The Economics of Innovation: A Survey

Section of Antitrust Law
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Task Force:
Philip Nelson, Chair
Stuart Gurrea
Gloria Hurdle
Kevin Marshal
David Smith
Robert Stoner
Darrell Williams

PREFACE

As chair of the Section of Antitrust Law, I am pleased to present *The Economics of Innovation: A Survey*. There exists decades of research by economists on the interaction between innovation and the patent system and the effects of market structure on innovation. This Survey does not undertake to supply a definitive answer to the difficult question of how best to encourage innovation. Indeed, the literature offers varying hypotheses and findings concerning the optimal breadth and length of patents, the benefits of "patent races," and the impact of firm size and market concentration on innovative activity. What this Survey does provide is a reference source encapsulating the wealth of scholarship and a springboard for further research and debate.

We owe a special thanks to Philip Nelson, who chaired the Task Force, and to Darrell Williams, Kevin Marshal, Robert Stoner, Stuart Gurrea, Gloria Hurdle and David Smith, who contributed to the project, to Richard Gilbert, who reviewed the Survey, and to Howard Morse, who chairs the Section's Intellectual Property Committee, who assigned and monitored this Survey.

Roxane C. Busey
Chair, 2001-2002

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The Economics of Innovation: A Survey[1]

I. Introduction: Importance of Innovation

As a leading antitrust treatise points out:

> Today it seems clear that the general goal of the antitrust laws is to promote 'competition' as the economist understands that term. Thus we say that the principal objective of antitrust policy is to maximize consumer welfare by encouraging firms to behave competitively, while yet permitting them to take advantage of every available economy that comes from internal or jointly created production efficiencies, or from innovation producing new processes or improved products.[2]

While the competition policy objective of promoting consumer welfare by encouraging efficient production and innovative activity appears straightforward, there are tensions between the underlying economic goals of static and dynamic efficiency.[3] Specifically, the promotion of static efficiency may, in some circumstances, lead to a decline in dynamic efficiency and vice versa. This tension is very apparent in economic justifications for patent law, which provides a patent holder with exclusive rights that may lead to some static inefficiency in the hope of promoting dynamic efficiency.

While the static benefits that result from increased competition are widely recognized,[4] it is important to recognize, as current antitrust law does, that dynamic efficiency is also a key

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1 This survey was prepared by a team of economists. Section I was prepared by Philip Nelson, Darrell Williams, and Kevin Marshall. Section II was prepared by Robert Stoner and Stuart Gurrea. Section III was prepared by Philip Nelson, Gloria Hurdle, and David Smith. We would also like to thank Richard Gilbert for helpful comments on a draft of this paper.

2 Areeda & Hovenkamp (1980), ¶ 110a.

3 Static efficiency relates to the optimal use of resources using available technologies to produce existing products. Dynamic efficiency relates to the optimal use of resources when it is possible for firms to develop new products and production processes.

4 As Hicks commented, "the best of all monopoly profits is a quiet life," which implies that insulation from competition may lead to inefficient production and higher costs Hicks (1935), p. 8.

policy objective. In particular, as is recognized by economists, social welfare may be improved by a policy that encourages dynamic efficiency, even if there is some sacrifice in static efficiency.[5]

Dynamic efficiency involves both the development of improved goods and services and the invention of more cost-effective methods of producing and delivering these goods and services. The technological breakthroughs during the last decade that allowed the introduction of automobiles, airplanes, radio, television, space travel, telephones, internet, modern pharmaceuticals and the like all evidence how innovative efforts have contributed to fundamental improvements in human welfare. Because of measurement problems, economists have had great difficulty in capturing the full effect of these monumental breakthroughs on consumer welfare.[6]

Perhaps because the measurement problems are somewhat less daunting, economists have devoted somewhat more effort to identifying how improvements in production processes can contribute to social welfare by reducing the resources that are consumed in supplying goods and services. These analyses have shown that a relatively small dynamic advantage can offset a larger static inefficiency. For example, as is shown in Figure I (which assumes that the relevant market has $1 million in sales per year), it only takes 5 years for even a 1% annual growth rate in cost efficiency to offset a 5% static loss due to price increases. After a decade, the dynamic efficiencies swamp the static efficiencies (leading to a net savings of over 50% of the assumed $1 million in sales).

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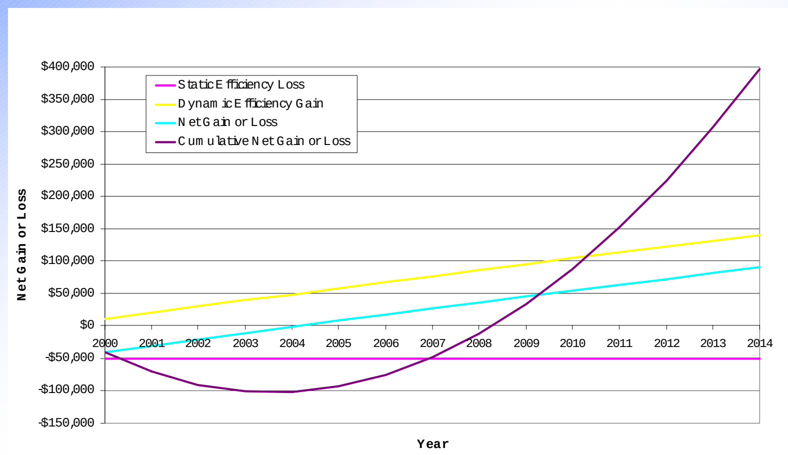
5 "Making the best use of resources at any moment in time is important. But in the long run, it is dynamic performance that counts. . . . [A]n output handicap amounting to 10 percent of gross national product owning to static inefficiency is surmounted in twenty years if the output growth rate can be raised through more rapid technological progress from 3.0 to 3.5 percent. Or if the growth rate can be increased to 4.0 percent, the initial disadvantage is overcome in 10.6 years." Scherer & Ross (1990), p. 614.

6 Id.

Figure I.

Innovation Is Critical Element of Market Performance: Dynamic Efficiencies Can Swamp Static Inefficiencies



Given the importance of dynamic efficiency, it is important for antitrust policy makers to understand the economics of innovation so that antitrust policies do not inadvertently have substantial adverse effects on dynamic efficiency. This paper is designed to provide a brief overview of some of the key findings in the economics literature to provide the reader with some background in the economics of innovation. It focuses on two issues: (1) How are intellectual property protection and innovation related? (2) How are market structure and innovation related? Since the economics literature that discusses both of these issues is voluminous, this report necessarily focuses on the key findings. This study does not cover some issues that are related to innovation. In particular, it does not focus on the economics literature that relates to the acquiring, protecting, or exploiting of market power through patents or other intellectual property rights.[7]

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7 Economists recognize that patents and other intellectual property rights do not necessarily convey market power, since there may be effective substitutes for the products that are protected by the intellectual property rights. However, there are some cases where firms may secure market power through legal intellectual property rights. Economists have recognized that a firm that obtains market power by obtaining a patent for which there are no effective substitutes may exploit its market power in a variety of different ways, including refusals to deal and tying.

With respect to refusals to deal, Gilbert and Shapiro (1996) find that the private incentives to license generally increase economic welfare. Where there is no private incentive to license (i.e., the patentee would refuse

Before turning to the studies of the innovative process, it is helpful to have some idea of what is meant by innovation. In particular, it is important to recognize at the outset that there are numerous types of innovation. For example, economists make distinctions between "process" innovation and "product" innovation. The former involves changes in the production process (which are designed to reduce the costs associated with producing a given product). The latter involves changes in the product itself (e.g., add new attributes or improve the quality of existing attributes). Less than a fourth of all U.S. industrial R&D expenditures are devoted to cost-saving ("process") developments. The rest is focused on product development and improvement.[8]

Economists have identified a number of fundamental characteristics of innovations and the innovative process that are helpful to keep in mind when considering innovative policies. These characteristics include:

- Innovation is a process that proceeds through different stages. Stages that are commonly recognized by economists include invention, entrepreneurship, investment, development, and diffusion.[9] The capabilities that are required to meet the challenges raised during the different stages vary.
- Innovation can be expensive, especially at the later stages.[10]
- Much innovative activity is privately funded, although public funding plays an

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to deal), economic welfare can only be enhanced under a narrow set of conditions. An important result of their study is that welfare consequences of a refusal to deal depend on the form of the license arrangement. See also Katz and Shapiro (1985).

Early economic analysis of the leveraging of market power through tying can be found in Bowman (1973). Bowan's work focused on the possibility that only one monopoly rent could be obtained and that, as a result, leveraging was unlikely. However, Whinston (1987) provides examples in which a monopoly owner of an input may profit by refusing to sell the input as a separate component.

8 Scherer (1984), p. 88.

9 "Invention is the act or insight by which a new and promising technical possibility is worked out (at least mentally, and usually also physically) in its essential, most rudimentary form. Development is the lengthy sequence of detail-oriented technical activities, including trial-and-error testing, through which the original concept is modified and perfected until it is ready for commercial introduction. The entrepreneurial function involves deciding to go forward with the effort, organizing it, obtaining financial support, and cultivating the market. Investment is the act of risking funds for the venture. . . . [D]iffusion (or imitation) is the process by which an innovation comes into widespread use as one producer after another follows the pioneering firm's lead." Scherer & Ross (1990), pp. 616-617.

10 Scherer & Ross (1990), p. 619. While not all innovation comes from expensive R&D laboratories, some does.

important role in some R&D efforts.[11]

- Successful innovation is not certain—there is often a random component[12] The riskiness of innovation can cause society to under invest in innovative efforts.[13] However, at some point during the process, the riskiness of the innovation effort may decline significantly because more is known about the requirements to fully implement the innovation and the likely market acceptance of the innovation.[14]

- The risk of innovative efforts varies across projects, and thus industries.[15]

- The level of innovative activity varies across industries and firms. Historically, much of the industrial innovative activity has been concentrated in manufacturing firms.[16] The importance of manufacturing sector to R&D is particularly striking when one recognizes that the manufacturing sector contributes a relatively small percentage (less than 20%) of the gross domestic product.[17] Even within the manufacturing sector, there is significant variation across industries. (See Figures II A-C).

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11 For a discussion of federally funded programs, *see* Burnett and Scherer (1989).

12 Scherer & Ross (1990), p. 618.

13 ". . . we expect a free enterprise economy to under invest in invention and research (as compared to the ideal) because it is risky, because the product can be appropriated only to a limited extent, and because of increasing returns to use. This under investment will be greater for more basic research." Arrow (1962), p. 619.

14 Scherer & Ross (1990), pp. 618-619.

15 Mansfield et al. (1968), pp. 56-61.

16 "The manufacturing sector conducts 97 percent of all industrial R&D and hence is the prime mover in generating technological progress. Among 238 U.S. manufacturing industries in 1977, the median industry devoted 0.8 percent of sales to company-financed R&D." The leading industry (ethical drugs) spent 10.2%. Scherer & Ross (1990), p. 615.

17 In 2000, the manufacturing sector contributed $1,566.6 billion to the United States' gross domestic product of $9,872.9 billion, which is about 16%. U.S. Government Printing Office (2002), p. 336.

Figure II A.

