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Market Structure and Innovation – What Do We Know?

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ABSTRACT

The effect of market structure on innovation incentives has been a controversial subject in economics since Joseph Schumpeter advanced the theory that competitive markets are not necessarily the most effective organizations to promote innovation. The incentive to innovate is the difference in profits before and after innovation occurs. The concept is straightforward, yet differences in market structure, the characteristics of innovations, and the dynamics of discovery lead to seemingly endless variations in the theoretical relationship between competition and expenditures on research and development or the outputs of R&D. This paper surveys the economic theory of innovation, focusing on horizontal market structure, the distinction between product and process innovations, and the role of exclusive and non-exclusive right to innovation, and attempts to draw conclusions from the different models. Exclusive rights generally lead to greater innovation incentives in more competitive markets, while non-exclusive rights generally lead to the opposite conclusion, although there are important exceptions. The paper reviews the large literature on empirical studies of innovation, and argues for greater reliance on industry-specific case studies.

I. Introduction

There is broad agreement among economists that research and development is a major source of economic growth. Although estimates differ, most studies show a high correlation between R&D expenditures and productivity growth after accounting for investment in ordinary capital. Studies also show that the social return to investment in R&D is much higher than the private return, which suggests that policies that promote innovation can pay large dividends for society. One way to achieve these benefits is to promote industry structures that promote innovation, including policies toward mergers and laws that govern exclusionary conduct.

The objective of this paper is to review the theory and empirical evidence on the relationship between R&D and market structure. The debate of course traces back to the Schumpeterian view that large firms provide a more stable platform to invest in research and development, and that perfect competition is not necessarily the most efficient market structure to promote R&D. The theoretical and empirical literature on this subject is voluminous, and the results often appear contradictory. My objective is to discern general patterns in this sea of information, a task that sometimes seems akin to unraveling the genetic code.

The focus of the survey is on the effects of competition on the R&D investment and outcomes for product and process innovations under conditions of exclusive and non-exclusive intellectual property rights. Despite the length of this survey it neglects many important aspects of market structure and innovation. For example, although the survey compares theoretical predictions for industries with exclusive and non-exclusive protection for innovation, it does not deal with information spillovers that reduce the cost of imitation. We also do not address vertical market structures, which may affect the flow of information from consumers to producers at different levels in a supply chain, nor do we deal with network effects. We also make the implicit assumption that firms exploit their own innovations and do not seek revenues by licensing others. While these other market characteristics and conduct can have profound implications for investments in R&D, we find that a limited focus on competition provides enough complexity for our task. Section II surveys the theoretical literature on competition and R&D with particular attention to key assumptions and how they affect the model predictions. Section III reviews empirical studies relating firm size and market concentration to R&D in light of the predictions from the different models. The empirical studies rarely account for the many factors that the theory suggests should be significant determinants of innovative activity. Our goal is to draw conclusions from these studies to provide a better foundation for future empirical work on the market determinants of innovation.

II. Economic theory of market structure and innovation

As a general statement, the incentive to innovate is the difference in profit that a firm can earn if it invests in R&D compared to what it would earn if it did not invest. These incentives depend on many characteristics of the invention, the nature of intellectual property protection, and the dynamics of R&D, including the following:

What is the nature of the invention?
Is it a cost-reducing process or a new product? Is it a minor advance, or does it have the potential to disrupt the industry hierarchy? Does it require fundamentally different capabilities than currently exist in the industry?

What is the extent of competition pre-innovation and post-innovation?
Is the innovator a participant in a highly competitive market, or a firm that is largely protected from competition? Is there significant price or product differentiation? Are there significant barriers to R&D? Does R&D require specialized assets that are not widely available? Is the inventor also the innovator, or does the inventor plan to license, sell, or assign the invention to a different entity?

What property rights exist to protect the invention? Is the invention protected by patent, and if so, is the patent easy or difficult to invent around? Are there other mechanisms to protect an innovator from imitation?

What are the dynamics of R&D competition and the stochastic nature of R&D?
Although R&D is necessarily uncertain, are the outcomes of R&D programs reasonably

predictable? Can firms observe and respond to rivals' R&D activities? Can firms coordinate their R&D activities to avoid redundant expenditures?

