Innovation and Intellectual Property: The Case of Genomic Patenting

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Abstract

In an effort to balance static and dynamic efficiency in the production and use of knowledge, societies institute intellectual property policies. In the United States, the patent system is a well-established mechanism to provide inventors with time-limited protection of new technologies in exchange for disclosure of information about their inventions. Emerging biotechnology, specifically the filing of patents on gene sequences, raises serious questions about whether the patent system is appropriately weighing societal costs and benefits in its grants of intellectual property protection. Gene sequences represent a hybrid case between discrete inventions and more general pieces of information that are useful for many, potentially very different, purposes. This information content in genes makes it possible for a patent on a gene to cover a wide range of possible technological applications and, as a result, be of unknown breadth when issued. This analysis explores the potential effect of these characteristics on future innovation in biotechnology. © 2003 by the Association for Public Policy Analysis and Management.

INTRODUCTION

In the absence of societal intervention, the economic incentives for the production, application, and diffusion of new knowledge and inventions are, at best, imperfect. The societal response to this problem is intellectual property (IP) policy or, more specifically, the patent. Patents provide an inventor with a limited-duration monopoly and a mechanism to legally challenge misappropriation in exchange for public disclosure of information about the invention. These measures seek to balance the interests of static and dynamic efficiency in the economy by both providing an incentive to innovate while still seeking to promote broad use of already invented technologies. Although patent givers seek to stimulate future innovation by providing the potential for profit, as grants of monopoly power, patents also have the potential to impede future innovation. By restricting areas of technology in private property rights, patents can generate disincentives to future inventors. Since patent owners can challenge future innovators via litigation,[1] technologies that are "close"

[1] It should be noted that it is the owner of a patent who decides when and how to challenge the innovative behavior of another firm or inventor via the filing of an infringement suit. As a result, future innovators face a significant amount of uncertainty regarding just what technologies and activities a patent owner believes are covered a patent. Because of the cost of litigation, the final outcome of the challenge may be less important than the resources the two innovating firms can dissipate contesting the infringement allegation.

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to an already issued patent may not be pursued because of the costs associated with such a challenge. These dual natures—that patents must balance issues of static and dynamic efficiency and can both stimulate and deter future innovation—highlight a tension in patent policy and imply that policymakers must be cognizant of its net effects if they are to approach efficient outcomes. Because of the nature of its products and the patent strategies adopted by some of its firms, the biotechnology sector—and the genomics sub-sector in particular—has stimulated considerable debate about the impact of intellectual property protection and whether the outcomes produced by current policies are societally efficient.

The vast body of data produced by the human genome project and our ever-expanding understanding of the ways such information can be utilized are producing growing interest in both the scientific and economic benefits that could be generated from exploitation and application of gene-based technologies. As in most industries, the biotechnology industry has sought IP protection to protect investments made in turning fundamental scientific understanding into technologies that can treat diseases, correct genetic defects, produce products, or play other roles both inside and outside the traditional realm of biology. To protect investments that may be based only on knowledge that a specific segment of the genome is involved in a known disease or disorder, individuals and firms have sought (and been granted) patents on gene sequences, segments of the biochemical blueprints found in all members of a species. Because of the large potential market in gene-based pharmaceuticals, a significant number of these patents claim genes from the human genome; however, genes and genomes from other organisms have been claimed as well.

Patents on gene sequences, unlike those in many other technological contexts, are unique in some respects that are problematic for the current patent system. Gene sequences are physical objects—chemical molecules whose characteristics are determined and are reproduced in laboratories—and, as such, can be patented in the same way as a novel pharmaceutical or any other new chemical substance. If the only utility of a gene sequence was as a single molecule used for one or two things, like a new drug or paint additive, there would be little difficulty. However, because these molecules also encode information—a portion of the programming that makes life possible—they have a range of potential uses that continues to expand as we learn more and more about biotechnology. This "hybrid" nature—that a gene sequence is both technology and information—can make it difficult to judge the scope of a sequence patent and, as a result, make its effect on innovation difficult to predict. Beyond this uncertainty in scope, gene patents have additional implicit uncertainties in their dynamic effects as well. Because these patents grant rights to portions of the information that forms the basis of all life, it is possible that no substitute goods or processes can exist for those granted monopoly protection. As a result, in contrast to markets where the information disclosed in the patent application stimulates improvement or the development of substitute goods, for gene patents subsequent innovative options may be constrained by biochemistry potentially making the monopolies more durable. To better understand these issues, this paper examines the social costs and benefits associated with patent grants and how the characteristics of gene sequences affect the economic and policy efficiency of granting them patent protection.

SOCIETAL COSTS AND BENEFITS OF PATENTS

To briefly summarize a vast literature on the economics of intellectual property, the societal costs and benefits of granting patent monopolies to new inventions can be broken down into a relatively small number of categories (Table 1)

Table 1. Societal costs and benefits of patent protection.

Benefits:	
	Provide incentive to future innovators
	Stimulate investment in the protected technology
	Rationalize development of broad technology fields
	Disseminate information about the technology
	Localize risk of certain innovations to particular firms
Costs:	
	Deadweight loss due to monopoly profits
	Negotiation over property rights involves transaction costs
	Assignment of property right can impede related or follow-on innovation

(Gallini and Scotchmer, 2001; Mazzoleni and Nelson, 1998). For individual inventions, it might be possible for rigorously society-efficient grants of patent rights could be made by determining the signs and magnitudes of the various costs and benefits. If the benefits exceeded the costs, the patent office would approve the application, but if the costs exceeded the benefits, it would deny it. Such a breakdown of individual costs and benefits, however, would require a world of perfect information and is obviously not practical in operational decisionmaking. Such a component approach is useful when examining particular technology areas, in this case genomics, whose characteristics influence the individual costs and benefits differently.

The most central social benefit associated with the grant of a patent is the incentive it provides to future innovators. This is the primary dynamic component of the patent's impact, and its value to society is related to the future innovation that providing patent protection stimulates.[2] The second societal benefit, and in some respects the most straightforward, is that protecting an invention from imitators stimulates investment in the technology and allows it to be made into a commercial product. This social benefit has both static and dynamic components: the commitment of capital to the invention enables immediate production, and it can result in improvement of the technology over time. A third area in which patents can benefit society is as a way to "rationalize" a new technology area and promote its "orderly development." By initially assigning rights to an early-stage invention, development of a new technology can proceed with less duplication of effort and potential waste of resources than when ownership is undefined (Mazzoleni and Nelson, 1998). It should be noted, however, that this effect could also generate a significant social cost by limiting the number of innovations that may occur in a new area.