R&D Varies Across Industries: Sector R&D/ Total R&D

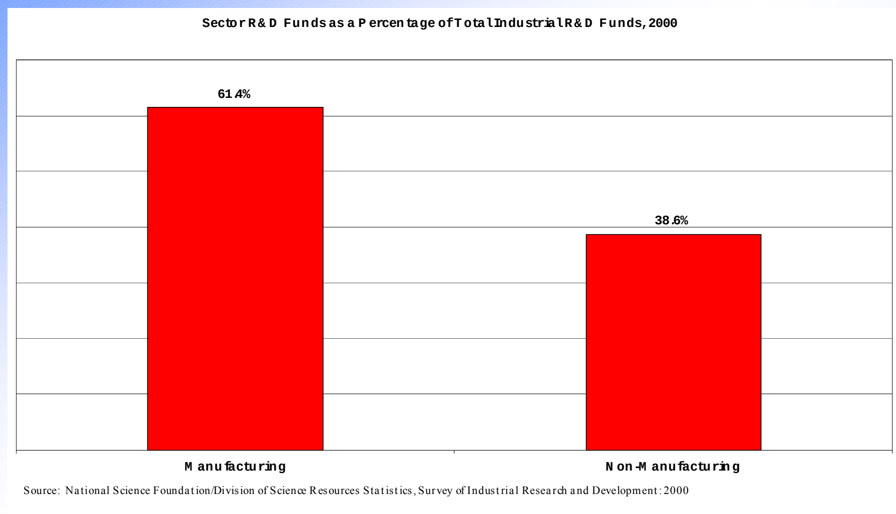
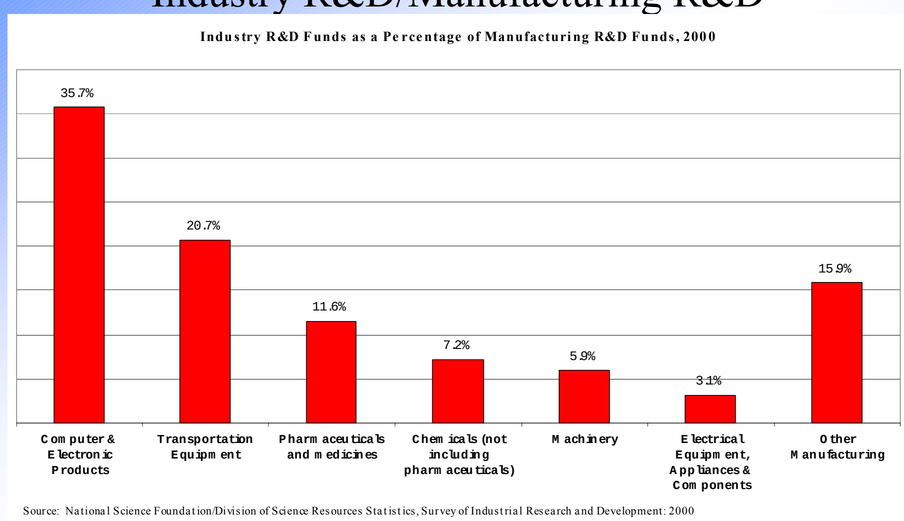
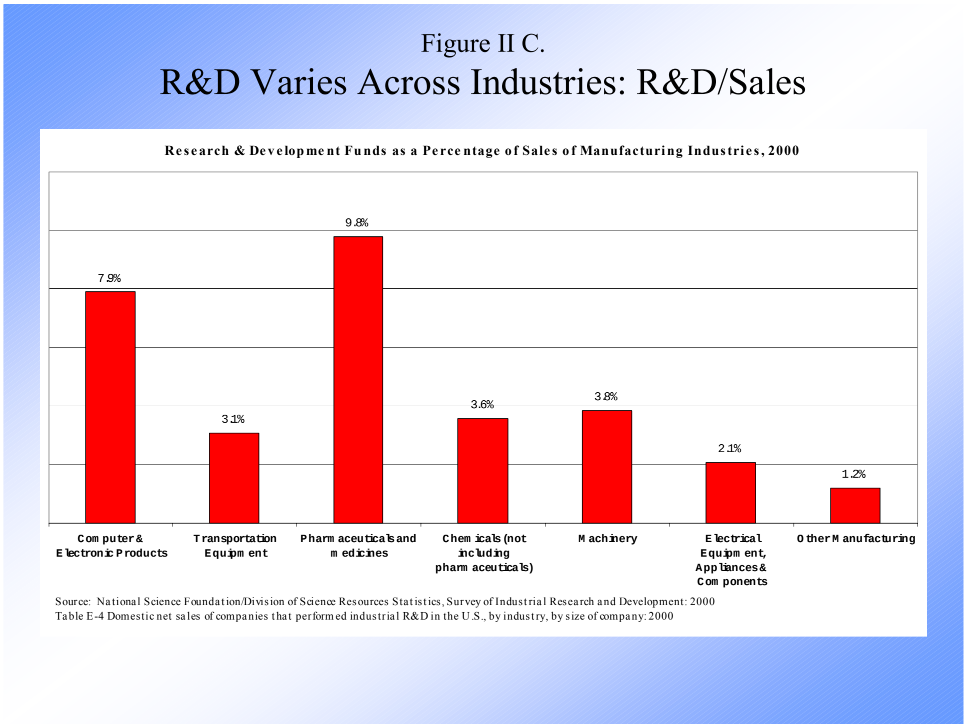


Figure II B.

R&D Varies Across Industries: Industry R&D/Manufacturing R&D





- A relatively small portion of R&D expenditures (less than 5%) are for basic R&D ("original investigations for the advancement of scientific knowledge, without specific commercial objectives") Much of this basic R&D is done by university, non-profit, and government labs.[18] In fact, historically more than 50% of the basic R&D has been done by academic and non-profit labs and more than 20% has been done by government labs.[19]

- Introduction of a successful innovation may require access to complementary capabilities or intellectual property. Supporting inventions may be required before the original innovation is technically or economically viable.[20]

- Inventions by one industry often must be accepted by another industry before consumers benefit.[21] Indeed, studies have shown that innovative ideas often

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18 Scherer & Ross (1990), p. 616. *See also,* Shrieves (1978), p. 329. Shrieves tested the effect of government supported research on privately financed R&D and found an inverse relationship at the firm level.

19 Scherer & Ross (1990), p. 616.

20 Scherer & Ross (1990), p. 618.

21 For example, a chemical company's new fiber must be used by textile manufacturers before it is available to consumers. Scherer & Ross (1990), p. 616.

come from outside of the firm that implemented them.[22]

- Innovations vary with respect to the cost others incur to replicate the invention and/or take advantage of it. In some cases, it may be very hard for others to free ride on the inventors' efforts, while in other situations it may be quite easy.

Given the importance of innovation and the fact that, if innovative ideas are not protected, there may be little incentive to undertake innovative efforts, it is not surprising that governmental policies, such as patent law, have been developed to provide at least transitory protection of an inventor's intellectual property. Section II of this paper explores in more detail the rationales for patent protection, including a discussion of the optimal length/breadth of patents. It also reviews the "patent race literature," which focuses on the issue of whether patent rights in combination with certain industry structures may stimulate firms to expend too many resources on innovation. This section concludes with an overview of the empirical literature that assesses the extent to which patents are important to the stimulation of innovative activity.

Section III provides an overview of the economics literature that has explored the nature of relationships between market structure and innovative activity. As this review indicates, economists have long debated the nature of the relationship between innovation and market structure. Some economists have argued that innovation is a form of competition and, as a result, a market structure that encourages price competition is also likely to encourage innovation. Other economists, often citing the early work of Joseph Schumpeter, have argued that large firms, perhaps in concentrated markets, are more likely to support innovation than smaller firms.[23] Still other economists have argued that fundamental characteristics of the technology, along with other structural characteristics of the market, simultaneously interact to shape the nature of innovative activity and market structure. Theoretical and empirical research relating to these hypotheses is reviewed in Section III.

Each section contains a brief essay that provides an overview of the relevant literature. There is a bibliography at the end of the paper that provides a complete citation for each publication that is identified in the essays. After this bibliography, there is an annotated

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22 Utterback (1974), p. 622 and Utterback (1971), p. 127.

bibliography that provides a short description of the key articles that relate to the material discussed in Sections II and III. Articles are arranged alphabetically by author's name under each major section in the associated essay.

23 Schumpeter (1950), p. 106.

II. Intellectual Property and Innovation

This section focuses on the economics literature that relates innovative activity to legal rights, such as patents, that protect intellectual property. It discusses the rationales for patent protection and the optimal length and breadth of patents. Both theoretical and empirical literature is surveyed as part of this review.

A. Rationales For Patent Protection

There are four principal benefits or rationales of patent protection that are discussed in the literature. These rationales are: "Invention Motivation," "Invention Dissemination," "Invention Commercialization," and "Orderly Cumulative[24] Development of Invention."[25] These rationales are sometimes conflicting, or at least create conflicting issues. More importantly, the context of the innovation process presumed in the different rationales can be very different. Thus, it is not surprising that the theoretical and empirical work on optimal patents that is reviewed in this section has conflicting conclusions—depending on the particular patent rationale and underlying innovation context that lie beneath each model.

We will discuss each of the four rationales for patent protection in turn. It is helpful to understand the different perspectives provided by these four theories when considering the theoretical and empirical work that has been done on optimal patent life.

1. Theory 1--Invention Motivation

Economists have long recognized that patent protection can encourage innovation by increasing the returns from innovative activity. Absent patent protection, innovators cannot appropriate the full benefits of their innovation; some of the benefits go to "free riders" without payment. Patent protection is said to restore appropriability and internalize externalities. Note

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[24] Cumulative innovation refers to a situation where subsequent innovations are dependent on preceding innovations. Non-cumulative innovation is present when innovations occur in isolation, so the ability to proceed with an innovation is not dependent on others (e.g., because there are no blocking property rights).

[25] We have adopted the rubric of Mazzoleni & Nelson (1998), but these concepts are widely recognized.

that the assumption here is that inventors cannot gain the full benefit of innovation by using a new product or process while keeping the relevant information secret to prevent rapid imitation. Further, the "invention motivation" theory of patenting is generally couched in terms of invention as a one time event, not a cumulative process whereby inventions build on each other. Thus, increases in appropriability unambiguously increase innovation since, under this rationale, there is no offsetting retardation of later innovation that could result if follow-on innovation is deterred by the presence of a patent on the pioneering innovation.

There are costs associated with encouraging invention through patent protection. Because patents restrict access to completed innovations and may allow the exercise of market power, there can be static costs to patent protection even under Theory 1. Moreover, if we relax the assumptions of Theory 1, there can be dynamic costs, when extending the life of the first-mover's patent beyond the time period necessary to elicit the innovative activity by the first-mover deters innovation by others. In addition, it is not always the case that more, or swifter, innovation is socially desirable. For example, more invention may not be desirable if it results in wasteful patent races to be the first successful inventor. Because of these offsetting potential costs to patent protection, there is an implied "optimal" patent duration and breadth that attempts to balance these factors. Much of the theoretical literature on optimal patent protection attempts to explore this balancing.[26]

2. Theory 2--Invention Dissemination

Economists have also considered whether patents may encourage the wider use of inventions. They have recognized that patents may encourage dissemination of inventions because, absent patent protection, inventors would be more likely to rely on secrecy to obtain their innovation rewards. Secrecy would both limit information flows to follow-on inventors and would discourage licensing of the innovation, both of which can benefit society. Unlike the first theory, where patenting is seen more as *restricting* the use of an invention, this theory stresses that patenting brings about *wider* dissemination. However, dissemination of the technology may be consistent with increased profits (and thus an increased incentive to innovate) when the patent

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26 See discussion in Section II B, C, and D below. *See also*, Green & Scotchmer (1995).

holder earns royalties from the dissemination of the technology.

Theory 2 is likely to have the most applicability when (a) the inventor by himself cannot exploit all uses of the invention and (b) secrecy would otherwise be effective in enabling the inventor to reap at least some returns. Some studies suggest that this is the case for many *process* innovations.[27] In these cases, to the extent that patents facilitate licensing, they increase the reward for disclosure relative to secrecy, and facilitate wider use. By contrast, for *product* (sometimes called "apparatus") innovations where secrecy may be less effective in the first instance as a means of appropriating returns, patents may do less to encourage disclosure.[28]

3. Theory 3--Invention Commercialization

Patents may induce development and commercialization of initial inventions which have little or no value in their initial form, but need further development to be commercially valuable. More specifically, patents can facilitate exclusive licensing to entities who would invest in necessary development work. They can also induce initial inventors to become entrepreneurs.

The need for patent protection to encourage firms to commercialize inventions is central to recent debates over whether patents should be granted for inventions that were developed through the use of government funds. The Bayh-Dole Act of 1980 gave universities and government labs patent rights even when their work has been supported by government funding. The rationale behind the Bayh-Dole Act is that, absent patent protection, key inventions would not be exploited because firms would not find it to be profitable to invest funds in the commercialization of the product because others would be able to free ride on this investment. Opponents of Bayh-Dole have argued that there is no reason that patents cannot be taken out on subsequent development work or that the results of such development work cannot be undertaken in ways that offer other protections from free riding. For example, a number of studies indicate that a simple head start on commercialization can yield large profits on a new product and that secrecy often can protect effectively new process technology used by the

27 *See, e.g.,* the survey conducted by a group of Yale economists. (Levin et al. 1987)

28 Patent lawyers often refer to these "product" innovations as "apparatus" innovations.

commercial developer.[29] If this is the case, a firm that commercializes the invention does not need a patent on the original invention to profit from commercialization of the product.