These are some of the many characteristics of R&D and the markets in which it occurs that affect innovation incentives. The many different predictions of theoretical models of R&D lead some to conclude that there is no coherent theory of the relationship of market structure and investment in innovation. That is not quite correct. The models have clear predictions, although they differ in important ways that can be related to market and technological characteristics. It is not that we don't have a model of market structure and R&D, but rather that we have many models and it is important to know which model is appropriate for each market context.

A. Incentives to innovate with exclusive property rights

The incentive to innovate clearly depends on the nature of rights to successful innovation. If an innovator cannot exclude imitators, this reduces the benefit from innovating and increases the value of not investing in R&D and following another's inventive activity. Here we assume that a successful inventor gains perfect and perpetual protection from innovators. This is of course an extreme assumption and unrealistic for most market situations. Patents, for example, do not confer substantial protection in many industries, although protection can come from other means, such as secrecy and complementary investments that deter imitators.[1]

1. *Competition and monopoly with exclusive protection for innovation*

Under the assumption that an innovator enjoys perfect and perpetual exclusive property rights to its invention, Arrow (1962) showed that a pure monopoly that is unexposed to competition for existing and new technologies has less incentive to invest in R&D for a process invention than does a firm in a competitive industry. Arrow shows that a monopolist's pre-innovation stream of profits results in lower R&D incentives relative to a competitive firm. Tirole (1997) calls this the replacement effect. A firm that has a

[1] See Levin et al. (1985) and Cohen et al. (1989b) for surveys of how firms value patents and other mechanisms to appropriate the value of discoveries.

monopoly position in a market has a flow of profit that it enjoys if no innovation takes place. The monopolist can increase its profit by innovating, however it loses, or "cannibalizes" the profits from its old technology. On net the monopolist gains only the increment to its profits. A firm in a competitive industry, by definition, has no legacy flow of profits to cannibalize, other than the normal profits for a competitive industry. If the competitive firm can capture the same benefit from innovation as the monopolist, its differential return is higher because it has no legacy profits that are replaced by the innovation. Hence Arrow concludes that a monopolist has a greater incentive to invest than a competitive firm.

Arrow's model has a number of important explicit and implicit assumptions. His analysis is for a process innovation that lowers the firm's constant marginal product cost from some c_0 to $c_1 < c_0$. Let $\Pi^m(c)$ be the monopolist's present-value profit when it has a constant marginal cost, c. The monopolist's incentive to invent is $\Delta\Pi^m = \Pi^m(c_1) - \Pi^m(c_0)$. Arrow compares this incentive to the incentive to invent for a firm in a competitive industry. The competitive firms supply the same homogenous product as the monopolist. Prior to invention, each competitor has a constant marginal cost c_0 and earns a profit $\Pi^c(c_0)$, which is zero if firms have equal constant marginal costs and behave as price-taking perfect competitors. If the firm invents, it earns $\Pi^c(c_1)$. Arrow assumes that there is only a single successful inventor (which would be the case if the invention is protected by patent). The inventor's only actual or potential competition comes from the former monopolist, and its return depends on the relative costs c_1 and c_0. If c_1 is sufficiently smaller than c_0, the inventor's monopoly price is less than the former monopolist's marginal cost. A firm with technology c_0 cannot earn a profit when a firm with technology c_1 chooses the monopoly price. Arrow calls this a *drastic* innovation. For a drastic innovation, the inventor's profit is the monopoly profit $\Pi^m(c_1)$, because the old technology is irrelevant. The former monopolist has no effect on the inventor's profit when the invention is drastic. Consequently, for a drastic invention, the competitor's incentive to invent is $\Delta\Pi^c = \Pi^m(c_1)$, which clearly exceeds the monopolist's incentive to invent, $\Pi^m(c_1) - \Pi^m(c_0)$.[2]

Arrow's analysis does not directly apply to product innovations, which are significant both because they account for a large fraction of total R&D expenditures and because they include many of the breakthrough products that spur economic growth and advance consumer welfare.[3] The analysis of innovation incentives is more complicated for product innovations for several reasons. First, even competitive firms can earn positive profits when they offer differentiated products. This means that competitive firms also face a replacement effect, although it is likely to be smaller for competitive firms because competition erodes the profit they earn using the old technology. Second, a new product changes the ability of a monopolist to discriminate among consumers, and this can make innovation particularly attract for the former monopolist. A third complication is that a competitor can earn significant profits from a new product even if the product is very similar to the former monopolist's old product.

