization. The proverbial pie is growing in the life sciences, for example, precisely because of privatization. While in one sense this intensifies the stakes, in another it makes research less competitive. Funding sources from the profit sector do not exist only for a limited few. Furthermore, as some scientists shift to industrial funding and entrepreneurial activity the competition for public funds could decline for those left in pure science. Privatization may also allow scientists more flexibility in advancing their own research agendas. Philip Sharp implies that he and his colleagues might not have gone commercial with Genentech if they had gotten grants from NIH for research to put the gene for somatostantin into a bacterial plasmid (Eisner, 1992).

Perhaps when all is said and done the question to be raised is not whether privatization is harmful to science but whether the lure of privatization has become so strong in fields such as biotechnology that young scientists are abandoning basic science for entrepreneurial activities in unprecedented numbers. It is one thing for mature scientists to engage in entrepreneurial activity. Life-cycle models of scientists assume that some type of entrepreneurial activity is part of the reward structure that encourages scientists to make contributions to basic research (Levy, 1988) and a case could be made that this is necessary in order to attract talented persons into science (Dasgupta and David, 1987). It is entirely another issue, however, when young scientists, as well as mature scientists, engage in rent-seeking activity by privatizing the knowledge they produce. The confluence of factors discussed here that is occurring in several fields of science may be doing precisely this and a whole generation of scientists may come of age thinking that secrecy is the norm in science, privatization the objective. If this occurs, we must be concerned over *who* remains to produce and communicate the basic science that will provide the foundation for growth in the twenty-first century.

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Notes

[1] Scientists do not want recognition of the Johnny Carson or *Newsweek* variety. What scientists want is recognition from their peers in the form of citations to their work, invitations to speak at important gatherings, appointments to prestigious departments, and awards.

[2] Stephen Jay Gould, for example, in an interview with Wolpert and Richards (1988, p. 146) said that scientists want "status, wealth and power, like everyone else".

[3] Strictly speaking, the marginal cost to use is greater than zero. Those learning the knowledge must use their time and buy access through subscriptions to journals or registration at meetings.

[4] In the words of Kenneth Arrow (1987, p. 687), "The incentive compatibility literature needs to learn the lesson of the priority system; rewards to overcome shirking and free rider problems need not be monetary in nature; society is more ingenious than the market".

[5] This observation is not unique to us, although others generally do not put it in this public-good context. It is, perhaps, most eloquently stated by Merton (1988, p. 606) when he speaks of reputation, saying that in science "private property is established by having its substance freely given to others who might want to make use of it". He continues (p. 620) by saying that "only when scientists have published their work and made it generally accessible, preferably in the public print of articles, monographs, and books that enter the archives, does it become legitimately established as more or less securely theirs". In the words of Dasgupta and David (1987, p. 531): "Priority creates a privately-owned asset – a form of intellectual property – from the very act of relinquishing exclusive possession of the new knowledge".

[6] Merton (1961) details numerous examples of multiples occurring over the past 300 years.

[7] It does not follow from this statement that prior scientific knowledge is a necessary condition for innovation. As Rosenberg (1994) so aptly demonstrates, innovation has a variety of roots, only one of which is science. Moreover, causality often flows from technology to science.

[8] Nelson (1992) distinguishes three broad classes of means through which firms are able to appropriate returns to innovation. They are: the patent system, secrecy, and advantages associated with a head start.

[9] This does not mean that proprietary rights are a necessary condition for capturing the returns to research and development. See discussion below.

[10] Similarities exist between science and technology races. Both are winner-take-all races characterized by uncertainty regarding feasibility, the possibility of a protracted period of research, and the possibility that a rival may innovate first. (See Dasgupta and Stiglitz (1980); Dasgupta (1988); Loury (1979); Reinganum (1982); and Tirole (1989).) Patent race models (depending upon whether patents provide perfect protection (Reinganum, 1982)) also predict excessive R&D, or "overproduction", just as we have suggested may be the case in some science races. Differences, however, also exist in the races. For example, in science there is no reward for reverse engineering and consequently no incentive to play a waiting game. (For a discussion of waiting games in research and development, see Dasgupta (1988).)