In an attempt to promote static efficiency, a fourth social benefit of patenting is the disclosure of technical information that occurs when a patent is issued. By

[2] Although the potential for any invention to be patented provides a general incentive to innovate, particular patents on specific inventions provide innovators with more direct incentives. Because of the great variety of technology and inventive activity, granting a patent most likely encourages "technologically close" innovation. For example, while a patent on a semiconductor-manufacturing machine is unlikely to inspire future innovation in flour-milling apparatus, it will likely stimulate inventive work in the microchip and related industries. As a result, the societal value ascribed to a given patent could depend on the field of technology it occurs in and the potential for and value of future innovation in that industry. This is particularly relevant to gene sequence patenting.

spreading the knowledge contained in the patent application, there is a static gain because of the potential for that knowledge both to lead to broader use of the technology and to catalyze other innovations.[3] Certain classes of technology might also benefit from assigning ownership of technologies through patents because the issuance of a patent can tie a given technology to a specific entity and, as a result of that "localization," can facilitate regulation of the consequences of the innovation. This effect involves both the physical localization of the technology to a single firm and the fact that the profits the firm can gain through the patent will offset regulatory costs imposed on the new technology.[4]

Just as social benefits are associated with the granting of the patent, clear social costs are associated with it, as well. The most obvious and quantifiable cost is the monopoly profit, through increased prices supported by the monopoly, which the firm can extract from purchasers and users of the invention. In addition to monopoly rents, the process of negotiating intellectual property ownership among parties—whether it is "amicable" negotiation of a license, or litigation in court—will always involve significant transaction costs. While monopoly rents and IP transaction costs can be determined, at least theoretically, the other dynamic cost of granting a patent is more difficult to quantify. These costs consist of the lost opportunities for other innovations because a portion of technology "space" has been circumscribed by a private property right.[5] Determinations of the value of these potentially lost innovation opportunities must be speculative. One factor that influences their magnitude is the position of the patented technology in the "technology trajectory" of its industry. If patent claims circumscribe an early technology fundamental to many subsequent innovations, then the costs will be much higher than if the grant of a monopoly is on a specific product later in the evolution of the industry. This is the basis for arguments against the patenting of "research tools": doing so may restrict more innovation than it encourages.[6] As a result, these costs will also vary over time with the overall pace of innovation within an industry. It should be noted that, unlike

[3] In economic terms, this benefit is the value to society of having the particular technological information disseminated rather than kept secret. It should be noted that this value will (and should) differ among different technologies based on their assumed effects and will change over time based on the current "state of the art" in the relevant fields.

[4] For example, in the pharmaceutical industry, patent protection on new drugs works very well and allows an inventor firm to garner monopoly prices during its period of marketing exclusivity. This effective monopoly protection is likely one of the reasons society has been able to require such stringent and expensive pre-market screening of new pharmaceuticals. If there were no "guaranteed" mechanism for recouping the high costs of the regulatory burden, firms would be unlikely to assume the risks of developing and introducing new drugs.

[5] Recent situations that graphically demonstrate potential risks of patents include: British Telecom (BT) has claimed that its U.S. patent (granted in 1989) on "Hidden Page documents" applies to hyperlinks on the Internet and has sought fees from U.S. Internet service providers. Depending on the terms that BT demands, this could have a serious effect on the Internet (Rohde, 2000). In another example, the software developer DE Technologies has a pending patent (which the U.S. PTO has said it is likely to issue) on "a process for carrying out an international transaction... using computer to computer communication." Since the claim would cover all international e-commerce, the *Wall Street Journal* estimates its value in the billions of dollars (Bukeley, 2000).

[6] These potential effects are made even more serious by the time lags required to allow government examination of a patent. If an extended time passes after initial patent filing, innovation could continue in an industry incorporating a technology that is only subsequently "assigned" to an inventor through the granting of the patent. In these cases, the patent then surfaces and the ensuing infringement litigation can halt innovation or, at the minimum, dissipate resources that might have been applied to further inventive activities.

most of the benefits, all of the social costs associated with a patent are determined by the voluntary actions of the patent holder. Depending on how the owner sets the price for the technology and chooses a licensing or litigation strategy, the costs could increase or decrease considerably.[7]

For both the societal costs and benefits of patenting, it is critical to note that the implementation of the patent law at the operational level strongly affects the magnitude of the variables. When patents are granted, the specific claims and language incorporated in the document will determine the potential effect of the patent. Patents can differ widely in breadth—how specific the language is circumscribing the grant of monopoly rights—with broad patents granting ownership over much more intellectual property than narrow patents. In addition, the duration of the patent—how long it protects the ownership interest of the patent holder—also has the potential to increase or decrease the societal costs and benefits of patenting. A considerable amount of literature examines various combinations of these operational variables (for recent discussions see Gallini and Scotchmer, 2001, or Hopenhayn and Mitchell, 2001).

Clearly such a rigorous assessment of the costs and benefits of individual patents is not practical.[8] However, examining classes of technologies to identify characteristics that make their patentability positive or negative from a societal point of view can produce relevant insights.[9] Unlike many other treatments of the topic, a cost/benefit approach highlights issues left unexplored elsewhere in the public debate over gene patents and suggests considerations that could prove crucial in making more informed policy choices for this rapidly evolving technology area.

GENOME PATENTING AND INNOVATION

In every living thing, the basic information needed to produce the machinery and structure of life is encoded in long molecules of deoxyribonucleic acid (DNA). This information is contained in the sequence of bases (symbolized by the letters A, C, T, and G) that make up the core of the right-handed double helix of the DNA. In the human genome, all the information needed to make up an individual person is encoded in approximately 3 billion letters in this chemical alphabet. Instructions to make the actual building blocks of the body—from the tough molecules that reinforce skin or hair to the much more intricate and fragile molecular machines that perform chemical reactions inside the body—are written out in long strings of these letters, which are called genes. The building block molecules, assembled based on the information in the DNA, are called proteins. Differences in these proteins produce unique characteristics in individual persons; in addition, errors in the DNA cause the resulting proteins to malfunction from the genetic basis for certain diseases. The sequence of these letters within the genome—whether they refer to nor-

[7] Although space limitations do not allow significant discussion of the topic, patents are viewed in many (if not most) industries as a poor way of protecting technology and are used for other purposes, such as impeding entry of new firms. How firms use patents within an industry will significantly affect the overall social costs of their granting.

[8] Furthermore, such individualized assessments would also introduce significant uncertainties into the IP system that might undermine its ability to serve as an incentive to innovation.