Denote by v a technology that enables the firm to produce a product. The monopolist's profit when it has the old technology v_0 is $\Pi^m(v_i)$. A new technology expands the firm's production possibilities and generates a profit $\Pi^m(v_1, v_0) > \Pi^m(v_0)$ for any market demand. The monopolist's incentive to invent is

$$\Delta\Pi^m = \Pi^m(v_1, v_0) - \Pi^m(v_0).$$

In the case of a process innovation, we made the assumption that $\Pi^m(v_1,v_0) = \Pi^m(v_1)$. This assumption is reasonable for most process innovation, although no doubt there are situations in which it does not hold. This is not a reasonable assumption for product innovations, although it may hold for some markets. Even if the innovation is drastic, a new product can allow a firm that has a portfolio that includes the old product to earn

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[2] This result could change if the process innovation expanded the monopolist's ability to price discriminate (see Baldwin and Scott (1987)). We assume that is not the case.

[3] The National Science Foundation estimated that in 1981, about 75% or all industry R&D was

more by offering both products than it could by offering only the new product, because it can differentiate its offerings to extract more surplus from consumers.

Let $\Pi^c(v_i,v_j,v_{-i})$ be a competitor's profit when it has technology v_i, the original monopolist has technology v_j, and all other competitive firms have technologies represented by the vector v_{-i}. The competitor's incentive to invent is

$$\Delta\Pi^c = \Pi^c(v_1,v_0,v_{-i}) - \Pi^c(v_0,v_0,v_{-i})$$

with $v_{-i} = v_0$ for all other firms.

As with a process innovation, if the product innovation is drastic, then $\Pi^c(v_0,v_1,v_{-i}) = 0$. A competitor cannot earn a profit if it has only the old product and the monopolist has the new product, when the new product is a drastic innovation. For a drastic product innovation, the innovation incentives for a monopolist and for a competitive firm are

$$\Delta\Pi^m = \Pi^m(v_1,v_0) - \Pi^m(v_0). \quad (1)$$

$$\Delta\Pi^c = \Pi^m(v_1) - \Pi^c(v_0,v_0,v_{-i}). \quad (2)$$

The second term in (1) is larger than the second term in (2), but so is the first term. We cannot make a general conclusion that for product innovations a monopolist has a lower incentive to invent, even if the innovation is drastic. Although we can say that if the old product does not allow a monopolist with the new product to discriminate more effectively among consumers (i.e., if $\Pi^m(v_1,v_0) = \Pi^m(v_1)$), then incentives to invest in a new product are lower for the monopolist when the new product is a drastic innovation.

The analysis is more complicated if the invention is not drastic. For a non-drastic innovation, the former monopolist's old technology constrains the price that the innovator can charge using its new process technology. Arrow shows that even in this case a competitive firm's return from innovation exceeds the return for a monopoly. Arrow's

directed to product innovations. National Science Foundation (1981).

findings for non-drastic *process* innovations do not, however, extend to *product* innovations, even for the comparison of pure monopoly and competitive market structures.

Greenstein and Ramey (1998) show that a monopoly can benefit more from a non-drastic product innovation than a competitor. Products are vertically differentiated in their model. All consumers prefer the new product to the old product. If the monopolist innovates, it can use the old as well as the new product to structure differentiated offerings that discriminate according to consumers' willingness to pay. They show that for a class of distributions of consumer preferences the benefit to the monopolist from introducing the new product exceeds the profit that a new competitor can earn by selling only the new product. For particular distributions of consumer preferences, the monopolist's ability to price discriminate using both products gives it a greater incentive to introduce the new product than a new competitor who sells only the new product.

The appendix provides another example of innovation incentives for non-drastic product improvements. Firms are horizontally differentiated in this example. With equal prices, a consumer prefers the product sold by the firm that is closest to her location. Consumers are uniformly distributed on a line of unit length. An incumbent firm is located at one end of the line. Entry may occur at the other end. There is an existing technology available to any firm, which enables production of a product for which all consumers have a willingness-to-pay equal to v_0 for one unit. Alternatively, either firm can invest to discover a new product, for which consumers are willing to pay $v_1 > v_0$. The appendix shows that if the horizontal differentiation is not too large, then the incentive for a single incumbent firm to invest in the new technology equals the social value of the new technology. An entrant's innovation incentive is tempered by the fact that it could adopt the existing technology and still earn a profit because the firm sells a differentiated product; that is, in this example the new technology is not a drastic innovation because the entrant can compete successfully using the old technology. The appendix shows that for a wide range of parameter values, the incumbent monopolist's incentive to invest in the new technology is larger than the entrant's incentive.