4. Theory 4--Orderly Cumulative Development of Innovation[30]

Comprehensive, enforceable patents may encourage the orderly development of technologies that are inspired by an initial insight with strong follow-on or cumulative potential.[31] When an initial invention is likely to serve as the basis for a number of follow-on ("cumulative") inventions, an orderly, perhaps sequential, innovative effort can be significantly more efficient than a more haphazard approach.[32] In such a situation, it can be the case that broad patent rights that go to the pioneer innovator may facilitate the efficient development of the full range of follow-on possibilities by controlling the licensing terms and avoiding duplicative efforts. Furthermore, broad patent rights in a cumulative innovation environment can foster frontier innovation by giving the innovator the rights to develop or collect royalties from follow-on discoveries.

Economists have suggested that in markets where sequential innovation is likely, it may be efficient to grant the prospect-opening inventor sufficiently broad patent rights that the inventor has an incentive to create what has been termed "broad shoulders" for following innovations to stand on.[33] Moreover, it has been argued that the creation of "broad shoulders" is only possible by preventing, through broad patent protection, duplicative R&D that closely

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29 *See, e.g.,* Levin (1987), Mansfield (1986), and Cohen et al (1996).

30 Theory 4 differs from Theory 3 in that, instead of positing that the initial invention has only one commercial product at the end of the invention process, the initial discovery or invention is seen as opening up a whole range of follow-on developments or inventions. Such a cumulative framework tends to set up a much richer set of theoretical modeling possibilities that is missing from the non-cumulative framework underlying, in particular, Theory 1.

31 These types of inventions are sometimes called "broad prospects " in acknowledgement of their cumulative potential.

32 *See* Scotchmer (1991).

33 Id.

mimics the patent holder's patent.[34] However, economists have also recognized that broad patent protection, while needed to maximize the incentive to create "broad shoulders" at the initial stage, might also hinder inventive activity at later stages if efficient licensing opportunities prove to be hard to transact and follow-on innovation is hindered because of the resulting over-reaching threat of infringement.[35]

B. Optimal Patent Length/Breadth Literature—Non-Cumulative Framework[36]

A significant portion of the economics literature that analyzes the optimal length and breadth of patents employs a static or non-cumulative perspective.[37] This literature essentially comes out of a Theory 1 framework of appropriability; i.e., it is primarily concerned with providing the best incentive mechanism to develop a primary invention that has no follow-ons. In this literature, there is a tradeoff between providing adequate incentive for the inventor to innovate and the static efficiency loss associated with the monopoly power that may be conferred by the patent (assuming that there are no effective substitutes for the patent).

The literature on optimal patent *life* is generally connected to Nordhaus (1969) and Scherer (1972). This literature has been extended by Gilbert & Shapiro (1990), Klemperer (1990) and others to consider both optimal patent life *and* breadth simultaneously.[38] This latter literature chooses a combination of breadth and patent length that minimizes the welfare loss

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34 The inefficiencies that arise from duplicative efforts have been addressed in different frameworks. For an early study see Kitch (1977).

35 Matutes et al. (1996) address the need for early disclosure while preserving the incentives to innovate.

36 The summary of the theoretical and empirical literature on optimal patent length provided here has particularly benefited from an earlier survey by Jaffe (1999). Jaffe surveys the major changes in patent policy and practice that have occurred over the last two decades and reviews some of the theoretical and empirical literature that bears on the expected effects of changes in patent policy on innovation.

37 When patents are non-cumulative, the economic analysis is simplified because it does not reflect the connections between innovative efforts that exist in a more dynamic market environment where innovative efforts can cumulate (build on each other).

38 The "breadth" of a patent refers to the range of applications that are covered by the patent. "Broad" patents cover more applications than "narrow" patents. Patent "scope" is often used synonymously with

associated with a specific degree of innovation incentive.

Klemperer (1990) considers two kinds of welfare loss in a differentiated product model: (a) reductions in the consumption of the (patented) preferred product by switching to less preferred products that are beyond the patent scope and so are sold competitively; and (b) simply not consuming the entire product class at all due to non-competitive prices of the (preferred) patented product. He concludes that if the reduction in consumption of the preferred product through substitution is the larger expected effect of extending patent breadth, then an optimal patent policy would be wider patents of shorter length (to eliminate inefficient shifts among closely substitutable products.) He also finds that if simply not consuming the product at all is the larger expected effect of extending patent breadth, then an optimal patent policy would be more narrow patents of greater length (to eliminate the efficiency from not consuming). Gilbert & Shapiro's model,[39] since it is a homogeneous product model,[40] only recognizes the inefficiency connected with not consuming the product in question due to higher prices. Accordingly, their model generally finds that long-lived patents of narrow breadth are superior (again, to eliminate the inefficiency of not consuming).

C. Patent Race Literature

A second strand of literature that analyzes the relationship between patents and innovation is the literature on patent races and so-called "over fishing."[41] When investment opportunities are public knowledge, multiple firms will have the opportunity to invest in innovation. In this environment, an optimal patent policy must take into account the strategic interaction between firms competing to develop the innovation. More competition is not necessarily efficient: firms might duplicate investments by entering races or engage in over-investment.

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patent "breadth."

39 Gilbert & Shapiro (1990).

40 Homogeneous products are products that are not distinguishable in the eyes of a consumer. In contrast, differentiated products differ in the eyes of a consumer.

41 Early patent race models are found in Loury (1979) and Dasgupta & Stiglitz (1980). "Over fishing" models are analyzed in Barzel (1968) and Dasgupta & Stiglitz (1980).

The patent race literature calls into question one of the implicit assumptions underlying Theory 1. The strictest version of Theory 1 presumes that potential inventors work on *diverse and non-competing ideas*, and thus that more inventive effort, and more inventors, means more useful inventing. Theory 1 takes on a different look if, instead, competition in R&D is allowed and firms are presumed to be *focused on a single research alternative* or a set of closely connected ones. In this latter setting, the patent race models point to a number of reasons why the increase in total inventive effort induced by the lure of a patent is not necessarily an unambiguous plus. If inventors perceive that *other* inventors are in the game, the expected returns will depend not simply on whether they achieve an invention, but on whether they achieve it *first*. Thus, patent protection may result in an outcome where firms invest their resources at a faster rate than the social optimum,[42] and too many firms will race towards the same inventive goal (or fish in a still limited "pool" of invention prospects).

Of course, this outcome will be less likely in industries where there is a wider menu of potential non-infringing ideas, such that different firms will pursue different approaches. In these industries broader patents will not deter innovative efforts since there is room for alternative non-infringing advancements. For this reason, some have suggested that an optimal patent policy ought to be *industry-specific*, allowing, for example, broad patent protection for industries such as the computer industry or telecommunications with many fertile, non-competing ideas, but limiting patent breadth in certain other industry categories.

Denicolo (1996) has specifically attempted to extend the analysis of the optimal patent breadth-length mix to the case of a patent race where there is R&D competition. Denicolo observes that the optimal patent breadth literature of Gilbert & Shapiro (1990) and Klemperer (1990) takes the socially desired R&D investment as pre-specified, and studies the efficient way (least deadweight loss) to incentivize firms to invest in R&D of exactly that amount. By contrast, Denicolo (1996) attempts to takes into account the effect of R&D competition itself on the incentive to innovate, and therefore on the optimal patent breadth. Denicolo concludes that, the more inefficient is R&D competition (in the sense that it spurs patent races), the broader and

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42 Since economists have found that the social rate of return to R&D is often higher than the private rate of return, there may still be too little R&D even when there are patent races.

shorter patents should be. The reason is that inefficient R&D is less likely to be promoted by broad patents that limit competition.

D. Optimal Patent Length/Breadth Literature—Cumulative Framework

Another important strand of literature is that connected to the determination of optimal patent breadth in a world such as that posited in Theory 4, where there is cumulative innovation, i.e., a multi-stage process of inventions, changes to these initial inventions, and improvement. In this framework, an optimal patent policy is concerned both with providing the best incentive mechanism to develop a primary invention as well as to assure incentives for secondary follow-on inventions. When an innovation can be subject to successive improvements, the incentives of the initial inventor will depend on the potential to share the benefits from follow-on innovations. To the extent that the patent protection for the primary invention controls the development of the follow-on invention, the patent may become an instrument for orderly development of more innovation.

Kitch (1977) views this as a problem of optimal coordination among different researchers working on related technologies. Without coordination, there is likely to be wasteful duplication of effort and possibly over-investment as firms try to be the first to break through. Kitch argues that granting broad patent rights to the initial pioneering inventor as a technology initially develops will rationalize the development process. Development will not stop, however, since the pioneering inventor would have an incentive to include in the development process other potential inventors with additional ideas or capabilities, via licensing or other contractual arrangements.

Later work has increasingly emphasized the incentives of the potential follow-on inventors.[43] In this line of research, patent scope of the original invention is measured as the magnitude of improvement represented by a follow-on invention before it is either granted its own patent or held to infringe the original invention. For example, Green & Scotchmer (1995) show that in the case of sequential innovation where the follow-on innovations compete with the

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43 *See, e.g.,* Scotchmer (1991; 1996), Green & Scotchmer (1995), Chang (1995) and O'Donoghue (1998)

primary innovation, there could be inadequate incentive to invest in basic research. According to Green & Scotchmer, an optimal patent policy will reduce this inefficiency by transferring profit to the first-generation innovators. Other literature in this line also confirms Kitch (1977)'s view that broad patents should be granted to initial inventions that form the basis for a cumulative development line. The intuition behind this result is that, absent a broad patent which allows the capture of positive externalities, the incentive to create broad "shoulders" for other inventors to stand on is socially inadequate. Scotchmer has even argued in some contexts that "second generation" products should not be patentable at all.[44] This result, however, seemingly depends on the assumption that the trajectory of innovation is known, such that the first innovator will have an *ex ante* incentive to license his technology to the second whenever it is optimal to do so under terms that do not prevent the development of second-generation invention. Others have pointed out that this assumption may not be tenable in some situations given the uncertainty of future innovation paths. If the *ex ante* licensing assumption is not tenable, then there may be situations, particularly when we are dealing with inventions that are likely to spawn many fertile lines of subsequent cumulative invention, that infringing "second generation" products will not be developed.

Hopenhayn and Mitchell (1999) explore how an optimal patent policy should take into account the fact that inventions differ in the extent to which they are likely to generate cumulative inventions, and the speed with which they are likely to do so. For example, if an innovation leads to multiple and rapid improvements, an initial innovation effort will likely require greater initial rewards (i.e., broader patents) in order to recover the value of the investment before the invention becomes rapidly obsolete. On the other hand, this broad patent protection might not be necessary when secondary improvements take place at a slower rate. Hopenhayn and Mitchell demonstrate how overall innovation incentives can be improved if patentees are offered a "menu" of combinations of patent duration and patent scope or breadth. Allowing patentees to choose different types of patents with different durations and different legal rights incentivizes them to reveal private knowledge regarding the fertility of their inventions and the likely speed of follow-on. This enables a better balance between the

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44 Scotchmer (1996).

incentives of the initial and subsequent inventors than can be achieved with uniform patent scope.

It should be noted that Cornelli and Schankerman (1999) suggest in a slightly different context that patent policy should take account of the heterogeneity of innovation. While Hopenhayn and Mitchell concentrate on heterogeneity between *innovations* in their future prospects, Cornelli and Schankerman consider optimal patent policy when R&D productivity differs across *firms*. They believe high R&D-productivity firms should receive greater patent protection than lower productivity firms. Since firm type is not observable they propose to use patent renewal fees as a mechanism to differentiate patent lives: firms with more valuable innovations will be willing to pay additional fees in order to renew the patent and extend the patent life.

E. Empirical Literature

Virtually all the systematic empirical work that has been done on the effects of patents has been guided by Theory 1, since it explores whether patents appear to provide an incentive to invent through increasing the effectiveness of appropriability. There have been several interview or survey studies that have explored the perceived importance of patents as a means of enabling firms to profit from their inventions, all of which have explored inter-industry differences. These include a study by Mansfield (1986), the Yale survey by Levin et al. (1987) the Carnegie Mellon Study of Cohen et al. (1996), and an update of the Yale survey by Cohen et al. (2000).[45]

All of empirical work in this area has come basically to the same conclusion—that patents are a particularly important inducement to invention in only a few industries. In pharmaceuticals, for example, patents seem to be an important part of the inducement for R&D. However, in industries like semiconductors and computers, the advantages that come with a head start, including setting up production, sales, and service structures and moving down the learning curve, were judged much more effective than patents as an inducement to R&D. In some of these industries, the respondents said that imitation was innately time consuming and costly,

45 The 2000 update of the Yale study largely confirmed the initial findings in the Levin et al. (1987) study. However, the updated report found some increase in the relative effectiveness of trade secrecy as a means of

even if there were no patent protection. In others, it was said that technology was moving so fast that patents were pointless. In any event, the empirical literature on appropriability certainly points up that there appear to be some industries where patents play a much smaller role than other forces in shaping the pattern of innovation. When we are looking at patent policy, we have to do so within the context of understanding how means other than patents induce invention and related activities. These other means include government grants and contracts, strong first-mover advantages, and rapid technological change.