[11] It is also important to realize that publication is not synonymous with replicability. Eisenberg (1987) examines a controversy that occurred at the *Journal of Biological Chemistry (JBC)* concerning whether publication of research findings was appropriate in cases where authors would not promise to make strains available upon request. While this is a fairly new issue, arising out of advances in biotechnology, she concludes that the records of the *JBC* controversy suggest that the financial incentives of privatization simply act to "reinforce conflicting incentives within the reward structure of science itself. Even among purely academic scientists, the norms may never have had the force that the community would like them to have" (p. 204).

[12] The delay has meant that it is "old" science that has had a technological impact, not "frontier" science (Rosenberg, 1994, p. 142). Rosenberg notes that a contributing factor to the length of the lag is the absence of essential complementary technology.

[13] Adams (1990) estimates the lag between the accumulation of theory and increases in manufacturing productivity in the U.S. for the recent past. For what Adams calls "own knowledge", the estimated lag was roughly twenty years between the appearance of research in the academic community and its effect on productivity; for what he terms "spillover knowledge", the lag was even longer, on the order of thirty years. On the other hand, for more applied research, such as in engineering and computer science, the gestation period was shorter, on the magnitude of ten years.

[14] The time collapse occurring in biotechnology is also discussed in Pisano *et al.* (1988).

[15] Biotechnology has also been plagued by a number of failures in recent years. The most recent is the disclosure by Telios, October 6, 1994, that their product Argidene Gel showed nearly equal healing in patient and control groups (Shrine, 1994).

[16] The integrated circuit was invented in 1960. Solid state-condensed matter physics provides an excellent example of an instance where generic knowledge of a basic nature was produced in an industrial lab and then *shared* with the scientific community. In June of 1952 Shockley conducted a six-day course at Bell Labs for professors to encourage the establishment of courses in transistor physics (Rosenberg, 1982, p. 155).

[17] C. T. Tang of Cornell University recalls "reading in a widely circulated trade journal, a well-reasoned and beautifully written article which argued eloquently and convincingly that lasers were merely an interesting scientific gadget and would have no technological impact" (National Science Board, 1985, p. 163).

[18] In a five-to-four ruling, the Supreme Court held that a "live human-made" microorganism with "markedly different characteristics from any found in nature and one having the potential for significant utility" is a "manufacture" or "composition of matter". Thus, it "plainly qualifies as patentable subject matter". For a discussion, see Weiner (1986, p. 41).

[19] The National Institutes of Health (NIH) provide the option of placing discoveries in the public domain. If this option is chosen, a letter to that effect must be filed with the application and signed by the principal investigator, porject leaders and representatives of the institutions involved. The principal investigator interviewed for this study stated that the perception among his peers was that NIH *required* patent application.

[20] Milbank (1991) chronicles several scientists' quest for funding.

[21] As more and more scientists become involved in product development the mores of the university are also beginning to change. Audretsch and Stephan (1994) find that 43 life scientists at Harvard University have contact with 21 distinct biotech companies that went public in the early 1990s. Such a heavy concentration suggests that, among university faculty, *not* being involved in product development will come to be considered deviant in the not too distant future.

[22] Exceptions do exist. Sloan-Kettering has reportedly received $50 million from the royalties to "Neupogen"; the five scientists involved have received approximately $500,000 apiece (Glazer, 1992).

[23] Etzkowitz and Peters (1991) indicate that, given the choice, universities today prefer formal licencing agreements to gifts since it is expected that the university will have the ability to negotiate a more ample payment for the transfer of knowledge produced in its labs than firms would voluntarily offer in the form of a gift.

[24] Walter Gilbert, a Nobel laureate, was a professor at Harvard and founding member of Biogen, the Swiss-based bioengineering firm (Panem, 1984, p. 81).

[25] The average SAB has 8.25 university-based scientists.

[26] When NIH and James Watson sparred over the patenting of expressed sequence tags in the Human Genome Project, it was Watson's stock portfolio that NIH chose to make an issue of, claiming that there was a conflict of interest (Roberts, 1992).

[27] These figures are calculated by taking the holdings for these scientists reported at the time the stock went public. It is important to realize that Rule 144 requires that insiders at the time of offer cannot sell their holdings for a specified period of time.

[28] In the United States an inventor has one year to file for a patent after publication. In most other western countries, publication involves giving up the right to patent.

[29] Eisenberg (1987) also discusses the delays in publication that the patent system fosters.