These examples show that even under the restrictive assumptions of the Arrow model, *i.e.*, a monopoly that is perfectly sheltered from competition and perfect protection for an entrant's invention, a monopolist's incentive to introduce a non-drastic product innovation can exceed the incentive for innovation by a rival firm. In the example with horizontal product differentiation, this occurs because the monopolist can appropriate the incremental social benefit from innovation and a rival earns significant profits even if enters with the old technology.[4]

Despite these qualifications to the results developed in Arrow (1962), we can generally conclude that competition is more likely to provide greater incentives for product innovations (as well as process innovations) if the following conditions apply:

- *The innovation is a major improvement.*
  A competitor gains more than a monopolist from a drastic innovation.
- *Competition in the old product is intense.*
  This lowers the pre-innovation profit for a competitor and increases its incentive to invent.
- *The innovation does not increase the ability of the monopolist to price discriminate among consumers.*
  This limits the monopolist's gain from innovation.

2. *Monopoly preemption*

Joseph Schumpeter's concept of "creative destruction" assumes that monopolies are temporary and give way to new competition that is the result of innovation. Yet Arrow's model made the strong assumption that the monopolist is entirely shielded from competition, even for the new product. How would innovation incentives change if we

[4] The fact that an entrant can earn positive profits with the old technology is central to this result. One can show that if entry would not be viable with the old technology, then the entrant's innovation incentive would exceed that of the incumbent monopolist (and would exceed the social benefit from innovation). The innovation would be drastic if the entrant could not profitably compete using the old technology.

allow for competition to invent new products or processes? Gilbert and Newbery (1981) consider a simple model in which a monopolist in an existing technology and a new competitor invest in R&D to patent a new technology. Their model assumes that the firm that invests the most wins the patent with certainty. The patent provides perfect and perpetual exclusion from competition in the new technology. Because the firm that invests the most wins the patent with certainty, the model is similar to an auction market in which the firm that bids the most wins the prize.

Gilbert and Newbery (1981) show that a monopolist has a *greater* incentive than a competitive firm to bid for the patent if the invention is non-drastic. If a competitor wins the patent, and the invention is not drastic, it competes with the former monopolist and earns $\Pi^d(v_1,v_0)$. Here v_1 represents the competitor's new technology and v_0 the former monopolist's old technology, and the superscript *d* notes that the firm competes as a duopolist with the former monopolist. If the competitor loses the bid for the patent, its profit is limited by the amount it can earn by competing with the old technology, which may be zero. Thus, the competitor's incentive to bid for the patent is no greater than $\Pi^c(v_1,v_0)$. If the monopolist wins the patent, it remains a monopolist and earns $\Pi^m(v_1)$. If it loses the bidding contest, it becomes a duopolist with the old technology and earns $\Pi^d(v_0,v_1)$. Thus the monopolist's incentive to invent is $\Pi^m(v_1) - \Pi^d(v_0,v_1)$, and this exceeds the competitor's incentive if $\Pi^m(v_1) - \Pi^d(v_0,v_1) > \Pi^d(v_1,v_0)$, or if $\Pi^m(v_1) > \Pi^d(v_0,v_1) + \Pi^d(v_1,v_0)$. But this is merely the condition that monopoly profits exceed the sum of profits in a duopoly. It is likely to hold if the invention is non-drastic. If it is non-drastic, $\Pi^d(v_1,v_0) < \Pi^m(v_1)$, because the old technology disciplines the profit that can be earned with the new technology, and $\Pi^d(v_0,v_1) > 0$, the new technology does not completely obsolete the old technology. The different between monopoly profits and the industry profits with entry of a new firm is what Tirole (1997) calls the efficiency effect. Note that for a drastic innovation, the bidding incentives would be the same for the monopolist and a competitor, provided that the competitor would earn zero profit if it did not win the bid.