[9] Others have pointed out (Gallini and Scotchmer, 2001) that the U.S. IP system already includes various "customized" types of protection applying to different types of IP. As a result, the concept of tuning the level or duration of protection for different classes of technology is not unprecedented.

mally functioning genes or defective genes associated with disease—is the particular IP at the center of gene patenting.[10,11]

The potential for products derived from genomic information—including tests for gene-based disease, gene therapies, use of sequence data to find new drug targets, use of the expressed proteins as drugs, use of the genes of other creatures or plants for human benefit, and many others—has attracted considerable commercial and investor attention. Since producing these products involves significant investment in research and development, it is understandable that firms have sought to protect those investments via the IP system. Use of IP protection—in both the biomedical and biotechnology industries—is not new; these firms have sought to protect parts of their research investment through patenting for as long as they have existed. Sequence patents, however, differ in important respects from "standard" patents and may have broader economic and innovative effect.[12]

Ownership of Technology or Ownership of Information?

The reason the monopoly rights granted on genes have the potential to be so broad hinges on the unique fact that, unlike a patent on a screwdriver or auto part, there is a significant amount of "information character" to a "genomic invention." Instead of merely being a patent on an invention, a gene patent is, practically speaking, also a claim on a piece of information that can be used to do many different things. This power comes from the fact that the same gene sequence (in addition to being in every member of the species from which it came) may have an infinite number of possible applications. The same gene

[10] It should be noted that this discussion ignores a significant amount of controversy about the patentability of various kinds of "genomic inventions." For example, there was discussion for some time about whether "raw" (unanalyzed) genomic sequence data vs. the sequences of individual genes vs. segments of DNA that were pieces of genes (so-called expressed sequence tags or ESTs) were or were not patentable. For the purposes of this discussion, these arguments—focused on how the wording of the current statutes applied or did not apply to sequence information—are irrelevant. Here the discussion regards the more basic question of how any patent on sequence data can influence innovation. As a result, although the unit of the gene has been selected for discussion, many of these arguments also apply to the other versions of the controversy.

[11] The concept of gene patenting has been controversial for reasons beyond arguments about innovation and monopoly rights. Other areas of public debate on this issue have included arguments about the ethics of assigning ownership to genetic information which is "in each one of us" and was "invented" by God or nature; and international equity concerns about scientists and firms in more advanced nations using the "genetic resources" of other nations. Nevertheless, the current discussion is restricted to the effects of gene patenting on innovation and technological development. This simplification allows more straightforward analysis of the potential effects of this unique area of patents on how the IP system accomplishes its primary function.

[12] For example, for most pharmaceutical firms, patents traditionally covered individual drugs. When these proprietary products are administered to a patient, they generally act by modifying the ways a specific protein functions in the body to correct a disease associated with that protein. The drugs were generally discovered by a laborious process involving a significant amount of luck as researchers sought cures to diseases usually without knowing the specific protein(s) in the body they needed to target.

Today, genomics has made it possible to reverse this process. For example, by sequencing the DNA in patients suffering from a disease, it is now easier to learn exactly what defective protein should be targeted to treat the disease state. Because these sequencing efforts also involve resource investments, this reversal has led firms to seek IP protection not on specific drugs, but on the gene sequences encoding proteins that represent future drug targets. This shift is relevant (and, to some, of concern) because gene sequences can be applied to considerably more uses than as putative targets for drug design. As a result, unlike the very narrow monopoly rights given to a pharmaceutical company over a particular drug, the rights granted over a gene could be quite broad.

could be relevant as a drug target, a pharmaceutical itself, part of a diagnostic test, a subject of bioengineering, a gene therapy target, and other applications. Knowledge of gene sequences and their functions can be as powerful and far-reaching as any basic piece of scientific knowledge that might serve as the basis for many later discoveries and innovations.[13] These other potential uses, none of which may be done at the time of the patent filing, often require a significant additional investment of resources in further fundamental research. Actually using the protein coded by the gene as a drug, for example, might require understanding how the protein is modified in the body after it is made, how it is transported through the blood, and whether a sample made outside the body can be effectively injected and still work as desired. Another firm or scientist may do this subsequent work that could involve investments far greater than those needed to sequence and identify the gene, yet the patent issued on the underlying gene would grant at least partial ownership to the sequencing firm. Many sequence patents will likely turn out to be worthless, the genes they cover not finding a profitable use. As a result, unlike more "standard" patents whose breadth can be estimated, it is difficult to predict the actual breadth of a patent issued on a given gene.

Although formally patenting an individual molecule of DNA containing the sequence of the relevant gene, the structure of genomic patent claims acknowledges both the "information character" and potential scope of monopolies on gene sequences. Even a superficial examination of some recently issued patents reveals ways their claims seek to ensure the broadest interpretation of their "inventions."[14] Frequently claims refer to nucleic acids or polynucleotides other than DNA—a broadening of language that will include other natural and synthetic polynucleotides that can carry the same information as the disclosed DNA.[15] Patents have also claimed undisclosed nucleic acids or proteins that are 85, 90, or 95 percent identical to the included sequences and fragments of the included sequences; both of these behaviors point out that it is the information in the DNA that is more important than the individual, physical piece of DNA claimed in the patent application.[16] Such claims are not necessarily different from standard patents, which gain protection under the "doctrine of equivalents" against other devices or processes that have only inconsequential changes from a patented version. They do, however, significantly increase the difficulty in inventing around a gene patent by further limiting the biochemical options that are available and

[13] There is significant argument in the literature about whether genomic information should be patentable at all. While far from a sufficient treatment of this subject, the central reason why is found in the fact that genomic "inventions" straddle many boundaries. They are expressions of information, but they are also tangible and usable for other purposes; the information contained in them is essentially a work of nature (and is valuable mainly because it is broadly found in nature) but, once purified and sequenced, the piece of DNA containing that information counts as "made by the hand of man" and is therefore entitled to patent protection (Dreyfuss, 1996, p. 507; Kinter and Lahr, 1982, pp. 18–22).

[14] In fairness, obtaining the broadest claims possible is the goal of any good patent advocate, no matter what the technology. Obtaining the broadest patent possible is obviously in the interest of the patent holder; the relevant question here is whether it is in the interest of society.

[15] See, for example, U.S. patents 6,140,117, 6,100,075, or 6,140,084.