[30] For more discussion concerning concealment, see the work by Mackenzie *et al.* (1988).

[31] The commercialization of faculty research can also bias the *type* of knowledge generated by the scientific community

as scientists pursue research agendas leading to quick payoffs, ignoring other areas which have the possibility of opening up new frontiers but require longer horizons. The resulting loss of knowledge may be significant (Feller, 1990).

[32] Rosenberg (1994, p. 150) expresses similar sentiments when he discusses the possibility that "the potentially great commercial value of scientific findings will lead to a loss of free and frank communication among university faculty members, and a reluctance to disclose research findings from which other faculty members or students might derive great benefit. Such developments could prove to be harmful to future progress in the realms of both science and technology, as well as to education itself".

References

Acs, Zoltan J., David B. Audretsch and Maryann P. Feldman, 1992, 'Real Effects of Academic Research, Comment', *American Economic Review* **82**(1), 363–367.

Acs, Zoltan J., David B. Audretsch and Maryann P. Feldman, 1994, 'R&D Spillovers and Recipient Firm Size', *Review of Economics and Statistics* **76**(2), 336–340.

Adams, James, 1990, 'Fundamental Stocks of Knowledge and Productivity Growth', *Journal of Political Economy* **98**(4), 673–702.

Arrow, Kenneth J., 1962, 'Economic Welfare and the Allocation of Resources for Invention', in R. R. Nelson (ed.), *The Rate and Direction of Inventive Activity: Economic and Social Factors*, Princeton: Princeton University Press, pp. 609–626.

Arrow, Kenneth J., 1987, 'Reflections on the Essays', in George R. Feiwel (ed.), *Arrow and the Ascent of Modern Economic Theory*, New York: New York University Press, pp. 685–689.

Audretsch, David B. and Paula E. Stephan, 1996, 'Company-scientist Locational Links: The Case of Biotechnology', *American Economic Review* **86**(4).

Blumenthal, David, Michael Gluck, Karen S. Louis, M.A. Stoto and David Wise, 1986a, 'University-Industry Research Relationships in Biotechnology: Implications for the University', *Science* **232**(4756), 1361–1366.

Blumenthal, David, Michael Gluck, Karen S. Louis and David Wise, 1986b, 'Industrial Support of University Research in Biotechnology', *Science* **231**(4735), 242–246.

Burrill, Steven G. and Kenneth B. Lee, Jr., 1992, *Biotech 93: Accelerating Commercialization*, San Francisco: Ernst and Young.

Burrill, Steven G. and Kenneth B. Lee, Jr., 1993 *Biotech 94: Long-Term Value, Short Term Hurdles*, San Francisco: Ernst and Young.

Cole, Jonathan R. and Stephen Cole, 1973, *Social Stratification in Science*, Chicago: University of Chicago Press.

Dasgupta, Partha, 1988, 'Patents, Priority and Imitation or, the Economics of Races and Waiting Games', *The Economic Journal* **98**(389), 66–80.

Dasgupta, Partha and Paul A. David, 1987, 'Information Disclosure and the Economics of Science and Technology', in George R. Feiwel (ed.), *Arrow and the Ascent of Modern Economic Theory*, New York: New York University Press, pp. 519–542.

Dasgupta, Partha and Eric Maskin, 1987, 'The Simple Economics of Research Portfolios', *The Economic Journal* **97**(387), 581–595.

Dasgupta, Partha and J. E. Stiglitz, 1980, 'Uncertainty, Industrial Structure and the Speed of R&D', *The Bell Journal of Economics* **11**(1), 1–28.

Diamond, Arthur, 1984, 'An Economic Model of the Life-Cycle Research Productivity of Scientists', *Scientometrics* **6**(3), 189–96.

Diamond, Arthur, 1986, 'What is a Citation Worth?' *Journal of Human Resources* **21**(2), 200–215.

Dickinson, Susan, November 25, 1991, 'Campus Science/Technology Officers Gain Stature', *The Scientist* **5**(23), 6–7.

Eisenberg, Rebecca S., 1987, 'Proprietary Rights and the Norms of Science in Biotechnology Research', *The Yale Law Journal* **97**(2), 177–231.

Eisner, Robin, January 6, 1992, 'Basic Biology Meets Biotechnology in a Bay State Forum', *The Scientist* **6**(1), 9, 25.