The Gilbert and Newbery model suggests that a monopoly has an incentive to preempt R&D competition by bidding more for a patent than a competitor can afford to invest. By doing so, the monopolist protects its monopoly profit, and this is worth more than the competitor can earn if it wins the bid but has to compete with the former monopolist. Preemption would allow the monopoly to persist in the face of R&D competition, however the preemption result rests on several key assumptions. These include: the firm that bids the most for the patent wins it with a high degree of certainty; the patent provides perfect protection from competition other than from the former monopolist using the old technology; there are no entry paths other than the patented technology; an entrant that wins a patent cannot bargain with the incumbent for exclusive rights to the new technology (see Salant (1984)); and the monopolist faces no competition in the old technology.

To illustrate the importance of the assumption that the incumbent is a monopolist, suppose instead that there are n incumbent firms, each with pre-innovation profit $\pi_n(c_0,...,c_0)$. If one of them wins the patent, its profit is $\pi_n(c_1,c_0,...,c_0)$ and the other incumbents earn $\pi_n(c_0,c_0,...,c_1)$. (We assume that firms are symmetric, so the ordering does not matter.) If a new firm enters with the new technology, it earns $\pi_{n+1}(c_1,c_0,...,c_0)$ and the incumbent firms earn $\pi_{n+1}(c_0,c_0,...,c_1)$. An incumbent has a greater incentive to bid for the patent only if

$$\pi_n(c_1,c_0,...,c_0)-\pi_{n+1}(c_0,c_0,...,c_1)>\pi_{n+1}(c_1,c_0,...,c_0).$$

This inequality does not generally hold. For example, it fails to hold for a Nash-Cournot oligopoly if $(c_0 - c_1)$ is sufficiently small.

3. *R&D Uncertainty and Dynamics*

The Gilbert-Newbery preemption result implicitly assumes that the firms bid for a patent, which is awarded to the highest bidder. Reinganum (1983) considers a model in which invention is uncertain; investment increases the probability that a firm will win the patent, but does not guarantee success. Her model assumes that discovery follows an exponential process. The probability that a discovery will occur before date t is $F(t) = 1 - e^{-ht}$. The parameter h is called the hazard rate, or more appropriate for this context, the success rate. It is the probability that a firm will make the discovery at time t conditional on no discovery before t. If the hazard rate is constant or a constant function of R&D investment, and if the payoffs to innovating are also constant (or appreciate at an exponential rate), then a firm's optimal investment in R&D is independent of time, conditional on no firm making a discovery.

Reinganum (1983) shows that the monopoly preemption result in Gilbert and Newbery (1982) disappears when R&D follows a discovery process that is exponentially distributed and the innovation is drastic. With exponential discovery, she shows that the monopolist's incentive to invest is strictly less than the competitor's incentive for reasons that can be traced directly to Arrow's replacement effect. If the competitor's R&D fails, the monopolist has a smaller incentive to invent than a competitor because a competitor benefits from the full value of the invention, whereas the monopolist benefits only from the incremental value of the invention relative to its old technology. If the competitor's R&D is likely to succeed, and the invention is drastic, the monopolist has the same incentive to invent as the inventor. In expected terms, it is profitable for the monopolist to invest less than a competitor when the invention is drastic. By extension, Reinganum argues that the monopolist has a smaller incentive to invest in R&D than a competitor even for some non-drastic innovations.

Reinganum (1985) extends the model to allow for many competitors and a sequence of innovations. Each innovation in the sequence is more valuable than its predecessor. A discovery generates a profit flow for the innovator and nothing for all other firms; that is, each discovery is a drastic innovation. The implications of this more general model parallel the results in the model with only two firms and a single innovation. A successful innovator is analogous to the incumbent in the duopoly model. The challengers are all the firms that did not discover the latest generation of the technology.

The incumbent invests less than a challenger, as in the duopoly model, and all challengers invest at the same rate.[5]

These results are insightful, but it does not follow that an incumbent firm has a lower incentive to invest in R&D for all non-drastic innovations, even when the probability of discovery is exponential. Indeed the monopoly preemption result in Gilbert and Newbery (1982) can rear its head if the old technology is a sufficiently close substitute for the new technology. Closed form solutions are difficult to obtain, but it is not difficult to generate plausible numerical examples for non-drastic innovations in which the incumbent monopolist invests at more than twice the rate of a potential entrant.