[16] See, for example, U.S. patents 6,124,095 or 6,140,117. From the biological standpoint, these "similar but not identical" nucleic acids would be a way of using the "information" included in the original patent application without using the disclosed invention itself. By including (and granting) these types of claims, both the applicants and the patent office seem to acknowledge that these patents cover the information content of the invention as well.

could serve to broaden the patent to include unforeseen applications requiring slight changes to the natural form of the sequence or protein. It is relevant to point out that the ways gene patents are structured and written are not wholly consistent, and the differences are also important in illuminating the nature of these property rights.

One example is U.S. patent 6,093,809 (issued July 25, 2000) which covers telomerase, an enzyme linked to aging and cancer. In a graphic demonstration of the assumed scope of a monopoly on a DNA sequence, the patent has only a single claim—on the sequence itself. In the description of the invention, however, the patent assumes that the sequence claim implies a claim on many applications over a very broad range. Examples include all the potential uses of genes cited earlier in this paper, namely claims on: related sequences, development of drugs targeting the protein, use of the gene sequences in study, and all the pharmacological compositions that could be envisioned at the time of writing.[17] The patent even states that the eventual dosage (of these still nonexistent drugs) will be determined by "the individual physician in view of the patient to be treated." In case there is doubt about the scope of the claims, the patent notes, "the [included uses] are provided in order to demonstrate and further illustrate certain preferred embodiments of the present invention and are not to be construed as limiting the scope thereof." Furthermore, "various modifications and variations of the described method and system of the invention will be apparent to those skilled in the art without departing from the scope and spirit of the invention." The patent, in effect, claims all subsequent ideas that knowledgeable individuals may devise to otherwise use the sequence.

It is this ability of patents on genes to "reach beyond" the original utility included in their claims that gives them the potential to have such a significant influence on innovation. Rather than just controlling a specific invention, the control they seek over the gene's "information content" means that they produce a monopoly with considerably more leverage. This innovative leverage—whose effect could be positive or negative—is the most central characteristic of genome patents. As a result, in contrast to most discussions of gene patenting, the question is not whether these patents are valid under current law,[18] but how the leverage they imply for current and subsequent innovation makes their issuance positive or negative from the perspective of society.

Social Benefits of Gene Patenting

The potential social benefit associated with a patent should be a primary consideration in its issuance. It is pertinent to point out that this question of social benefit—relating only to patent issuance—is related to but quite different from the potential

[17] The description of the invention includes claims on: many other related sequences, many proteins, methods for study, changes to the claimed sequences for various intentional reasons, nucleotides that will hybridize to the sequence, virtually every naturally occurring mutation in the protein (whether the changes are tied to disease or are irrelevant), a number of laboratory uses for the gene, expression of the protein, purification methods for the protein, disease diagnosis, development of drugs targeting the protein, use of the protein therapeutically, therapeutic use of the polynucleotide sequence itself (in all conceivable forms), the use of those polynucleotides as probes for study, the use of the sequence to find other similar enzymes in other genomes, and a number of pharmacological compositions.

[18] Under current law, genes qualify for patent protection (Fraser, 2000; Regalado, 2000). As a result, arguments on that level are less productive than asking whether they should qualify.

social benefits associated with the technologies themselves. In this case, the social benefits of patent issuance hinge on whether the assignment of the property right will affect or facilitate the technology. To systematically examine these benefits, it is useful to examine gene patents with respect to the individual potential benefits discussed above (Table 1).

Stimulating Investment in the Technology. The central and most important argument proponents of gene patents make is that, without the protection of IP ownership of the discoveries of genomics, private firms will not step up to invest the resources necessary to convert these "inventions" into commercial innovations. This argument acknowledges that development of subsequent uses of the gene sequence may require substantial investment—to understand the proteins' functions and interactions, for example—and that firms will not make those investments without IP protection at the outset. The most dramatic example of these potential costs, the development of the gene sequence or a related product into a new drug, could involve hundreds of millions of dollars (Lisagor, 2000). The concern of these scientists and firms is that, without IP protection, a sort of reverse tragedy of the commons will occur vis-à-vis genomic innovations. If the data are in the public domain, then they will be underutilized to the detriment of all.[19]

The arguments described in the previous section focus on what could be labeled "the pharmaceutical model" of innovation. Because pharmaceuticals require such intensive research and testing before they enter the market, it is broadly accepted that they require (and receive) stringent patent protection to allow that investment to be recouped. Members of the industry (Haseltine, 2000; Henner, 2000; Scott, 2000) often single this out for particular attention. Firms that make truly gene-based drugs—drugs that consist of the "natural" protein prepared through use of an isolated gene—do require patent protection like any other pharmaceutical firm to protect their products and methods of production. As a result, it is clear that, for this category of products, there is a social benefit to IP protection that enables that particular type of investment and product development. What is not clear, however, is whether this requires protection of the entire gene or whether a more narrowly drawn protection—on the optimized, commercialized protein drug itself and its production method—would suffice from society's point of view. This situation would be roughly analogous to patenting in the pharmaceutical industry where patents cover medicines but not the proteins in the body those medicines interact with. The argument for gene IP protection based on the high investments required for pharmaceutical development is also undermined by the many other products that could be derived from genome information that require less investment for commercialization.

This ambivalent situation—that IP protection is needed, but that patents on the genes themselves may not be the right answer—is further emphasized by the fact that not even all pharmaceutical (or, more generally, biotechnology) firms agree on the necessity or appropriate scope of gene patents. The SNP Consortium, a group of 13 firms searching for single nucleotide polymorphisms (single base changes in the genome associated with diseases), is not only publishing its discoveries but is also filing official paperwork with the PTO

[19] It should also be pointed out some argue for making patents easier to get in biotechnology as a whole; the rationale for the argument is that this is a way of stimulating an important industry that does not require direct investment from the public (Boyd, 1997). Although such a strategy may not include direct expenditures of government funds, it is far from a costless strategy.

disclaiming rights to its "inventions" (Steinberg, 2000). The large pharmaceutical firm Merck has also argued against "locking up the basic structural and descriptive elements of the genome by narrowly held patent protections" (Caplan and Merz, 1996, p. 926).[20]