Etzkowitz, Henry, 1983, 'Entrepreneurial Scientists and Entrepreneurial Universities in American Academic Science', *Minerva* **21**(2), 198–233.

Etzkowitz, Henry and Lois Peters, 1991, 'Profiting from Knowledge: Organisational Innovations and the Evolution of Academic Norms', *Minerva* **29**(2), 133–166.

Feller, Irwin, 1990, 'Universities as Engines of R&D-based Economic Growth: They Think They Can', *Research Policy* **19**, 335–348.

Florida, Richard and Martin Kenney, 1988, 'Venture Capital-financed Innovation and Technological Change in the U.S.A', *Research Policy* **17**(3), 119–137.

Frank, Robert H. and Philip J. Cook, 1991, 'Winner-Take-All Markets', Unpublished Paper, Cornell University.

Gaston, Jerry, 1971, 'Secretiveness and Competition for Priority of Discovery in Physics', *Minerva* **9**(4), 472–492.

Glazer, Sarah, November 17, 1992, 'Dividing the Royalty Pie', *The Washington Post*, 9.

Hagstrom, Warren, 1965, *The Scientific Community*, New York: Basic Books.

Hamermesh, Daniel, George Johnson and Burton Weisbrod, 1982, 'Scholarship Citations, and Salaries: Economic Rewards in Economics', *Southern Economic Journal* **49**(2), 472–481.

Hazen, Robert, 1988, *The Breakthrough: The Race for the Superconductor*, New York: Ballentine.

Hicks, Diana, 1994, 'Publishing, Reputation Building and Corporate Management of the Public/Private Character of Knowledge', Unpublished Paper, Center for Research In Management, Haas School of Business Administration, University of California Berkeley, and Centre for Science, Technology, Energy and Environmental Policy, Science Policy Research Unit, University of Sussex.

Hull, David, 1988, *Science as a Process*, Chicago: University of Chicago Press.

Jaffe, Adam B, 1989, 'Real Effects of Academic Research', *American Economic Review* **79**(5), 957–970.

Jefferson, Thomas, 1967, in John P. Foley (ed.), *The Jefferson*

Cyclopedia, vol. 1, New York: Russell and Russell, p. 433.

Johns, David, 1991, 'Patenting DNA', *Science* **254**(5036), 1276.

Johnson, Harry G, 1972, 'Some Economic Aspects of Science', *Minerva* **10**(1), 10–18.

Kuhn, Thomas, 1970, *The Structure of Scientific Revolutions*, 2nd Ed., Chicago: University of Chicago Press.

Levin, Sharon and Paula Stephan, 1991, 'Research Productivity over the Life Cycle: Evidence for Academic Scientists', *American Economic Review* **81**(1), 114–132.

Levy, David, 1988, 'The Market for Fame and Fortune', *History of Political Economy* **20**(4), 615–625.

Loury, Glenn C, 1979, 'Market Structure and Innovation', *Quarterly Journal of Economics* **9**(3), 395–410.

Mackenzie, Michael, Alberto Cambrosio and Peter Keating, 1988, 'The Commercial Application of a Scientific Discovery: The Case of the Hybridoma Technique', *Research Policy* **17**(3), 155–170.

Mackenzie, Michael, Peter Keating and Alberto Cambrosio, 1990, 'Patents and Free Scientific Information in Biotechnology: Making Monoclonal Antibodies Proprietary' *Science, Technology & Human Values* **15**(1), 65–83.

Marshall, Eliot, 1994, 'NIH Tunes Up Peer Review', *Science* **263**(5151), 1212–1213.

Milbank, Dana, November 7, 1990, 'Scientists Have to Beat the Bushes for Money to Stay in Business', *The Wall Street Journal*, p. 1, col. 1.

Merton, Robert, 1957, 'Priorities in Scientific Discovery: A Chapter in the Sociology of Science', *American Sociological Review* **22**(6), 635–659.

Merton, Robert, 1961, 'Singletons and Multiples in Scientific Discovery', *Proceedings of the American Philosophical Society* **105**(5), 470–486.

Merton, Robert, 1969, 'Behavior Patterns of Scientists', *American Scientist*, **57**(1), 1–23.