We return to this dynamic theory of R&D later in the discussion of empirical studies of R&D competition. As a theoretical matter, we note here that Arrow's result that incumbent monopolies have less to gain from innovation than competitors applies to dynamic models of R&D when the probability of discovery is exponentially distributed and the invention is drastic. However, that result can change if old technologies are close substitutes for new discoveries. Furthermore, the results that follow from a model of R&D competition when the probability of discovery has an exponential distribution do not generalize to other, plausible, R&D technologies.

Beyond Exponential Discovery: Preemption and Leapfrog R&D

An alternative representation of the discovery process is that firms accumulate knowledge by investing in R&D and discovery occurs when the stock of knowledge exceeds some threshold. We also assume that the first firm to cross the threshold wins a patent on the new technology that protects the patentee from imitators. Fudenberg et al. (1983) suppose that firms can add to their stock of knowledge at a cost. Firms can apply greater effort to accumulate more experience at a more rapid rate, but this incurs a higher

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[5] Increasing the number of competitors reduces the expected time to discovery; however the effects on each firm's R&D efforts depend on the particular formulation of fixed and flow R&D expenses. Increasing the number of competitors increases R&D spending per firm when R&D is a flow cost as in Lee and Wilde (1980). It has the opposite effect when R&D is a fixed cost (see, e.g., Loury (1979) and Dasgupta and Stiglitz (1980a)).

cost. In particular, they can add one unit to their knowledge stock at cost c_1 or add two units at cost c_2 with $c_2 > 2\ c_1$. The first to reach K units wins the patent. Furthermore, each firm can observe the other firm's knowledge stock with a one a lag of one period.

The equilibrium of this model has the property that firms compete aggressively (by adding two steps to their knowledge stocks) when their knowledge stocks are similar. However, if a firm falls more than two steps behind, the leader can guarantee success by investing at the moderate rate of one step per period or more if necessary. Knowing this, the follower might as well drop out of the R&D race. The outcome is similar to the strategy in a sailing race. The boat that is ahead can stay ahead by blocking the wind for its competitor. It does not have to put on additional sail to increase its lead. It only has to make sure that the other boat cannot overtake it.

The model in Fudenberg et al. (1983) is one in which discovery occurs if and only if a firm acquires the requisite knowledge stock. The qualitative results can extend to other formulations, where discovery is stochastic, but the probability depends on cumulative investment in R&D. Doraszelski (2003) considers such a model. In his model, the probability of discovery has an exponential distribution, but the success rate may depend on the firm's cumulative investment in R&D. This generalization of the standard exponential model allows for equilibrium R&D strategies that depend on past investment rates. However, general analytical results are difficult to obtain.

B. R&D Incentives Without Exclusive Property Rights

The theoretical results described so far assume that the innovator has an exclusive and permanent right to exploit her invention, perhaps because the invention is rewarded with a very long-lived patent that provides effective protection against imitators. We would expect the theoretical predictions to depend on this exclusivity assumption, although that is not necessarily true. The monopolist's incentives to invent do not depend on whether the monopolist has exclusive rights because by assumption there is no one else who can compete in either the product market or in R&D.

Without exclusive rights, the incentives for competing firms to invest in R&D depend on the extent of competition that would occur among firms who succeed in developing the new technology. The incentive to invest in R&D is low if competition post-invention would dissipate all or most of the profits. But this intuition can be misleading. Suppose that firms invest in process R&D to reduce marginal production costs from c_0 to $c_1 < c_0$. Moreover, suppose that if two or more firms have the new technology, they would behave as perfect competitors and the resulting price would equal their marginal cost. In this case, if one firm has already developed the new technology, no rational second firm would invest in R&D. A second inventor would earn no net revenue with the new technology and would suffer the costs of R&D. The first firm to invent therefore has effective exclusivity, because no rational second firm would invest. In this case, where post entry competition is intense, the exclusivity assumption is not important. Of course this presumes that firms invest rationally in R&D and that they observe whether a firm has succeeded in R&D before they invest.