There have also been several studies of the effects of different degrees of patent scope on invention. First, there are two studies *across countries*. Kortum and Lerner (1998) study the significant increase in patenting in the U.S. since the mid-1980s. They look at four possible explanations: the creation of the Court of Appeals for the Federal Circuit viewed as favorable for the scope of patent protection; favorable changes in the regulatory system; the development of new areas such as biotech and information technology; and increases in research productivity. They conclude that stronger patent protection and increased scope did not explain the surge in patenting; rather the main factor was judged to be an increase in the productivity of the research process. Brandsetter & Sakakibara (1999) estimate the impact of an apparent increase in the scope of Japanese patent protection starting in 1988, when Japan converted to a system much like the US in which a single patent can have multiple claims. They find no evidence of an increase in inventive activity, either in terms of overall R&D spending by Japanese firms or the number of innovations produced by Japanese firms in the US.

Nor is there compelling *industry* evidence on the effectiveness of changes in patent scope. Hall and Zionidis (2001) analyze the semiconductor industry, which is characterized by rapid technological change and cumulative innovation. They do not find that stronger patent protection since the 1980s is driving the innovation effort or output of firms in the semiconductor industry. They find that patenting in this industry is driven by patent portfolio races aimed either to ensure access to technology and not be "held-up" by rival patenting of the same technology, or to strengthen bargaining power when negotiating the access to other technology.

Finally, one study, by Merges and Nelson (1990), presents evidence on how patent scope

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appropriation.

affects innovation in a cumulative setting. Based on case studies of several important historical technologies, Merges and Nelson question the theoretical literature advocating broad patent protection for pioneering innovators in the context of cumulative innovation. The analytical basis for the disagreements is that Merges and Nelson believe that *ex ante* uncertainty and disagreement among competitors about which lines of development will be most fruitful makes licensing agreements or other such coordination mechanisms unlikely and or ineffective. Examining the historical development of electrical lighting, automobiles, airplanes and radio, they argue that the assertion of strong patent positions, and disagreements about patent rights, inhibited the broad development of the technologies rather than aiding subsequent development.

III. Market Structure and Innovation

This section focuses on the economics literature that relates market structure to innovation. In particular, it reviews economics literature that analyzes how market structure can affect innovation. It not only identifies factors that may cause innovation to increase in competitive markets, but also considers the possibility that large firms in concentrated markets may undertake more innovative efforts. In addition, it considers the possibility that innovation and concentration levels are jointly determined by fundamental characteristics of the market, such as technological opportunities. Both theoretical and empirical literature is surveyed as part of this review.

A. Competition and Potential Competition Can Increase Innovative Activity

Economists have constructed theoretical models that indicate that incentives associated with outperforming rivals can encourage competitive firms to innovate. In some cases, it is the lure of supra-normal returns that encourages competitive firms to innovate. In others, innovative activity is promoted by the possibility that rivals will take customers, threatening the firm's long-run existence. In contrasts, firms that are insulated from competitive pressures may chose a "quiet life,"[46] and not undertake aggressive R&D programs.

In early work analyzing how the incentive to innovate varies across market structures, Arrow (1962) presented models in which a monopolist's incentive to innovate is always less than competitors' incentive to innovate.[47] In Arrow's model, which ignores the difficulties of appropriating the information generated by innovative efforts, a monopolist takes into account pre-innovation profits and produces less output, which means that the monopolist will earn fewer incremental profits from process innovation.

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46 As Hicks commented, "the best of all monopoly profits is a quiet life," which implies that insulation from competition may lead to inefficient production and higher costs. Hicks (1935), p. 8.

47 Arrow (1962) uses a model in which the innovator licenses all firms that wish to use a cost reducing innovation that pay a royalty. Once the royalty is paid, all firms engage in perfect competition.

Economists have expanded on this early work by studying the relationship between innovative activity and market structure in other game theoretic models.[48] For example, using a completely symmetric, Cournot-duopoly,[49] new product game,[50] economists have shown that, in equilibrium,[51] both firms undertake more R&D than they would in the absence of rivalry.[52] Some economists argue that an uncooperative outcome to such games is particularly likely because competitors tend to overestimate their own R&D abilities and underestimate the capabilities of rivals.[53] Cooperative behavior (which includes both tacit and explicit collusion) is also less likely when R&D involves secret competitive activity which complicates the detection and punishment of cheating on a collusive outcome. Moreover, it has also been shown that an increase in the number of symmetric rivals can accelerate R&D, at least to some point.[54] However, if the number of rivals is too large, it may be that the returns from R&D that an individual firm can capture are viewed as too small to justify R&D (both because of the sharing of the rents among more firms and because the size of the rents that are to be shared are reduced due to increased price competition), causing firms to do no R&D.[55]

Yi (1999) extended Arrow's analysis to models that assume Cournot competition. He found that for process innovation, if the innovation is not drastic (i.e., results in lower costs such

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48 Game theoretic models are models that predict market outcomes based on assumptions about the competitive interactions of firms. These competitive interactions are modeled by making behavioral assumptions about the firm strategies and the market outcomes that result when particular combinations of strategies are selected.

49 The Cournot model is an economic game in which the players each assume that the other players will maintain the output levels they produced in the previous period. A Cournot-duopoly is a Cournot game with two competing firms (players).

50 A new product game is a game in which at least one player has the option of introducing a new product.

51 Equilibrium occurs when no market actor has an incentive to change its behavior given the actions of the other market actors.

52 Scherer & Ross (1990), p. 634.

53 William Fellner, (1951).

54 Scherer & Ross (1990), p. 636.

55 Scherer & Ross (1990), pp. 636-637.

that the firm's monopoly price is below the cost of incumbent firms), the benefit of a small process innovation decreases with the number of firms under certain conditions. Intuitively this is because the benefit of a process innovation is correlated with output of the firm, which declines as the number of firms increases. Since output increases with the lower price resulting from the innovation, it is also intuitive that the result depends on the elasticity of demand. For constant elasticity of demand, the benefit of a small innovation may increase or decrease with N [the number of firms] up to and including 3 firms, but will decrease with N thereafter. These results hold for innovations up to the size of "almost drastic."[56]

Boone (2001) generalized the results to include a parametric measure of the intensity of competition with Bertrand[57] and Cournot competition as special cases. Boone considers firms with differing costs. He also assumes that the number of firms is determined endogenously by the cost history and the intensity of competition. The model uses three firms located in a triangle. Intensity of competition is measured by the inverse of travel cost. Boone assumes that the value paid by the highest bidder is positively correlated with the speed of technological progress. The discount factor is assumed to be constant across firms. In his model, the intensity of competition determines whether the lowest cost firm will purchase the innovation and at what value. He finds that under his assumptions, in weakly competitive industries with a stream of small innovations, a small rise in competition may reduce the speed of technological progress. He also finds that if competition is intense and innovations lead to major changes in technology, small increases in competition may speed innovation because the leader is under pressure to innovate because a failure to innovative would cause the leader to lose its competitive advantage.

As is explained in more detail in Section II in the analysis of patent races, firms that perceive competition for technical opportunities may have a strong incentive to innovate. However, firms that see that they are behind in an innovation race may slow down their R&D

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56 Yi (1999), p. 379. An innovation is defined to be drastic if the innovating firm's monopoly price is below the other firms' marginal costs.

57 Bertrand competition is an economic game in which competitors all assume that the other competitors will charge the same price that they charged in the previous period. It differs from Cournot competition because it focuses on prices as the competitive variable, rather than quantities (which Cournot competitors assume will not change between periods).

efforts since they perceive that there are fewer returns from such an effort.[58]

Economists have shown that the threat of competition may lead to more innovation by incumbents, relative to potential entrants.[59] For example, Gilbert and Newberry (1982) show that, under certain conditions, incumbents will have a greater marginal incentive to invest in R&D than will entrants, when entry is a serious threat. This encourages preemptive patenting leading to industries that tend to remain monopolized by the same firm. The monopolist will preemptively invest in R&D if the cost is less than the profits it would earn by preventing entry.[60]

Extending the work of Gilbert and Newberry (1982), Reinganum (1983) assumes that the inventive process is stochastic rather than deterministic.[61] As a result of this changed assumption, Reinganum finds that an incumbent will invest less on a given project than will a potential entrant. In the Reinganum model, the incumbent firm receives a flow of profits while it is in the process of innovating. The greater the investments that the firm makes in R&D, the sooner its existing product will be replaced and the shorter will be the period of time during which it receives the profit flow from its existing product. The incumbent effectively replaces its existing product with a more profitable product. Since an entrant profits from the results of its R&D, but has nothing in the market that will be displaced by the new product, the entrant has a greater marginal incentive to invest in R&D than does the incumbent.

Lin (1998) extends the Reinganum model using a two-stage game. Firms compete in the first stage, then engage in a patent race. Firms behave so as to "soften" rivals' incentive for future R&D. The result is an equilibrium price that is higher than in the standard duopoly models and a slower pace of innovation than the standard duopoly equilibrium outcome. Coordination

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58 *See, e.g.,* Scherer (1967), p. 359 and Grossman & Shapiro (1987), p. 376.

59 For a discussion of this literature, see also Tirole (1994), pp. 394-399.

60 One key assumption in this work is that the date of an invention is a deterministic function of the time path of expenditures.

61 An inventive process that is "stochastic" has a random (uncertain) component to it. In contrast, a deterministic process is perfectly predictable given knowledge of the underlying behavioral relationships.

of R&D (e.g., through the formation of a joint venture by the competitors) eliminates the R&D threat and permits the standard duopoly outcome to be obtained. The results hold for both Cournot and Bertrand models. The welfare effects are ambiguous, depending on the degree of wasteful R&D in the patent race and the effect of the reduced product market price from cooperation.

Harris and Vickers (1985) extend the Gilbert and Newbery model by distinguishing two kinds of patent races. A "standard race" is one in which a price is awarded to the first player to reach the finishing line. An "asymmetrical race" it is also true that a prize is awarded if someone reaches the finishing line, but it is also true that one player loses something of value if one of his rivals reaches the finishing line (and as a result this player is content if nobody wins). Harris and Vickers model asymmetrical races, since they believe that this provides insights into patent races in which an incumbent firm's principal, if not sole, concern is preventing potential rivals from entering his market.[62] They find that in a model of an asymmetrical race the challenger is often deterred from making an effort to win the race because strategic interactions are such that incumbents would outdo any reasonable effort by the challenger. Moreover, to deter the challenger, the incumbent often does not need to complete the patent itself. On the other hand, there are some situations in which the challenger does proceed and cross the finishing line first. Nonetheless, they conclude that among the strategic advantages that an incumbent firm might enjoy in patent races (especially when the parties begin far from the finishing line) is the possibility that the incumbent will benefit from a result in which no one wins the patent race. Moreover, they suggest that this strategic advantage may underlie the persistence of market power in some markets.[63]

Katz and Shapiro (1987) considered the possibility that a firm might benefit from its rival's innovation. In their model, each firm compares the profits that it would earn assuming no innovation with the profits that it would earn should it be the innovator and, separately, with the profits it would earn if a competitor does the innovating. The authors note that when patents are

62 Harris and Vickers (1985), p. 461.

63 Id., p. 477.

not perfect, and the innovation is not essential to survival, imitation might occur. If a firm can imitate its rival quickly, effectively, and at low cost, it may benefit from a discovery made by a competitor. Even when patents are so strong that imitation is impossible, licensing may allow a firm to profit from a rival's innovation. For minor innovations, Katz and Shapiro find that the industry leader will typically be the innovator, whether or not imitation and licensing are feasible. In markets where patent protection is strong, they find that major innovations will be made by industry leaders. But if imitation is easy, the innovators will be smaller firms or entrants.