It should also be noted that the assertion that a patent must give rights to the original gene to make subsequent investment possible has embedded within it assumptions about where competition in product development should occur in the biotech-pharmaceutical industry. If the patents claim the gene, the "high stakes" competition occurs at the level of gene identification since that is the point at which initial property rights are assigned; this allocates benefits to firms that have positioned themselves at that point in the product development cycle. The firm that holds the gene patent—whether that firm is the initial sequencer of the gene or another firm that has licensed or purchased the rights—can then restrict competition during the process of subsequent investment to use the sequence information. If patents are drawn to the drugs and their production methods, more vigorous competition can occur in the process of understanding the biochemical and practical difficulties of putting the genetic information to use; forestalling assigning the property right preserves the incentive for many different firms or researchers in other organizations to compete with different strategies for using the gene. For example, under protection of a gene patent, a firm might chose to pursue only the protein encoded by that gene as a drug target and ignore its potential as a protein-based drug. While only pursuing one route would conserve resources and would help ensure a return on the firm's investment, there would be no incentive to ensure that individual genes were used via the best strategies. In this example, for instance, the gene might be more useful as a protein-based drug than as a target for a traditional pharmaceutical. With ownership given at the gene level, the strategies pursued to exploit each gene will likely be determined by the competency of the owner firms rather than by the relative promise of the different options. It is not clear what the net effect of these shifts within the industry will be and, most likely, it would vary from gene to gene. One might predict that giving a gene a single owner might increase the probability that investments will be made to commercialize it, but, by reducing technical competition during commercialization, might reduce pressure to put the gene to the best use (see Merges and Nelson, 1990).

Localizing Innovation to Facilitate Regulation. Similarly, the social benefit that may arise from localizing innovation, and thereby facilitating societal regulation of new genomic technologies, also differs from product to product. As in traditional pharmaceuticals, localizing development of a new genomic pharmaceutical to one firm does facilitate safety and efficacy regulation. As a result, for these products, strong patent protection produces an important benefit. It seems likely, however, that a strong patent on the drug itself (rather than on the gene) could have the same result.

For the many other applications of a single gene's information—in testing, gene therapy, etc.—localization seems unlikely, much less a measurable social

[20] Clearly these differences of opinion among firms reflect serious differences in "business models" and, more importantly, how central to those plans ownership of a gene is. Biotechnology firms that use genes to produce products—whose position is that genes must be patentable in the context of producing things—like Genentech are much more moderate than firms whose primary activity (and stock price support) is sequencing and patenting DNA. Compare, for example, the testimony of Genentech (a biotech firm) and Incyte Genomics (a more "pure" genomics firm) in the recent congressional hearing mentioned above.

benefit. Because of the many different capabilities needed to take advantage of all applications of a given gene, it is more likely that patent-holding firms will allocate different applications to other firms through licensing, rather than develop the entire spectrum of products themselves. This is particularly true for firms whose fundamental capability is genome sequencing rather than "final" product development. Furthermore, because of the diversity in the applications, whether there would even be benefits to localizing them in a single firm is questionable. Because different regulatory requirements apply to such disparate activities, it is difficult to see any potential efficiency gains by dividing markets along gene-based lines.

Rationalizing Development of the Technology Field. Because individual genes open up so many possible routes of subsequent innovation, one could argue that this field represents an opportunity for broad initial patents to rationalize the way firms pursue potential follow-on inventions and prevent duplication of effort (Mazzoleni and Nelson, 1998). The grant of a patent to the discoverer of the gene therefore allows that firm or organization to regulate which of the many potential uses are pursued. Because of the very large number of scientific and market uncertainties surrounding the use of any given gene, it is difficult to make broad generalizations about whether this control represents a societal benefit or will actually be a societal cost. For particular, high-profile genes whose associated products may have a very large market, having potential follow-on innovators negotiate licenses with a single firm may reduce duplicative and wasteful efforts overall. Having three major pharmaceutical firms pursuing the identical gene-based drug, for example, would likely waste millions of dollars. On the other hand, such rationalization could have a cost as well. In the case of genes where the market for a drug is less certain, adding the transaction costs needed to negotiate gene licenses might cause firms to choose not to pursue those potential targets. Furthermore, forcing such negotiation could result in a reduction of innovation since inventors with different approaches might be excluded from pursuing their ideas with the gene.

Disclosure of the Information Contained in the Patent Application. One of the central benefits for patent protection is that the public immediately gains access to information that was costly to produce, information that firms would otherwise keep as a proprietary trade secret. Although this is clearly relevant for many inventions, in the case of genetic information, this social benefit is of questionable importance. Because of the large public- and private-sector sequencing efforts that put their results in the public domain, it is clear that gene sequences can in no way be effectively held as proprietary secrets. Furthermore, it is also questionable whether the simple act of disclosing a sequence is of sufficient value to merit the societal reward of monopoly rights (Alberts, 2000). From a purely economic viewpoint, this social benefit represents the amount society is willing to pay for disclosure of the information in the patent application. Because of the uncertain value of sequence information and the more important fact that other parties are willing to provide that information essentially for free, it seems reasonable that this term is very small (if not negligible) for genomic patents.

Providing Incentives for Future Similar Inventors. The last element of the presumed social benefit from patent issuance is the incentive that the grant of monopoly provides to future innovators. When society issues a patent on a gene sequence, it is providing an incentive for future sequencers to produce genomic "inventions" so they too can obtain monopolies. It should be noted that this term is separate from the incentive to invest in developing commercial products from the gene. The

patents issued on those products—whether protein drugs, gene test kits, or pharmaceuticals targeting the gene product—will provide incentives for future innovators in those areas. For a number of reasons, it seems reasonable that this particular societal benefit should also be near zero with respect to gene patents. First, it has been argued that the "inventive" activity involved in DNA sequencing and computer-aided gene identification for patenting is essentially repetitive mechanical work, which should not be so richly rewarded. James Watson, one of the discoverers of the structure of DNA itself, has characterized the sequencing effort as "monkey work"—work so trivial that its results do not merit patent protection (*The Economist*, 2000). Although such an argument is not relevant vis-à-vis current patent law (which does not make distinctions based on "mode of invention"), it directly addresses the question of whether this behavior should be further reinforced through patents. Second, returning to an earlier argument, since research groups are willing to perform these tasks and disclose their results without the reward of patent rights, society should pay no premium to other firms or individuals to do so. Third, and most pragmatically, since the human genome is finite (and now complete) there is no reason to risk any social costs to give further incentive to sequencing efforts.[21]

Social Costs of Gene Patenting

Just as the patent office should consider the potential benefits of the patent grant as it deliberates on an application, it should consider the social costs as well. Again, it is important to emphasize that this discussion does not seek to address the potential social costs of genomic technologies themselves, only the decision to assign ownership to gene sequences through the grant of patents. Because of the structure of current patent requirements, these costs are not considered in the patent decisionmaking process beyond the requirements that an invention be novel, non-obvious, and useful. This coarse filter does prevent society from bearing significant costs for technologies where it would be obviously inefficient (see, for example, Eisenberg, 1997). However, by focusing on the relationship between the proposed technology and prior art, the examination process does not directly consider the potential social costs of the patent specifically. As a result, it does not take into account the characteristics of particular technologies or particular patents, which can significantly increase or decrease the size and nature of their associated social costs.