More generally, the incentives to invest in R&D without exclusive rights depend on the intensity of competition before and after innovation. Following Dasgupta and Stiglitz (1980b), consider the case of an oligopoly comprised of N identical firms, each of which has pre-innovation marginal cost, c. The firms sell a homogenous product at price p. Each firm can lower its marginal cost to $c_1 < c_0$ by investing an amount R in process R&D. Suppose the innovation is drastic, meaning that the monopoly price at marginal cost c_1 is less than c_0: $p^m(c_1) < c_0$. Competition will occur only among the firms that invest successfully in R&D. Index the firms by $i = 1,...,N$ and suppose that $n \leq N$ firms invest in R&D. Omitting the cost of R&D, each firm makes a gross profit excluding the cost of R&D equal to

$$\pi_i(c_1, n) = (p - c_1)q_i(p),$$

where the price depends on the number of firms that develop the new process and the nature of the competition between them. If R&D incurs a cost, K, and the firms are symmetric, then the number of firms is the largest number n for which

$$\frac{1}{n}(p - c_1)Q(p) \geq K \ . \tag{3}$$

If the firm is maximizing profits, its price-cost margin will be inversely related to its firm-specific elasticity of demand, ε_f. This is the elasticity of the demand curve faced by the firm and is typically more elastic than the market demand curve. For example, if the firm maximizes its profits under the assumption that other firms do not change their outputs, then $\varepsilon_f = n\varepsilon$, where ε is the elasticity of demand for the entire market and n is the number of firms that successfully invent. In this case,

$$\frac{p - c_1}{p} = \frac{1}{\varepsilon_f} = \frac{1}{n\varepsilon} \ . \tag{4}$$

Suppose the R&D breakeven constraint (3) holds with equality. Then substituting equation (3) in (4) gives

$$\frac{nK}{pQ} = \frac{1}{n\varepsilon} \ . \tag{5}$$

The left-hand-side of (5) is the aggregate R&D intensity for the entire industry: the ratio of total industry R&D to total sales. The right-hand-side is clearly decreasing in n, implying that the industry R&D intensity is a decreasing function of the number of firms that invest in R&D. Under the assumptions of this model, industries with fewer firms should have higher R&D intensity. However, we cannot conclude that an increase in market concentration would reduce R&D intensity, because concentration is an equilibrium condition determined by characteristics of the industry and the R&D technology.

In a social optimum, R&D investment should occur only once and the results should be made available to all of the firms in the industry. In this example, all of the n firms invest in R&D. Competition without exclusive rights to the process innovation results in redundant R&D expenditures whenever $n \geq 2$. It would be better for one firm to invest in R&D and to share the results of that knowledge with others. The would avoid $(n\text{-}1)K$ in R&D costs.

In this example, firms either choose to invest in R&D or they do not. Suppose instead that marginal cost is a declining function of investment in R&D. If a firm invests K_i, its marginal cost is $c(K_i)$ where $\frac{dc(K_i)}{dK_i} < 0$. In an industry where the products of the firms are homogeneous, each firm chooses its output q_i and R&D investment K_i to maximize

$$(p - c(K_i))q_i - K_i .$$

If the firms behave as Cournot-Nash competitors, necessary conditions for profit maximization are

$$-\frac{dC(K_i)}{dK_i} q_i = 1 \tag{6}$$

and

$$\frac{p - c(K_i)}{p} = \frac{s_i}{\varepsilon}, \tag{7}$$

where s_i is the firm's market share and ε is the industry elasticity of demand.

In a symmetric equilibrium with n firms, $K_i = K$ and $s_i = 1/n$.[6] The number of firms in the industry is an equilibrium break-even condition for all active firms, however we can imagine varying n by varying a fixed cost that firms have to pay in addition to the cost of R&D. If the industry elasticity of demand is constant, equation (7) shows that the industry price is decreasing a function of the number of competitors for a given level of investment in R&D. But what about R&D effort K and the corresponding production cost? Dasgupta and Stiglitz (1980b) show that if the elasticity of marginal cost with respect to R&D is also constant, then equilibrium output per firm is a decreasing function of n and therefore, from equation (6), so is the level of investment in R&D. Furthermore,

[6] The equilibrium number of firms can be determined by a break-even condition that includes fixed costs, in addition to R&D expenses, that are associated with being an active supplier in the industry.

as the number of number of competitors increases, the aggregate industry R&D expenditure, nK, increases, but the level of cost reduction decreases. Thus, if all else is held equal, R&D expenditure (nK) and R&D outputs (the level of $C(K)$) move in opposite directions with respect to market concentration.[7] Summarizing:

With non-exclusive rights to process innovation, competition is harmful to R&D both because it results in redundant R&D expenditures and because it reduces the level of realized cost-reduction for each firm.