Boone (1998) notes that an individual company's response to competitive pressure will depend on its own cost level relative to those of its opponents. As a result, the effects of competitive pressure on the innovation response of firms will differ across firms. Because of this, any study that tries to find a single innovation response for all firms in an industry will be flawed. An increase in competitive pressure may raise some firms' incentives to innovate, but decrease those of other firms. Also, Boone shows that an increase in competitive pressure cannot increase incentives for both fundamental research and development at the industry level. In Boone's model, an increase in competition cannot increase overall efficiency in the market and also increase the number of new products introduced into the market.[64]

Bonanno and Haworth (1996) examined two questions with regard to the effect of competition on innovation. First, they considered whether cost-reducing innovations are positively or negatively correlated with the intensity of competition. Second, they analyzed what factors might be important to a firm when deciding whether to engage in process (cost reducing) innovation or product (quality improving) innovation.

To address the first question, they considered two industries that were identical except that one has Cournot competition and the other had Bertrand competition. They assumed that the industry characterized by Cournot competition was less competitive, because this process leads to lower output and higher prices. The authors found that any given cost reduction increased profits more in the case of Cournot competition than in the case of Bertrand competition. Thus,

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64 Boone (1998).

they concluded that there are cost-reducing innovations that would be pursued under Cournot that would not be pursued under the more competitive Bertrand scenario.

With respect to the second question, Bonanno and Haworth found that the degree of competition in a market does affect the choice between process and product innovation.[65] A firm with a high quality product is more likely to go for product innovation if it is a Bertrand competitor, and process information if it is a Cournot competitor. In a Bertrand regime, a cost reduction has a negative strategic effect that leads to more competition so that the new equilibrium following process innovation would lower prices for both firms. Product innovation will lead to a price increase for the innovator, but might either increase or decrease the price of the other firm. A firm with a low quality product is more likely to go for process innovation if it is a Bertrand competitor, but will prefer product innovation if it is a Cournot competitor. Process innovation by the firm with a low-quality product has negative strategic effects, so the innovator and the competitor will both lower their prices. Product innovation by the firm with the low quality product would potentially have positive strategic effects, since it shifts the innovator's reaction curve up.[66]

B. Innovation by Large Firms in Concentrated Markets

The conclusion that competitive market structure will lead to dynamic efficiency has been challenged by a number of economists. Schumpeter (1942) is most often cited as the originator of the view that atomistic firms operating in competitive markets may not be as dynamically efficiency as a larger firm operating in a more concentrated market. Specifically, Schumpeter concludes that "What we have got to accept is that it [the large-scale establishment or unit of control] has come to be the most powerful engine of progress and . . . long-run expansion of total output . . . through this strategy which looks so restrictive when viewed in the individual case and from the individual point of time."[67]

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65 The results are likely to be dependent on the particular models that were employed and may not be present in more general models.

66 Bonanno & Haworth (1996).

67 Schumpeter (1942), p. 106.

Schumpeter's argument has been interpreted in two slightly different ways. First, it could be that large firms are more innovative than smaller firms. Second, it could be that firms in concentrated industries undertake more innovation. While both theories may be consistent, there are differences and they have spawned somewhat different empirical tests of the "Schumpeter Hypothesis."[68]

Economists have developed a number of situations in which a large firm in a concentrated industry may have an incentive to invest more heavily in innovative activity than a smaller firm in a less concentrated industry. Some of these explanations are based on the premise that innovative activity is less costly for large firms. Other explanations are based on the belief that large firms may obtain more benefits from innovative efforts.

The principal basis for believing that large firms may have lower innovation costs is that there are significant economies of scale in the innovative process.[69] Economies of scale in the innovation process may be generated in three ways. First, firms that undertake large amounts of R&D may be able to employ more specialized resources, reducing the marginal costs of innovation. Second, to the extent that innovation involves significant fixed costs, large scale firms will face smaller average total costs because they can average the fixed costs of their innovative effort over a greater level of output.[70] Third, large firms may be able to support a larger portfolio of R&D efforts, increasing the likelihood that it will develop an improved product or process, which makes large-scale innovation efforts less risky.[71]

The costs of innovative activity may also be smaller for large firms if the cost of investment capital is lower. As a result, some economists have hypothesized that large firms will undertake more innovation because they have access to inexpensive capital. In some cases, economists have argued that inexpensive capital is generated internally. Specifically, it is argued

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68 The empirical literature is reviewed in Section III.C of this appendix.

69 Scherer & Ross (1990), p. 652.

70 Cohen & Klepper (1996), p. 926.

71 Scherer & Ross (1990), p. 652.

that monopolistic profits are used to fund increased innovative activities.[72] However, others have argued that large firms face lower capital costs in capital markets.[73]

Economists have identified a number of factors that may increase the benefits of innovation to large firms in concentrated markets relative to smaller firms. First, large firms may obtain a larger total benefit from a process innovation that lowers production costs because a given percentage decline in costs will lead to greater cost savings when it is applied to a larger number of units of production.[74] Second, a large firm may be more likely to benefit from an innovative effort because it is more likely to be diversified into a number of different products, which will increase the likelihood that a discovery will be applicable to one of its businesses.[75] Third, large firms may be able to market new products more effectively, increasing the value of new product development to them, which encourages innovative activity.[76]

C. Empirical Studies of the Relationship Between Market Concentration or Firm Size and Innovation.

As indicated above, Schumpeter (1942) led economists to two hypotheses: (1) Large firms are more likely to undertake innovation than small firms and (2) Higher levels of innovative activity are more likely to be observed in concentrated industries. This section considers the numerous empirical studies economists have done to test the two "Schumpeterian hypotheses."

Summary data on R&D activity provides some support for Schumpeter's hypotheses. Historically, large enterprises have performed a significant share of formal R&D (e.g., firms with

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72 "One hypothesis is that profits accumulated through the exercise of monopoly power are a key source of funds to support costly and risky innovation." Scherer & Ross (1990), p. 630.

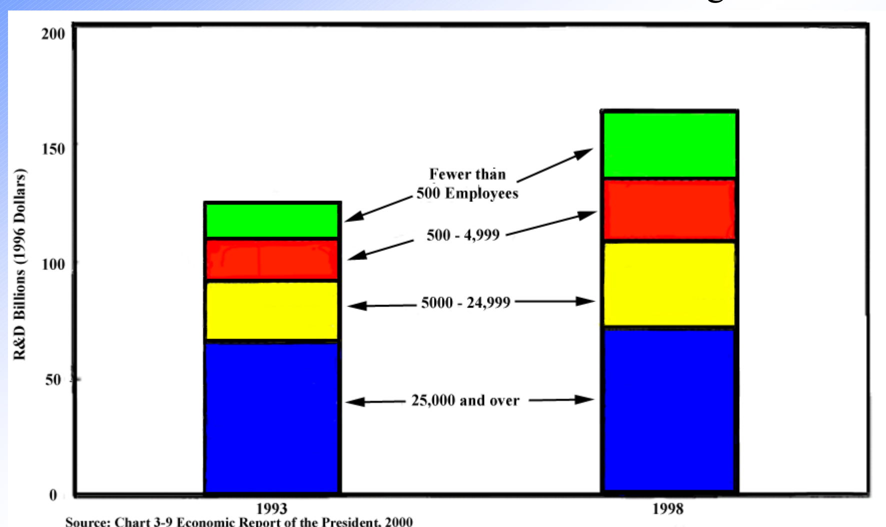
73 Scherer & Ross (1990), p. 652.

74 Link (1980), p. 771.

75 "[A] monopoly may create superior incentives to invent [because] appropriability may be greater under monopoly than under competition." Arrow (1962). *See also*, Scherer & Ross (1990), p. 659. However, there is limited empirical support for this proposition. *See, e.g.,* Scott, (1988) and Cohen et al. (1987). However, larger firms do appear to do more basic R&D. *See, e.g.*, Link & Long (1981).

more than 10,000 employees performed more than 80% of formal R&D).[77] As Figure III shows, large firms continue to perform a significant share of the R&D. However, as Figure III also shows, smaller firms have performed an increasing share in recent years. Moreover, it has long been the case that small firms have performed a significant share of R&D. For example, Jewkes, Sawers, and Stillerman (1969) reviews seventy important Twentieth Century inventions and finds that only 24 had their origins in industrial research laboratories.

Figure III.
Large Firms Fund Most R&D,
But Small Firm R&D Has Been Increasing Faster



In an effort to test the two Schumpeterian hypotheses, economists have undertaken numerous statistical studies that have attempted to control for the myriad of factors that affect innovation besides firm size and market concentration. These studies have been reviewed by a number of economists.[78] As a result, rather than reproducing an exhaustive review of the literature, this section identifies key findings, focusing on more recent findings. The discussion distinguishes between relationships between firm size and innovation and market concentration

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76 Scherer & Ross (1990), p. 652.

77 Scherer & Ross (1990), p. 654.

78 *See, e.g.,* Scherer (1980); Kamien & Schwartz (1982); Baldwin & Scott (1987); Cohen & Levin (1989); Scherer & Ross (1990), pp. 613-660; Cohen (1995).

and innovation, since the economics literature has focused on both relationships.

1. Firm Size and Innovation

Economists have found a positive relationship between firm size and the likelihood that a firm performs R&D.[79] While early work was based on somewhat limited data,[80] more recent work that allows one to control for industry effects (i.e., to control for other industry characteristics that might affect the performance of R&D) has confirmed the basic relationship.[81]

Early studies found that R&D rose more than proportionately with firm size. However, these studies did not control for industry effects and thus may have reported biased statistics.[82] Subsequent work, most notably Scherer (1965), suggested that innovation increases more than proportionately with firm size only up to some size level. This view was the consensus view during the 1980s.[83] More recent work suggests that "R&D rises monotonically with firm size, and proportionately beyond some modest firm size threshold."[84] In addition, economists have often found that R&D varies "closely with firm size within industries, with size typically explaining over half of its variation."[85] As a result, economists increasingly came to believe that "large firms did not possess any advantages in R&D competition."[86] Specifically, "studies not only confirmed that large firms do not conduct a disproportionate amount of R&D relative to size, but also indicated that large firms actually generate fewer innovations per dollar of R&D

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79 For a contrary view, see Schmookler (1959).

80 Villard (1958); Nelson et al. (1967).

81 Bound et al. (1984) and Cohen et al. (1987). For a general discussion of the use of the FTC's line of business data to study structural relationships, such as the concentration-margin relationship, see Salinger (1990).

82 Illustrative of these early studies are Horowitz (1962) and Hamberg (1964).

83 *See, e.g.*, Scherer (1980), Kamien & Schwartz (1982).

84 Cohen (1995), p. 186.

85 Id.

86 Cohen & Klepper (1996a), p. 1.

than smaller firms, which has been widely interpreted as reflecting a disadvantage of size."[87]

More recent work by Cohen & Klepper (1996a) suggests that some modification of the previously existing consensus may be in order. Specifically, they report evidence that increased size may be associated with increased R&D (and more productive R&D) because firms with larger business units can spread the costs associated with R&D over greater sales revenues. In addition, they found that, "for the firms in the FTC data set, the close relationship between R&D and size appears to be due principally to business unit [subsidiary or division level] rather than corporate level factors."[88] In a related study, Cohen and Klepper (1996b) find that the relationship between firm size and innovation is stronger for process innovations than for product innovations. They caution, however, that their findings do not indicate that large firms are the engines of economic growth, nor do they indicate that there are no disadvantages to large size.[89]

2. Market Concentration and Innovation

Economists have explored how today's market structure affects the level of innovation.[90] As Scherer & Ross (1990) point out, "[m]ost studies for the United States and other leading nations reveal a positive correlation between concentration and industry R&D/sales ratios, or

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[87] Id. Other studies done during this time period found that inter-industry differences in R&D intensity have a much more significant effect on the level of R&D than differences in the size of firms within an industry. *See, e.g.,* Cohen et al (1987).

Economists have also looked at the relationship between firm size and R&D intensity. For example, based on an analysis of FTC Line of Business Data, Cohen et al. (1987) concluded:

> [O]verall firm size has a very small, statistically insignificant effect on business unit R&D intensity when either fixed industry effects or measured industry characteristics are taken into account. Business unit size has no effect on the R&D intensity of business units that perform R&D, but it affects the probability of conducting R&D. Business unit and firm size jointly explain less than one percent of the variance in R&D intensity; industry effects explain nearly half the variance.

[88] Id., p. 938.

[89] Cohen & Klepper (1996).