Monopoly Rents Charged by the Patent Holder. The most straightforward social cost associated with a patent grant is that the firm holding it will charge monopoly rents to allow others to use the technology. These monopoly rents are not necessarily negative from the perspective of society since this is the reward that "pays" for the societal benefits described in the previous section. The size of the monopoly

[21] It could be argued that since other genomes have not been sequenced, then providing incentives to sequence them is still valuable. This may be more difficult than it sounds, however. At the gene sequence level, the differences in the sequence of proteins are often very similar among a wide range of species. For a particular protein, the sequence from a human and a mouse may differ by only 5 to 10 percent. Such cross species comparison is one way predictions about functions of unknown genes are made. Depending on how the patent on the human gene has been worded (see below), it is possible they could already claim the sequence of the mouse protein as well. As a result, this large uncertainty may prevent continued gene patenting from providing a straightforward incentive to continue sequencing.

profits is relevant, however, since these costs should be commensurate with the social benefits they are "buying."

Concern that monopoly rents demanded by gene "owners" will be excessive is already considerable. Physicians and academic medical centers have asserted that high fees and strict licensing terms are already making it difficult to do diagnostic genetic tests for patented genes. For example, Miami Children's Hospital holds a patent on the genetic mutations that cause Canavan disease, a neurological disorder that affects the Ashkenazi Jewish community. The hospital demanded $12.50 per test performed as a royalty on the patent.[22] This is not payment for a kit to do the test, but simply to use the knowledge of the mutations when manually sequencing the DNA from an individual patient (Regalado, 2000).[23] While it is difficult to assess the reasonableness of such numbers in isolation, the fact that some diseases involve multiple genes can make even reasonable sounding per-gene rates matters of concern. If a disease involves 10 genes, for example, and each gene license costs $12.50, a test kit designed to evaluate a patient in all 10 would cost $125 even before any physical parts of the product are designed and manufactured. This could be a serious detriment to the spread of the technology (Technology Roundtable, 2000).

Likewise, firms that hold the patents on genes involved in breast cancer and Alzheimer's disease have reportedly exercised their patent-given right to be the sole performer of tests for those defects (Regalado, 2000). For the Alzheimer's disease gene, the commercial test is of significantly higher cost to patients than when academic genetics labs performed their own versions of the test (Harris, 2000). Filing the patent on the gene—the information that serves as the basis for the test—rather than a physical product like a test kit, has made it possible to have a durable monopoly in a service (Merz, 1999, 2002). This is very unusual since service industries generally have relatively weak appropriability of their processes and products, which allows rapid diffusion of new innovations. It is true that the complexities of genetics do generate the possibility that such monopolies will not occur across the entire field. Where multiple markers or genes exist (and the rights to these alternatives are held in different hands), then the market and the ability of consumers to choose among different providers will drive price down. However, even where diseases involve multiple genes, the potential for monopoly control still exists. Because physicians might reasonably seek a test provider who can perform all the relevant screens for a disease, market forces might force consolidation when separate firms own the rights to different genes connected to the same disease. This might result in the first firm to patent any gene associated with a particular disease having inordinate market power over its potential competitors (Technology Roundtable, 2000). Even when firms that do not perform genetic tests hold the relevant patents, the potential for exclusive licensing of a gene to another firm generates the potential for monopoly. Such restricted licensing increases the monopoly rents charged and reduces the overall societal benefit of the technology. In a recent survey of licensing behavior associ-

[22] This particular case has become the subject of a lawsuit with the families of the patients who collaborated and provided samples to the scientists to identify the gene, challenging the royalty and IP policies of the patent owners (Marshall, 2000).

[23] The potentially high licensing fees for some genetic tests raises another fairness issue that has not been considered at this point. Because genetic diseases often involve small populations and may be confined within certain ethnic communities or countries, how should cultural and minority group equity issues be addressed?

ated with gene patents, just more than half of the licenses that were granted by firms were exclusive (Merz, 2000).

The overall ramifications of monopoly rents on the social cost of gene patenting are, of course, based on the behavior of many individual firms. When confronted by a high licensing fee demand, a firm seeking to use a gene in a subsequent invention will have to decide whether to give up the research activity, to attack the underlying patent, or to accede. Depending on the particular genes and diseases involved, these may be the only choices since there may be no substitutes or routes to invent around the patent. Whichever decision the firm makes, the result will likely be large wealth transfers that may not make any sense. The overall magnitude of this social cost could be significantly reduced if firms charge low fees and grant licenses readily for access to the gene sequences in their patent portfolios. An expectation of such behavior from all firms—especially if their stock prices are supported only by the assumption of significant returns on such transactions—is highly unreasonable.

Restricted Innovation Due to Privatization of Portions of Technology-Space. All patents restrict innovation. Privatizing some part of technology-space unavoidably blocks the way for some later innovators. As a result, the fact that gene patents can block innovation is neither unusual nor unique. What is relevant to assess is the extent to which such restriction could occur so that its "value" can be injected into debate and decisionmaking on the topic. Due to a number of different characteristics, the potential for gene patents to restrict areas of innovation appears to be significantly greater than many other categories of patent monopolies.

Because of the sheer complexity of living systems, the assignment of intellectual property rights to small parts of those systems may have unpredictable effects on later innovators. Within an organism, even the seemingly simple process of copying a gene from the genome and translating it into protein is a very complex process. The sensitive regulatory systems that modulate the amount of proteins that are produced and how they are modified may involve tens or even hundreds of other biological molecules. Once a protein is made, its actual functioning in the body is even more complex, involving not only interactions with other molecules but also signals from the environmental conditions facing the plant or animal. These complex webs of interactions and reactions are very difficult to understand, but it is necessary to understand how the protein manufactured by a gene functions for it to be most useful as a pharmaceutical. In many scientists' opinion, sequencing a gene is relatively easy compared with the research required to tease out the complex biological processes through which the proteins are made, function, and are regulated. As a result, if property rights are assigned based on "possession" of the gene, rather than possession of this critical knowledge, there may be a serious disincentive for any researcher other than the patent holder to perform the necessary research.