Merton, Robert, 1988, 'The Matthew Effect in Science, II: Cumulative Advantage and the Symbolism of Intellectual Property', *Isis* **79**(299), 606–623.

National Institutes of Health, 1994, 'Request for Cooperative Agreement Applications: National Cooperative Drug Discovery Groups for the Treatment of Opportunistic Infections and Tuberculosis in AIDs, unpublished.

National Science Board, 1985, *Science Indicators – 1985 Report*, NSB 85-1, Washington, D.C.: Government Printing Office.

Nelkin, Dorothy, 1984, *Science as Intellectual Property*,New York: MacMillian.

Nelson, Richard R., 1989, 'What is Private and What is Public About Technology?' *Science, Technology and Human Values* **14**(3), 229–241.

Nelson, Richard, 1992, 'What is "Commercial" and What Is "Public"', in Nathan Rosenberg, Ralph Landau and David C. Mowery (eds.), *Technology and the Wealth of Nations*, Stanford, Ca: Stanford University Press, pp. 57–71.

Panem, Sandra, 1984, *The Interferon Crusade*, Washington, D.C.: The Brookings Institution.

Pavitt, K., 1987, 'On the Nature of Technology', Inaugural Lecture given at the University of Sussex, 23 June 1987.

Pisano, Gary P., Weijian Shan and David J. Teece, 1988, 'Joint Ventures and Collaboration in the Biotechnology Industry', in David C. Mowery (ed.), *International Collaborative Ventures in U.S. Manufacturing*. Cambridge, MA: Ballinger, pp. 183–222.

Reinganum, Jennifer, 1982, 'A Dynamic Game of R and D: Patent Protection and Competitive Behavior', *Econometrica* **50**(3), 671–688.

Roberts, Leslie, 1988, 'The Race for the Cystic Fibrosis Gene', *Science* **240**(4849), 141–144.

Roberts, Leslie, 1992, 'Why Watson Quit as Project Head', *Science* **256**, 301–302.

Rosenberg, Nathan, 1976, *Perspectives on Technology*, Cambridge: Cambridge University Press.

Rosenberg, Nathan, 1982, *Inside the Black Box: Technology and Economics*, Cambridge: Cambridge University Press.

Rosenberg, Nathan, 1994, *Exploring the Black Box: Technology, Economics and History*, Cambridge: Cambridge University Press.

Rosovsky, Henry, 1990, *The University: An Owner's Manual*, New York: W.W. Norton.

Shrine, Jim, October 10, 1994, 'Telios Offers to Buy Back Shares From Offering', *BioWorld Today*, 1.

Stephan, Paula, 1994, 'Does Scientific Reputation Affect the After-market Price of IPO's: The Case of Biotechnology', Unpublished Paper, Georgia State University, Atlanta, GA.

Stephan, Paula and Stephen Everhart, 1995, 'The Changing Rewards to Science: the Case in Biotechnology', Unpublished Paper, Georgia State University, Atlanta, GA.

Stephan, Paula and Sharon Levin, 1992, *Striking the Mother Lode in Science: The Importance of Age, Place, and Time*, New York: Oxford University Press.

Stipp, David and Udayan Gupta, February 24, 1992, 'For Biotech, Pure Genius Isn't Enough'. *Wall Street Journal*, B1, B7.

Tirole, Jean, 1989, *The Theory of Industrial Organization*, Cambridge/Massachusetts/London, England: MIT Press.

Tuckman, Howard, 1976, *Publication, Teaching and the Academic Reward Structure*, Lexington, Ma.: Lexington Books.

Tuckman, Howard and Jack Leahy, 1975, 'What Is an Article Worth?' *Journal of Political Economy* **83**(5), 951–967.

Waldholz, Michael and Hillary Stout, April 17, 1992, 'A New Debate Rages Over the Patenting of Gene Discoveries', *The Wall Street Journal*, 1, 6.

Weiner, Charles, February-March, 1986, 'Universities, Professors, and Patents: A Continuing Controversy', *Technology Review*, 33–43.

Wolpert, Lewis and Alison Richards, 1988, *A Passion for Science*, New York: Oxford University Press.

Ziman, John, 1968, *Public Knowledge*, Cambridge, England: Cambridge Press.

Zuckerman, Harriet A., 1977, *The Scientific Elite*, New York: Free Press.