[90] Schumpeter was also concerned with how the incentive to innovate was related to ex post market structure (and associated market power). There has been substantially less research on this issue. Phillips (1966) discusses this possibility.

cruder proxies of these ratios."[91] However, there are some contrary results. For example, a few studies have found that that concentration is negatively associated with R&D.[92]

In related work, Greer and Rhoades found that market power as measured by concentration is positively correlated with productivity changes.[93] However, the inclusion of R&D expenditures in the equation eliminated the explanatory power (statistical significance) of market concentration. Some have interpreted this result as indicating that "the chain of causation appears to run from higher R&D spending, which is correlated with seller concentration, to higher productivity growth."[94]

While most studies have focused on a linear relationship between market concentration and innovation, Scherer (1967) found that there may be a non-linear relationship. Specifically, it is possible that innovation increases with concentration up to some point and then declines. This finding has been replicated by others.[95]

Some early work by economists suggested that innovation might have deconcentrating effects.[96] Subsequent work has suggested that innovation and entry are sometimes associated with each other.[97] Granger causality tests performed by Geroski (1991a, 1991b) suggest that entry may cause innovation, rather than vice versa.[98] Similarly, others have found that innovation may be associated with the growth of smaller firms or entry, which may lead to lower

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91 Scherer & Ross (1990), p. 646. *See also*, Baldwin & Scott (1987).

92 *See, e.g.,* Williamson (1965); Bozeman and Link (1983); Mukhopadhyary (1985).

93 Greer & Rhoades, (1976). *See also*, Amato & Ryan (1981).

94 Scherer & Ross (1990), p. 645.

95 *See, e.g.,* Scott (1984) and Levin et al., (1985).

96 Blair (1948).

97 *See e.g.,* Geroski (1990, 1991a, 1991b)

98 Granger causality tests are statistical tests that are designed to test for causal relationships between economic variables in a statistical study.

concentration in innovative markets.[99] Moreover, Gort & Konakayama (1982) found that entry rates were higher than exit rates in the early stages of major product developments, which suggests that product innovation can have a deconcentrating effect. However, Geroski observes that the presence of significant industry fixed effects implies that other structural characteristics of markets may simultaneously determine both innovation and entry.[100]

Numerous economists have observed that the results that relate concentration to innovation are sensitive to industry characteristics.[101] For example, Scott (1984) and Levin et al. (1985) found that the addition of variables that controlled for differences in company characteristics and industry characteristics eliminated the statistical significance of concentration as an explanation for variations in innovative activity,[102] suggesting that the statistical significance that was observed in some regressions may be a statistical artifact of statistical relationships involving fundamental industry characteristics.

D. Fundamental Structural Characteristics of Technology May Determine Market Structure and Innovative Activity

Economists have recognized that both concentration and R&D efforts may be simultaneously determined by other market characteristics. Specifically, it may be that "the market structure affecting R&D decisions is not given, but endogenously determined by technology and competition."[103]

A number of economists have explored the relationship between innovation and

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99 Mukhopadhyay (1985).

100 *See* Section D below for a discussion of the simultaneous determination of innovation and market concentration.

101 *See* articles reviewed by Cohen (1995), p. 195.

102 Concentration was included in these regressions in two forms: expenditures and expenditures squared. The coefficients on both of these variables were insignificant when company and industry effects were included in the regressions. Regressions are statistical tests that are designed to estimate statistical relationships between variables. Statistical relationships are revealed in regression coefficients that are produced by the statistical test. When the statistical test is done properly, the regression coefficients can be interpreted to identify the likely direction and statistical significance of the relationships between the variables.

concentration by using multi-equation models in which concentration and R&D are both simultaneously determined by other factors.[104] When performed, statistical tests support the view that both innovation and concentration are simultaneously determined.[105] As a result, some have concluded that "[r]ecent empirical works suggests that R&D intensity and market structure are jointly determined by technology, the characteristics of demand, the institutional framework, strategic interaction and chance."[106]

One of the market characteristics that may simultaneously shape both market structure and innovation is the set of technological opportunities that firms face. Specifically, if rich technological opportunities mean that an innovator may not be able to retain significant rents because others will develop competing innovations (as may be the case when there are numerous technological opportunities), one may not see as much innovative activity in unconcentrated markets where there are rich technological opportunities as one sees in more concentrated markets.[107] In a study that uses levels of innovative activity at one point in time to control for technological opportunities in the industry at other points in time, it was observed that higher seller concentration was associated with less innovation.[108] Some have concluded that "interindustry differences in technological opportunity, however measured, have much greater power in explaining varying R&D or innovation intensities than differences in such market structure indices as concentration."[109]

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103 Scherer & Ross (1990), p. 642.

104 *See, e.g.,* Farber (1981); Wahlroos and Backstrom (1982); Connolly and Hirschey (1984); Levin & Reiss (1984); and Levin et al. (1985).

105 Simulation models also support this view. *See, e.g.,* Nelson and Winter (1978).

106 Symeonidis (1996).

107 Scherer (1984); Comanor (1967).

108 Geroski, (1990).

109 Scherer & Ross (1990), p. 648.

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Annotated Selected Bibliography

Section II

Optimal Patent Length/Breadth Literature—Non-Cumulative Framework

1. Arrow (1962), "Economic Welfare and the Allocation of Resources for Invention": Explores whether competition yields the optimal allocation of resources in the context of innovation. The author identifies three sources of possible inefficiency: indivisibility, inappropriability and uncertainty. The study concludes that an optimal allocation of resources would require institutions with non-pecuniary motives to govern the innovation process.

2. Nordhaus, W. (1969), *Invention, Growth and Welfare: A Theoretical Treatment of Technological Change*:
This book addresses broadly the economics of technology, presenting a model of invention and considering its implications for competition and diffusion. This book also addresses the economics of patents and optimal patent life, concluding that when the efficiency of patents is low, as in the case of large inventions characterized by large investments and positive externalities, other mechanisms to foster innovation should be introduced.

3. Scherer, F. M. (1972), "Nordhaus' Theory of Optimal Patent Life: A Geometric Reinterpretation":
Extends Nordhaus' work. This study proposes a flexible system of patent protection adapted to each patent. This might be enforced though a system of compulsory licensing and putting the burden to justify the need for longer protection on the side of the patentee.

4. Tandon (1982), "Optimal Patents with Compulsory Licensing":
Patent protection has associated inefficiencies caused by conferring market power on the patent holder. This paper proposes using compulsory licensing to minimize this tradeoff. The optimal patent policy combines a licensing rate and a patent life. This optimal patent will have indefinite life for both process and product innovations.

5. Waterson (1990), "The Economics of Product Patents":
Explores the effect of patent protection. In this model patents do not prevent entry, i.e., they do not create a monopoly but they do affect entry behavior. The characteristics of the patent system and enforcement can affect the rival's choices and the market equilibrium. This implies that when variety is socially valuable, an optimal patent policy will have narrower patents.

6. Gilbert, Richard and Carl Shapiro (1990), "Optimal Patent Length and Breadth":
Model of non-cumulative innovation and homogeneous products. Patent breadth is defined as the price-cost margin that the patent holder can set. The only source of welfare loss is the inefficiency connected with not consuming the product in question. The optimal policy will be to minimize the welfare loss by defining narrower patents with longer-life, i.e. set prices to minimize the loss from non-consumption.

7. Klemperer, Paul (1990), "How Broad Should the Scope of Patent Protection Be?": Model of non-cumulative innovation with product differentiation. Broader patents eliminate the deadweight loss from consumers choosing less-preferred goods at a lower price within the same product class. Broader patents also confer on the patentee greater market power, which generates a welfare loss by driving some consumers out of the market. If consumers have similar valuations of the preferred good relative to not consuming, then short-lived wide patents are optimal; if the substitution costs across varieties of the same class of goods are similar, then narrow long-lived will be optimal.

8. Gallini (1992), "Patent Policy and Costly Imitation": Introduces a model with costly imitation of patented innovations. With longer patent protection there are greater incentives to imitate. In this framework optimal patent policy would define broad patents with patent length sufficiently short to discourage imitation.

9. Arora and Gambardella (1994), "The Changing Technology of Technological Change: General and Abstract Knowledge and the Division of Innovative Labor": Innovation is described as a process in which general and abstract knowledge is increasingly used, allowing for the specialization and the division of innovative labor. In this framework the authors advocate a strong patent regime: broader patents increase technological change by providing incentives for innovators without downstream capabilities.

Patent Race Literature

10. Barzel (1968), "Optimal Timing of Innovation": This study highlights the problems of appropriability and over-investment that characterize the innovation process. Competition between innovators leads to excessive investment in innovation. On the other hand the inability to fully appropriate the output of innovation reduces the incentives to innovate.

11. Loury (1979), "Market Structure and Innovation": Model of innovation with uncertainty on both the success of the firm in developing the technology and on the rival's success to develop a competing one. Rivalry reduces the incentives to innovate but increases the probability of innovation. A social welfare maximizing policy would reduce entry and wasteful duplicative efforts with licensing fees and finite life patents.

12. Dasgupta and Stiglitz (1980a), "Uncertainty, Industrial Structure and the Speed of R&D" Study of the nature and effects of competition in the R&D market, and how this affects competition in the product market. Competition in the R&D market is likely to increase the level of innovation beyond the social optimum. Competition in the product market reduces innovation relative to monopoly. Paper makes the important assumption that firms face uncertainties about the date at which they will achieve innovative success, so that all firms do not follow the same research strategy.

13. Dasgupta and Stiglitz (1980b), "Industrial Structure and the Nature of Innovative Activity":

Authors attempt to provide an analytical framework relating market structure to the nature of inventive activity. They conclude that there is no reason for supposing that a market economy invests too little in R&D, and there may well be over-investment. Unlike Dasgupta and Stiglitz (1980a), this article assumes that all firms are obliged to follow the same research strategy. If the first firm to succeed gains most of the reward for invention, then to the extent the risks that firms undertake are positively correlated, pressure of competition will ensure only a few firms innovate. Still, pressure of competition may result in excessive speed in research.

14. Harris and Vickers (1985), "Patent Races and the Persistence of Monopoly":
Explores the consequences of an asymmetrical patent race in which an incumbent firm's sole concern is to prevent potential rivals from entering the market, not winning the standard patent race. It is shown that the challenger is often automatically deterred from making any effort to win the race, because the strategic interactions between the players are such that the incumbent would outdo any reasonable effort made by the challenger in order to stop the challenger from being first to reach the finish line. The reason is that the incumbent—unlike the challenger—need not go all the way to the finish line to achieve his objective.

15. Lippman and McCardle (1987), "Dropout Behavior in R&D Races With Learning":
Examines a game-theoretic model of a two-firm R&D race in which expenditures on R&D and the associated increase in experience/learning enable the firms to increase their probability of discovering an invention. The learning process is subject to uncertainty, and generates an outcome for identical firms where the leader never drops out, but the follower drops out if the leader gains a significant lead. By contrast, if the firms value invention differently or have different R&D efficiencies, the leader can find it optimal to drop out. Thus, results are between vigorous competition and natural monopoly.

16. Lerner (1995), "Patenting in the Shadow of Competition":
This study examines the patenting behavior of 419 firms in the area of biotechnology. Firms with high litigation costs are less likely to patent in areas in which there are many other patentees, especially if these have low litigation costs. This study highlights the importance of allocating the costs of litigation in the overall design of patent policy.

17. Denicolo (1996), "Patent Races and Optimal Patent Breadth and Length":
Extends the analysis of the optimal patent breadth-length mix by introducing R&D competition. This competition affects the incentives to innovate, and therefore the optimal patent breadth. The more inefficient the R&D competition (wasteful duplicative efforts), the broader and shorter patents should be. Inefficient R&D is less likely to be promoted by broad patents that limit competition.

18. Jensen and Thursby (1996), "Patent Races, Product Standards, and International Competition":
Examines anticipatory product standards intended to improve the strategic position of firms in an international patent race where firms do R&D to develop products that are close substitutes. The effects of a standard depend on the way the standard is specified, which firm develops which product, and the order of discovery.

Optimal Patent Length/Breadth Literature—Cumulative Framework

19. Kitch (1977), "The Nature and Function of the Patent System":
    Model of cumulative innovation. In the absence of coordination, competing innovators will duplicate efforts, and possibly over-invest. Broader patent rights for pioneering inventors will allow them to ensure an orderly development of the technology. The pioneering inventor will have the incentive to include other valuable ideas or capabilities in the development process via licensing or other contractual arrangements.