Because of the nature of biomedical research, this issue of biological complexity also raises a serious fairness issue in the way these rights are assigned. Since we know so little about the activities of many genes and their roles in disease, a not unlikely possibility is that researchers studying diseases (rather than genomics) will discover roles for genes unknown to the firms or scientists who patented the genes. Such a case arose with respect to a gene involved in the infection of immune cells by HIV, the virus that causes AIDS. The gene involved encoded a receptor that the HIV virus uses to get into and infect human immune cells. The gene previously had been patented by Human Genome Sciences only as a cell receptor that might have

utility for various purposes. Unaware of the patent, independent researchers discovered the role of the gene in HIV; while its patent on the gene as a "promising drug target...may not give [HGS] the right to market products based on anti-AIDS effects,... it could insist on a cross-licensing arrangement with anyone who did" (Technology Roundtable, 2000). At the very minimum, such a situation emphasizes the fairness issues attached to gene patenting.[24] More important for innovation, however, if the scientific community (both commercial and public) perceives that the lion's share of the rewards for their research will unfairly go to others, that perception alone could generate a very real disincentive for other scientists to work on already patented genes.

The complexity of biological systems may also cause IP problems when genetic information is actually translated into drugs and products. Because of the many interactions among proteins inside the body, a given drug can affect the activity of many different gene products. In such a situation, it is unclear how licensing and royalty arrangements can be crafted to compensate all the patent holders involved. If the drug was designed to target a single gene, should royalties be restricted to that patent holder and any other effects be considered superfluous? What if it is one of the other effects that produce the important activity of the drug? Such a list of hypothetical conjectures could go on for pages, producing scenario after scenario that, as they arise in commercial endeavors, will likely have to be resolved by litigation.

In addition to the inherent complexity associated with the biological systems that gene patents seek to address, the fact that gene sequences have a dual nature as both invention and information makes it possible for gene patents to "reach through" their original claims to take at least partial ownership of subsequent inventions. This characteristic means they can seriously influence those subsequent innovators. The perception is that "[t]hose who would patent human DNA sequences without real knowledge of their utility are staking claims not only to what little they know at the moment, but also everything that might later be discovered about the genes and proteins associated with the sequence" (Alberts, 2000, p. 73). If this characteristic of gene patents withstands challenge, patent-holders could create technical monopolies over entire categories of products. To illustrate this point, it is instructive to compare a patent on a gene with a patent on a traditional pharmaceutical targeting the product of that gene. In the case of the pharmaceutical, since the patent protects the drug itself, competitors would have the opportunity to follow and make other competing drugs that might be superior to the original. The Patent and Trademark Office (PTO) would not allow a broad claim on all possible drugs targeting that gene product when the inventor has produced only one. Issuing the patent on the gene, however, generates that very situation with the potential for a technical monopoly over the drug target rather than narrowly drawn protection for the drugs themselves (National Advisory Council for Human Genome Research, 2000).

Because gene patent claims can be so broad, covering any use of the gene and anything that targets it or its function, their scope is potentially infinite. By allowing the patenting of something that will be an integral "tool" in future study and innovation, this allows the original "inventors" to "assert that the new discoveries are, in effect, an extension of their tools—therefore, also part of their intellectual

[24] This type of situation is the source of the perception that, more often than not, these gene patents act as submarine patents. In this instance, the HGS patent only "surfaced" when the subsequent discoveries gave it significant commercial value (Regalado, 2000).

property. It's as though the inventor of the electron microscope could also claim all the discoveries made with that instrument" (Harris, 2000, p. R174).[25] It is almost inconceivable that this situation will not be a detriment to subsequent innovation by anyone other than the firm holding the original patent.[26] At the absolute minimum, the subsequent innovator could have to obtain a web of licenses from many disparate IP holders to market his or her product. The ability of any one of these individuals or firms to stop the process in its tracks presents a serious barrier and financial disincentive to subsequent researchers. A recent example of the problems associated with IP licensing in this field was the so-called "golden rice," a rice strain fortified in beta-carotene, a precursor to vitamin A. The academic scientist who developed the variety sought to give the technology to the developing world, since many children suffer blindness or death because of vitamin A deficiency. The technologies used in the laboratory to generate the strain of rice were covered by 70 patents held by as many as 32 companies and institutions. Although they could be used in the laboratory under the so-called "experimental use" exemption to patent exclusivity (Eisenberg, 1997), once the rice left the lab, the force of all the IP rights came into play. Paying to license each technology would make the rice far too expensive for its target market. Although some firms have waived their rights or negotiated reasonable agreements, even one holdout could stop the use of the rice (Gillis, 2000).

The politics and negotiation surrounding licensing brings up yet another mechanism through which gene patents could deter innovation. The particular intellectual property strategies adopted by the firms could significantly restrict other companies' use of these general-purpose technologies. Competitive firms have long used intellectual property strategies to constrain the activities and abilities of their competitors rather than to promote innovation. For example, patent strategies such as patent fences, identifying and holding strategic individual patents, blanketing certain technology areas, or forming patent "girdles" around competitors, are all ways IP has been used both offensively and defensively (Granstrand, 1999). If firms adopt similar strategies with genomic patents, their potentially broad range could cripple the activities of competing (or potentially competing) firms. One could conceive of the situation, for example, of a firm gaining and holding an unused genomic patent to protect the market position and profitability of an earlier non-genomic product. If these events do occur, serious market structure and anti-trust issues would certainly arise.

Lastly, the great uncertainty surrounding the acceptability, scope, and durability of gene patents also has the potential to significantly impede innovation in this industry. Patents have been filed (and granted) on fragments of genes called expressed sequence tags (ESTs).[27] Applications for patents on at least 500,000 gene

[25] In the literature of various disciplines, this situation is referred to as "patenting of research tools" or the allowance of IP rights "too early in the technology trajectory" of these products. Both discussions consider the effects of giving out private ownership of these "early stage" technologies that can go on to be incorporated or used in the construction of many subsequent products.

[26] This situation again raises the question that, if the patent holder of a "research tool" developed that tool with support of taxpayer money, why should another taxpayer have to pay to use it? This points out a potential problem with the thinking behind the Bayh–Dole Act that allowed universities to patent and market technologies; though the rationale held that technology was "sitting on the shelves" of universities and not being commercialized, these types of research tools (including genes) could be used simply from the information published by the academic scientists. As a result, it is unlikely that the market failure that the Act was intended to remedy ever existed in this particular area of technology-space (Jaffe, 2000).