20. Schmitz (1989), "Imitation, Entrepreneurship, and Long-Run Growth":
    This model studies the effect of entrepreneurship on economic development. One feature of this model considers the imitation activities by entrepreneurs, not only their direct role in the creation of knowledge. In this model imitation, by transferring and implementing technology, has an important role in economic growth.

21. Scotchmer (1991), "Standing on the Shoulders of Giants: Cumulative Research and Patent Law":
    Model of sequential innovation. Follow-on innovations compete with the primary innovations, which can prevent innovators from recovering their investment, and could reduce the incentives to invest in basic research. Optimal patent policy will reduce this inefficiency by transferring profit to the first-generation innovators.

22. Chang (1995), "Patent Scope, Antitrust Policy and Cumulative Innovation":
    In an environment of cumulative innovation, this article proposes a model to address the question of how should courts set legal standards for patent infringement. Courts should grant broad patent protection to patents both with low and large value relative to the subsequent improvements that others might add.

23. Green & Scotchmer (1995), "On the Division of Profit in Sequential Innovation":
    Broader patents for initial innovators can preserve the incentive to innovate when subsequent innovators can erode the profits derived from innovation. The ability to transfer this wealth to the initial innovator is smaller when there is more than one secondary innovator. In these cases longer patents are necessary to preserve the incentives for the basic innovation.

24. Matutes et al. (1996), "Optimal Patent Design and the Diffusion of Innovations":
    First-generation innovators may have incentives to develop second-generation innovations before commercializing the product. A socially optimal patent policy should use patent scope to induce early disclosure of the basic innovation without eliminating the incentive to innovate. When competition in the market for applications is greater, protection should be stronger.

25. Scotchmer (1996), "Protecting Early Innovators: Should Second-Generation Products Be Patentable":
    In some contexts that "second generation" products should not be patentable at all. This model assumes that the trajectory of innovation is known, such that the first innovator

will have an *ex ante* incentive to license his technology to the second whenever it is optimal to do so under terms that do not prevent the development of second-generation invention.

26. O'Donoghue (1998), "A Patentability Requirement for Sequential Innovation":
In a framework of cumulative innovation in which improvements constantly take place, the incentives to innovate may fail because the innovator cannot recover his investment once the initial innovation is improved upon. In order to preserve the incentive to innovate while maintaining constant improvement, a minimum innovation size can be required to grant a patent. Requiring a greater innovation will increase the effective patent life, which will allow the innovator to recover the investment associated with the innovative effort.

27. O'Donoghue, Scotchmer, and Thisse (1998), "Patent Breadth, Patent Life, and the Pace of Technological Progress":
In a model of cumulative innovation, effective patent life is defined as the time until a patent expires or a noninfringing product displaces the product. This model distinguishes lagging breadth, which protects from imitation, from leading breadth, which protects from improved products. Adjusting statutory patent life to its effective life by narrowing and broadening it will improve diffusion; allowing patents to end by replacement lowers the costs of R&D.

28. Hopenhayn and Mitchell (1999), "Innovation Fertility and Patent Design":
An invention's likelihood and speed to generate subsequent inventions varies. An optimal patent policy should take into account this heterogeneity. Innovation incentives can be improved by offering patentees a "menu" of patent breadth-length mix. This induces patentees to reveal their private knowledge regarding likelihood and speed to generate subsequent inventions. This menu is better than a uniform patent in balancing the incentives of initial and subsequent inventors.

29. Cornelli and Schankerman (1999), "Patent Renewals and R&D Incentives":
Model of optimal patent policy when R&D productivity differs across firms. High R&D-productivity firms should receive greater patent protection than lower productivity firms. Patent renewal fees can be used as a mechanism to differentiate patent lives when firms have private information on the value of their innovations: firms with more valuable innovations will be willing to pay additional fees in order to renew the patent and extend the patent life.

30. Shankerman and Scotchmer (1999), "Damages and Injunctions in the Protection of Proprietary Research Tools":
Study of the optimal enforcement of patents for research tools in order to maximize the incentives for their development. The authors show that treating patent damages as a reasonable royalty is incorrect. To maximize the incentives either injunctions should be available or damages should be limited to the infringer's profits.

Empirical Literature

31. Mansfield (1986), "Patents and Innovation: An Empirical Study":
Empirical study based on a sample of 100 U.S. manufacturing firms. Finds that in many industries the effect of patents is very limited. Only in a few industries such as pharmaceuticals and chemicals are the effects substantial. Despite this, even in industries in which patents are not necessary to foster innovation, patentable innovations are generally patented.

32. Levin et al. (1987), "Appropriating the Returns from Industrial Research and Development":
The so-called "Yale Survey" addresses the conflict between appropriation and cumulative innovation implied by the patent system by providing survey evidence on how patents work as an instrument of appropriation in more than one hundred manufacturing industries. The results emphasize the importance of other means of appropriation such as secrecy. The survey also indicates that there is large cross-industry variation in appropriability and that strong patent regimes do not guarantee higher innovation.

33. Merges and Nelson (1990), "On the Complex Economics of Patent Scope":
Based on a review of important historical technologies in the U.S., this study questions the theoretical literature advocating broad patents for pioneering innovators. *Ex ante* uncertainty about which lines of development will be most fruitful makes licensing agreements or other such coordination mechanisms unlikely and/or ineffective. Strong patent positions, and the disagreements about patent rights, inhibited the broad development of the technologies rather than aiding subsequent development.

34. Lerner (1994), "The Importance of Patent Scope: An Empirical Analysis":
For a sample of biotechnology firms, the relation between patent scope and firm valuation is studied. The findings suggest that broader patents increase the value of the firm, especially when close substitutes are available. This confirms the importance of patent breadth as a policy tool.

35. Kortum and Lerner (1998), "Stronger Protection or Technological Revolution: What Is Behind the Recent Surge in Patenting?":
This study looks at the surge in patenting in the U.S. since the mid-1980s. Four explanations are provided: changes in the legal system (broader patents); changes in the regulatory system; the development of new areas such as biotechnology and information technology; and increases in research productivity. They conclude that the main factor that explains increased patenting was an increase in the productivity of the research process and not stronger patents.

36. Hall and Ham (1999), "The Patent Paradox Revisited: Determinants of Patenting in the U.S. Semiconductor Industry, 1980-94":
Study of the patenting behavior of firms in the semiconductor industry based on interviews with patent lawyers and IP managers. Patents are used not as a means of appropriation but as part of large portfolios put together for negotiation in cross-licensing agreements.

37. Sakakibara & Branstetter (2001), "Do Stronger Patents Induce More Innovation? Evidence from the 1988 Japanese Patent Law Reforms":
    This study estimate the impact of an apparent increase in the scope of Japanese patents starting in 1988, which allowed a single patent to have multiple claims. They find no evidence of an increase in inventive activity, either in terms of overall R&D spending by Japanese firms or the number of innovations by Japanese firms in the US.

38. Cohen et al. (2001), "Protecting their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not)":
    This survey shows that firms have multiple tools to protect the profits derived from their innovations. Among these tools, patents are the least important; secrecy and lead-time are the most important. The survey shows that patents also serve as a strategic tool by blocking rival's products in discrete product industries (e.g., chemicals), or as bargaining chips in complex product industries (e.g., telecommunications).

39. Hall and Ziedonis (2001), "The Patent Paradox Revisited: An Empirical Study of Patenting in the U.S. Semiconductor Industry, 1979-1995":
    Analysis of the determinants of the patenting behavior in the semiconductor industry between 1979 and 1995, based on interviews with managers. The study finds that the increase in patenting is a result of stronger patent protection used not as a means to appropriate the rents derived from R&D innovation but as a strategic tool in a rapidly changing industry.

Section III

Literature on How Competition and Potential Competition Can Increase Innovative Activity

1. Cave, J.A. (1985), "A Further Comment on Preemptive Patenting and the Persistence of Monopoly":
   Discusses whether bargaining allows for efficient innovation when a new entrant joins the market.

2. Dasgupta, Partha and Joseph Stiglitz (1980), "Uncertainty, industrial structure, and the speed of R&D":
   In this theory paper, Dasgupta and Stiglitz examine the relationship between competition in R&D and competition in the product market. Their analysis is broader than previous work that has focused on the influence of market concentration on R&D expenditures. Their research uses two extreme sets of assumptions to cover a wide range of possible outcomes. They have four main conclusions. First, if the product market is dominated by a monopolist, there is likely to be more R&D than when the market structure is competitive. The reason is that there will be less competition and more profits in the post-invention world. Second, competition in the R&D market always leads to more research than does monopoly. Third, even if R&D is competitive, under certain conditions a monopoly may persist in the product market. Competition in R&D does not guarantee competition in the product market because a monopolist in the latter can deter entry by engaging in sufficiently fast research that it does not pay any other entrant to engage in R&D. Fourth, uncertainty determines the number of firms engaged in R&D at any particular time. If there were no uncertainty, there would only be a single firm engaged in R&D. With uncertainty, there may be several

3. Rapp, Richard T. (1995), "The Misapplication of the Innovation Market Approach to Merger Analysis":
   Rapp disagrees with recent attempts, starting in 1993, by DOJ and the FTC to apply traditional merger analysis to an innovation market. There is little basis in theory or fact that an increase in concentration reduces R&D, or that reducing R&D is likely to diminish innovation. Merger policy has a theoretical basis (with roots in Stigler's oligopoly theory) in addition to the empirical evidence of the effect of concentration on price-cost margins. There is no theoretical basis for concluding that higher concentration leading to lower innovation. Rapp also points out that the capacity to innovate would be difficult to monopolize. The antitrust agencies already have the ability to bring cases based on competition issues in product and technology markets. Nothing is gained by bringing cases based on innovation markets, too.

4. Reinganum, Jennifer F. (1985), "Innovation and Industry Evolution":
   In this paper, Reinganum extends her earlier work by developing a theoretical model in which a sequence of innovations is possible. In this scenario, a successful innovation does not imply that the successful firm will reap monopoly profits forever. Instead, it will only earn these profits until the next, better innovation comes along. The model consists

of one firm, the current monopolist, and a number of potential entrants. The anticipation of additional future innovations reduces the value of incumbency by shortening its expected lifespan. Therefore, the monopoly incumbent always invests less than each challenger since greater investment tends to shorten the length of the current stage by hastening the discovery of the next innovation.

5. Spence, M. "Cost Reduction, Competition and Industry Performance" in Stiglitz, J.E. and Mathewson G.F. (1986), *New Developments in the Analysis of Market Structure*:
   Spence treats R&D expenditure as a cost reduction achieved through more efficient production. Cost savings from R&D are dependent upon the scale of production. Spence also discusses the externality problems resulting when competitors benefit from a firm's developments.

6. Tandon, P. (1983), "Rivalry and the Excessive Allocation of Resources to Research":
   This article presents a simple probability model of R&D which suggests that competitive firms may over-invest resources in research, even in the face of uncertainty, inappropriability, and increasing costs of research. In the presence of uncertainty, some duplication of R&D efforts maybe justified because of the increased probability of success that results, but competitive equilibria may be characterized by excessive duplication. Further, when different firms can discover different things, excessive knowledge may be produced, even when each firm individually performs less R&D than is socially desirable. This is a consequence of excessive entry.

Literature on Innovation by Large Firms in Concentrated Markets

7. Caballero-Sanz, F., Moner-Colonques, R. and Sempere-Monerris, J.J. (1998), "Market Structure and R&D Joint Ventures: The Case of Product Innovations":
   Departing from the received fact that research joint venture agreements are allowed on the grounds of a permissive ruling, we study what conditions are necessary for venture partners to carry on R&D cooperation to the marketing stage. We treat the case of product innovations exploitable with different usages in unconnected markets. Two main results appear: firms always have incentives for a distribution of varieties, but not always agree on the distribution of products. The condition for the last result to happen gives a useful rule for antitrust authorities relating the degree of substitutability across varieties and the relative profitability of the markets.

8. Fishman, A. & Rob, R. (1999), "The Size of Firms and R&D Investment":
   Fishman and Rob construct an industry-equilibrium model in which it is costly for consumers who have previously purchased from one firm to switch to competitors. This gives firms a certain degree of market power over their established customers. The equilibria identified under these conditions have the following properties: (1) there is a nontrivial size distribution of firms, although firms are intrinsically identical, (2) larger firms make higher profits, (3) larger firms spend more on R&D, (4) larger firms charge (on average) lower prices, and (5) profits are positively correlated over time. These properties match empirical regularities concerning the manufacturing and retail sectors in the U.S. economy.

9. Greenstein, S. and Garey R. (1998), "Market Structure, Innovation and Vertical Product Differentiation":
   Greenstein and Garey consider product innovations that are *vertically differentiated* from older products. Competition and monopoly in the old product market provide identical returns to innovation when (i) the monopolist is protected from new product entry, and (ii) innovation is non-drastic, in the sense that the monopolist supplies positive quantities of both old and new products. If the monopolists can be threatened with entry, monopoly provides *strictly greater* incentives. Welfare may be greater under monopoly when innovation is valuable

10. Jorde, Thomas M. and David J. Teece (1990), "Innovation and Cooperation: Implications for Competition and Antitrust":
    Jorde and Teece believe that U.S. antitrust laws hamper innovation because they undervalue the benefits of cooperation among competitors. The traditional "serial model" of innovation breaks it down into a number of sequential steps. The "simultaneous model" of innovation considers linkages and feedback among firms. They believe that much innovation nowadays should be analyzed using the simultaneous model and it is likely to require horizontal linkages among firms. Combining technologies from different sources is often necessary for innovation. But combining technologies often means combining people, which may not be feasible under current antitrust laws. Horizontal linkages among firms can also help to overcome scale barriers in research and avoid duplication of effort. The authors propose seven modifications to U.S. antitrust law to improve the way it treats cooperative research. First, clarify the rule of reason to better take into account the benefits of cooperation. Second, define a safe harbor for market shares. Third, focus market definition on a broad market for know-how. Fourth, integration by contract or joint venture should not be treated less favorably than mergers. Fifth, the NCRA (National Cooperative Research Act) should be expanded to include joint commercial efforts to exploit innovation. Sixth, create an administrative procedure to evaluate and certify cooperative arrangements among firms with higher market shares. And seventh, private antitrust plaintiffs challenging cooperative research should not be allowed treble damages.

11. Lee, T. & Wilde, L. (1980), "Market Structure and Innovation: A Reformulation":
    Lee and Wilde examine model of the relationship between market structure and innovation developed by Loury, who examines "a world in which…firms compete for the constant, known, perpetual flow of rewards…that will become available only to the first firm that introduces [some given] innovation" [Loury, 1979, p.397]. Among Loury's major conclusions: (1) as the number of firms in the industry increases, the equilibrium level of firm investment in R&D declines, and (2) when there are initial increasing returns to scale in the R&D technology, then a zero expected profit industry equilibrium with a finite number of firms always involves "excess capacity" in the R&D technology. Lee and Wilde investigate the effects of alternate specifications of the costs of R&D on Loury's conclusions. They determine that "if fixed costs are more important that variable costs in the R&D technology (in some appropriate sense), then an increase in rivalry should lead to a decrease in the equilibrium level of firm investment in R&D. Similarly, if variable costs are more important than fixed, then an increase in rivalry should lead to an increase in the equilibrium level of firm investment in R&D."

12. Loury, Glenn C. (1979), “Market Structure and Innovation”:
   Prior analysis of this issue has suggested that a degree of concentration somewhere between pure monopoly and perfect competition is the best in terms of R&D performance. A shortcoming of much of this earlier work is that it was partial-equilibrium analysis. Loury’s equilibrium model assumes firms invest in R&D under both technological and market uncertainty. Technological uncertainty refers to the stochastic relationship between a firm’s R&D investment and the time at which the innovation may be introduced. There is market uncertainty because no firm knows if any rival’s R&D efforts will be successful. He uses the model to study the impact of market structure on R&D at both the firm and industry level. Loury’s model shows that more competition is not necessarily socially desirable. With continuously diminishing returns to R&D investment, atomistic competition is optimal. But in the more realistic case of initial scale economies, the optimal market structure involves a limited number of firms.

13. Van Cayseele, P.J.G., (1998), “Market Structure and Innovation:
   A Survey of the Last Twenty Years”: This article provides a survey of the theoretical contributions to the relationship between market structure and innovation over the last twenty years. In 1975, Morton Kamien and Nancy Schwartz engaged in a similar exercise (Kamien and Schwartz (1975)). This article, together with their book in 1982 and an article by Dasgupta (1986) are the starting points of the present contribution. Regarding the empirical contributions, we do not provide a counterpart of their survey but refer to the article by Cohen and Levin (1989) in the Handbook of Industrial Organization. Concerning the aspect of the diffusion of technologies, the reader should consult Reinganum (1989), in the same source. Another valuable reference providing an overview of related issues such as the economics of science is Dasgupta and David (1994). Here, the main findings regarding the theoretical relationship between market structure and innovation that come out of these previous survey publications will be briefly summarized. Those interested in more details should directly consult these works or the references therein. Instead, we mainly discuss the novel contributions made in the last two decades. We do not aim at an exhaustive enumeration but rather focus on the economic intuition behind what we think to be the most important contributions.

Literature on Empirical Studies of the Relationship Between Market Concentration or Firm Size and Innovation.

14. Angelmar, R. (1985), “Market Structure and Research Intensity in High-Technological-Opportunity Industries”:
   Where the cost and uncertainty of R & D are high and conditions favor speedy imitation by competitors, concentration has a statistically significant and substantial positive impact on research intensity. But its impact is clearly negative when R & D cost and uncertainty are low, and where high barriers to imitation exist. A sample of 160 business unit observations for 1978 was drawn from the PIMS Data Base. All the sample business units' industries recently experienced major technological changes. Research intensity was measured by non-government-financed R & D expenditures as a percentage of sales.

15. Brouwer, M., (1998) “Firm Size and Efficiency in Innovation:
   Comment on van Dijk et al.”: Van Dijk et al. found different results for some variables

explaining the large/small firm innovation advantage in a number of Acs and Audretsch publications. Their own research adds to this variety. However, the differences van Dijk et al. found between the Acs and Audretsch studies can be largely attributed to specification and sample differences. The same applies to the observed differences between Acs and Audretsch and van Dijk et al.

16. Cohen, W.M., Levin, R.C. & Mowery, D.C., (1987), "Firm Size and R&D Intensity: A Re-Examination":
Using data from the Federal Trade Commission's Line of Business Program and survey measures of technological opportunity and appropriability conditions, this paper finds that overall firm size has a very small, statistically insignificant effect on business unit R&D intensity when either fixed industry effects or measured industry characteristics are taken into account. Business unit size has no effect on the R&D intensity of business units that perform R&D, but it affects the probability of conducting R&D. Business unit and firm size jointly explain less than one percent of the variance in R&D intensity; industry effects explain nearly half the variance.

17. Dasgupta, Partha (1986), "The Theory of Technological Competition":
In this paper, Dasgupta summarizes the empirical literature. First, he identifies six empirical observations that should influence the choice of hypotheses on which a model is based: 1) There is a positive correlation between R&D effort and innovative output. 2) The cost of developing something increases more than proportionately with a shortening of the development time period. 3) Innovation does not display economies of scale with respect to firm size. 4) Technological advances are not independent of advances in basic scientific knowledge. 5) Successfully innovative firms are likely to continue being more successful at innovating than are their rivals. 6)A principal goal of R&D is the creation of entry barriers. Dasgupta identifies another eight empirical observations that theory should explain: 1) Larger firms do not engage in more R&D activity relative to their size than smaller firms. 2) Up to a point, there is a positive correlation between industry concentration and innovative activity. 3) Industries facing grater technological and innovative opportunities tend to be more concentrated. 4) Demand growth stimulates R&D activity. 5) Firms that have had earlier R&D successes are more likely to have further R&D successes. 6) Research activity is strongest where entry barriers are neither too high nor too low. 7) There is a positive relationship between a firm's R&D activity and its stock value. 8) Imitative research is a pervasive phenomenon.

18. Fritsch, M. & Meschede, M. (2001), "Product Innovation, Process Innovation, and Size":
Fritsch and Meschede test the hypothesis that large firms devote a higher proportion of their R&D expenditure on process innovation than smaller firms. According to the estimates, process and product R&D expenditure rise less than in proportion to size. The size effect is somewhat stronger for process R&D but the difference to product R&D is in no way dramatic. This difference with regard to size elasticity of process and product R&D is somewhat more pronounced when accounting for possible interrelationships between expenditure on process and product R&D but remains statistically non-significant.

19. Geroski, P.A. (1990), "Innovation, Technological Opportunity, and Market Structure":
Geroski develops an empirical test of the Schumpeterian idea that monopoly deadweight

loss is the price that must be paid for higher levels of innovative activity. Geroski identifies, and then measures, an indirect effect and a direct effect of market power. The indirect effect of actual monopoly power on innovative behavior is the effect that current monopoly power has on the likelihood of achieving a certain level of post-innovation market power. He expects this to be positive since a current monopolist could erect barriers to future entry and whatever entry barriers exist today to protect a monopolist might well continue to exist in the future. The direct effect of actual monopoly on innovative behavior could be positive or negative. A positive direct effect could result when a monopolist uses its higher profits to innovate. A negative direct effect could be caused by any of three factors: 1) x-inefficiency because of a lack of competitive pressure, 2) increasing the number of firms seeking innovation may increase the probability of one achieving it, and 3) monopolists have a disincentive to innovate to the extent that it makes their past investments obsolete. Geroski's empirical work does not support the Schumpeterian hypothesis. He finds that competition tends to increase innovation more than does monopoly.

20. Levin, R.C., Cohen, W.M., & Mowery, D.C. (1985), "R&D Appropriability, Opportunity, and Market Structure:
New Evidence on Some Schumpeterian Hypotheses": This paper is a reexamination of one set of Schumpeter's hypotheses concerning innovation and industrial market structure. It looks at those hypotheses that focus on the effect of market concentration on R&D and technological advance using new data on R&D appropriability and technological opportunity collected by Levin et al. (1984) in a survey of R&D executives in 130 industries.

21. Tandon, P. (1984), "Innovation, Market Structure, and Welfare":
Tandon uses a method of R&D analysis developed by Dasgupta and Stiglitz to show that barriers to entry, in addition to those created by R&D, are desirable in order to maximize social welfare. By entering an industry, a marginal firm will inhibit larger firms from reaping the scale benefits that R&D results create. Thus the marginal firm will in general make a net negative contribution to social welfare, even when the further dynamic effect on R&D incentives is disregarded. Tandon finds that free-entry outcome performs relatively worse for industries that are characterized by high levels of technological opportunity. Tandon also finds, however, that except for very high values of the technological opportunity parameter, the optimal degree of concentration will typically involve more than one firm.

22. Vossen, R.W. (1999), "Market Power, Industrial Concentration and Innovative Activity":
Vossen discusses the paradox between the positive effect of industrial concentration on R&D spending, and its non-positive effect on the number of innovations. Vossen also analyzes whether concentration has different effects on small- and large-firm R&D. The analysis shows that the positive effect of industrial concentration on R&D spending is at least as strong for small firms as it is for large firms within an industry, which indicates that the possession of market power is not in itself conducive to innovative effort. In addition, high concentration appears to be attended with a loss of efficiency in R&D spending.

Literature on How Fundamental Structural Characteristics of Technology May Determine Market Structure and Innovative Activity

23. Dasgupta, P. & Stiglitz, J. (1980), “Industrial Structure and the Nature of Innovative Activity”:
    Dasgupta and Stiglitz provide an analytical framework relating market structure to the nature of inventive activity. They argue that except in the short run both market structure and the nature of inventive activity are endogenous; that the degree of concentration in an industry ought not to be treated as given; that they both depend on more basic ingredients, such as the technology of research, demand conditions, the nature of the capital market (i.e. market rates of interest, and the ability of firms to borrow to finance R&D), and the legal structure (e.g. patent rights). As the degree of concentration and the nature of innovative activity are both endogenous, their relationship, unlike the neo-Schumpeterian thesis, ought not to be regarded as a causal one.

24. Futia, C.A. (1980), “Schumpeterian Competition”:
    Futia describes a stochastic model of the process of competition via technological innovation as it might occur within a single industry. Individual firms undertake R&D projects in the hope of acquiring a decisive competitive advantage over their rivals. But such advantages and the economic rents arising from this are only temporary; they eventually disappear in the face of imitation, entry, and innovation by other firms. At the industry’s long-run equilibrium, concentration and the pace of technological innovation are jointly determined by the conditions of entry and the extent of innovative opportunity. Futia’s model implies relationships among these variables that have in fact been detected in the empirical R&D literature.