[27] It should be noted that, under the recently revised utility guidelines, fragments of genes are generally no longer considered patentable so the scope of this potential quagmire has been somewhat reduced.

fragments have been filed with the U.S. PTO, suggesting that fragments of virtually every human gene have already been claimed. Questions remain unresolved about how patents on two different fragments of the same gene will stand with respect to one another or the relative standing of a patent on a full-length gene versus one containing only a partial sequence (Steinberg, 2000). These types of uncertainties may result in firms "negotiating with the wrong patent holder" or being exposed to unforeseen IP challenges even if they did everything in their knowledge (and in good faith) to resolve patent-related issues surrounding their product line. The potential also exists for firms to file patents on databases containing some or all of the sequences in a genome. For example, one of Human Genome Sciences' recently issued patents[28] has claimed an entire genome—that of *Haemophilus influenzae*—for the purposes of diagnostics and database searching (Thomas, 1999). If such patents were issued on databases containing human gene sequences in machine-readable form, the involved firms would be able to prevent people from using or selling a database containing the claimed sequences (Fraser, 2000). Such a situation would mean that any researchers (even non-commercial ones) who wanted to use that particular information for comparison or analysis would either "have to resort to paper and pencil—or presumably pay for access to a private database" (Harris, 2000).

In contrast to the fears of an "inverse tragedy of the commons," the many mechanisms through which gene patents can restrict innovation have led some to worry about exactly the opposite. Rebecca Eisenberg has described this situation as a potential "anti-commons," where the assignment of private rights (perhaps overlapping private rights) to the genome will lead to underutilization of the resource. Such a situation occurs when "multiple owners each have a right to exclude others from a scarce resource and no one has an effective privilege of use" (Heller and Eisenberg, 1998, p. 698). This situation is very difficult to escape, and doing so requires significant transaction costs and behavior alteration on the part of market participants; the process is therefore often "brutal and slow" (Heller and Eisenberg, 1998, p. 698). Unless it is overcome, however, any time a single technology user needs access to multiple "upstream" inputs to put together a useful product, "[e]ach upstream patent allows its owner to set up another tollbooth on the road to product development, adding to the cost and slowing the pace of downstream biomedical innovation" (Heller and Eisenberg, 1998, p. 699).

Transaction Costs—Licensing to Litigation. In addition to the restrictions they could place on innovation in the biotechnology sector, the various mechanisms will invariably produce another social cost: the transaction costs involved with negotiating IP licenses or resolving conflicts over alleged infringement in court. The costs of licensing gene patents (monopoly rents) will be highly dependent on the strategies adopted by the owner firms.[29] Just as the absolute licensing fees represent an important cost, the efforts and resources that must be devoted to negotiating and maintaining interfirm agreements can also be significant (see, for example, Roberts, 2000). Because larger firms are more likely to have available resources to pay these transaction costs, this could force consolidation in an industry which has, to date, been driven by a large number of small, innovative

[28] U.S. patent 6,355,450: "Computer readable genomic sequence of *Haemophilus influenzae* Rd, fragments thereof, and uses thereof."

[29] See Schankerman and Scotchmer (2001) for a recent discussion of this topic particularly relevant to gene patents.

companies. Although one strategy to minimize these transaction costs is the formation of patent pools, they also represent a significant barrier to entry and can have other anti-competitive effects (Carlson, 1999; Clark et al., 2000).[30]

When firms cannot agree, legal action is the only remaining mechanism for society to judge these issues. The costs associated with legal judgements will result in large transfers of wealth among members of these sectors likely to run into hundreds of millions, if not billions, of dollars. The resources all must spend on legal representation and other expenses related to the litigation itself represent funds transferred out of the industry and no longer available to support further research and development. At the very minimum, these can represent extreme transaction costs that could greatly increase the costs of these technologies and limit their availability to society. In a development likely to increase the litigation burden and increase these transaction costs further, companies focusing on proteomics—direct examination (and patenting) of proteins rather genes—are now rapidly expanding their activities and beginning to execute their own IP strategies. At the minimum, conflicts between gene and protein patents will "produce a confusing landscape of competing...claims, perhaps setting the stage for legal battles for control over the future of genetic medicine" (Service, 2001, p. 2082).

In an effort to control litigation costs, the insurance industry has begun to underwrite insurance on a firm's intellectual property. The risk-transfer service, debuted by Aon, "allows companies to secure in excess of $200 million of blanket protection to recover damages or enforce rights for patents, trademarks, copyrights or other intellectual property assets" (Goch, 2000, p. 109). Although this provides a way for firms to shift the risks and costs associated with this situation, from society's point of view, it still represents a cost in resources (now paid to insurers rather than directly to lawyers). The ability to obtain IP insurance may also become a barrier to entry in these industries leading to changes in industry structure and potentially detrimental effects on innovation and economic growth.

CONCLUSIONS

The unique character of genomic patents—their hybrid nature as both innovation and information—makes them particularly difficult for IP policy. This author believes that their societal costs likely outweigh their benefits and that mechanisms should be explored for preventing these patents from granting an exclusive, durable monopoly on the "information content" of gene sequences. Because of the comparative newness of this area, the arguments advanced here are, by necessity, illustrated by example rather than supported by comprehensive data sets of gene patents and their effects. The magnitude of costs and benefits of these patents is, therefore, still subject to a great deal of uncertainty. As an increasing number of sequence patents, many pending since the mid-1990s, are now being issued, presumably a larger data set of firms' behavior and legal consideration will become available over time. As a result, this will be fertile ground for additional policy, legal, scientific, and economic research.

Depending on the choices made regarding the prosecution of infringement claims and royalty demands by firms and other organizations holding sequence patents—particularly the forerunners whose actions will set both market expectations and

[30] A more complete discussion of the potential effects of patent transaction costs and industry structure is available in Somaya and Teece (2001).

industry norms—the possible problems outlined in this paper may not occur. If firms set licensing fees too high, hold onto exclusive rights to all facets of particular genes, or take advantage of the possibility to construct durable monopolies in gene sequence-based services, then the social costs of these property rights could compound over time to become very high indeed. Given biotechnology's possibilities, it is clear that understanding how best to create incentives for societally beneficial innovation is very important.

It is often the case, early in the developmental trajectory of new technology, that policy cannot advance rapidly enough to appropriately deal with change. During the period of adjustment, as policy catches up with technical progress, one can only hope that actions taken in the application of earlier policies do not cause unintended negative effects. Today, with the sequencing of the human genome completed, the translation of this genetic information into true innovations is beginning to be realized. However, current patent policy may hurt rather than help the efficiency of that process. Pursuing a more complete and rigorous understanding of whether that is the case is clearly critical in the process of adapting intellectual property policy to changing technological circumstances.

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