In this model the incentives for innovation in an industry with n firms are similar to the incentives for n small monopolies to invest in cost-reducing R&D. Larger numbers of firms correspond to smaller monopolies in this analogy. A monopolist's incentive to invest in cost-reducing R&D is proportional to the firm's output. From Shepard's lemma, $\frac{\partial \pi(c)}{\partial c} = -q^m(c)$, where $q^m(c)$ is the monopoly output when the firm has marginal cost, c. Thus, it is not surprising that as the number of firms increases, the level of cost-reduction falls in this model, precisely because the output per firm decreases. Furthermore, a monopoly in R&D can avoid redundant R&D expenditures.

The outputs of innovative efforts are difficult to observe, and consequently empirical studies of R&D often focus on R&D expenditures, or in some cases patents. For production of conventional goods and services, there is typically a proportional relationship between inputs and outputs. While differences in productive efficiency may disrupt this relationship, a safe assumption is that outputs and inputs move in the same direction. R&D is unlike expenditures on conventional goods and services because R&D has properties of a public good. After discovery of a new product or process, others can use the invention at a cost that is a fraction of the cost of the original discovery. With non-exclusive intellectual property rights, firms may waste economic resources by

[7] In a model of Cournot-Nash competition with non-exclusive intellectual property rights, Farrell et al. (2004) find that the total number of R&D projects in which the industry invests has an "inverted-U" shape, reaching a maximum at an intermediate level of market concentration. R&D output falls with the number of competitors, while total welfare peaks at intermediate levels

investing in R&D to create redundant inventions. Models of R&D competition with non-exclusive intellectual property rights illustrate the hazards of using R&D expenditures as a proxy for innovative output. Exclusive intellectual property rights would encourage a firm to either develop the invention at a large scale or license the invention to others, which economizes on redundant R&D expenditures.

Many of the models we have discussed so far have a monotonic relationship between the extent of competition and innovative output. For example, in the patent race model with exponential discovery probabilities, more R&D competitors advances the expected date at which discovery occurs.[8] In the Dasgupta-Stiglitz (1980b) model of cost-reducing R&D with non-exclusive property rights, increasing the number of competitors (by reducing the fixed costs of entry) reduces the amount of cost-reduction; the effect of competition is also monotonic in this model, although in the opposite direction. There is an intuitive argument that the effect of competition on innovation should peak at moderate levels of market concentration. At very low levels of market concentration, corresponding to highly competitive markets, the incentive to innovate may be low because the innovator's small scale of operations may limit its benefit from a new technology. At very high levels of market concentration, the Arrow replacement effect should dominate. This would leave intermediate levels of market concentration as the most fertile environments for innovative activity.[9]

A theme that resonates in the popular press is that monopolies have little incentive to innovate. For example, Steve Jobs, the CEO of Apple Computer, said "[W]hat's the point of focusing on making the product even better when the only company you can take business away from is yourself?"[10] Firms have to innovate to stay ahead when others can develop new competitive products. "Only the paranoid survive" -- the motto of Andy

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of concentration due to price competition.

8 See Reinganum (1985).

9 I use the terms competition and concentration interchangeably only for discussion. It is well known that competition reflects market conduct, which need not be closely related to measures of market concentration. Furthermore, as Boone (2001) emphasizes, market concentration is an equilibrium condition that is determined by characteristics of firms, demand, and the R&D technology.

Grove when he was the CEO of the Intel Corporation -- is testimony to the vigor of dynamic competition. In markets with strong intellectual property rights, Arrow's replacement effect reinforces this view. Monopolies that are protected from innovation competition are reluctant to innovate because they merely replace one profit flow with another, while new competitors capture the entire benefit of an innovation. At the other end of the competition scale, highly competitive markets limit incentives to innovate because the innovator can appropriate only a fraction of the total benefits.

The inverted-U shape for innovation incentives is the holy grail for industrial organization economists. Many have searched for it, and some have even claimed that they found it. Yet theories that generate inverted-U-shaped innovation incentives are often quite fragile, resting on particular assumptions of the nature of competition or the characteristics of the innovating firms.[11] Similarly, empirical studies of innovation incentives, although sometimes consistent with the inverted-U when applied to aggregate data, lose significance when individual industry effects and changing technological opportunities are taken into account.

It is not difficult to generate innovation incentives that bear a non-linear relationship to market structure. For example, in a model with non-exclusive rights to cost-reducing R&D, incentives can increase moving from monopoly to duopoly, and then decrease with more competitors. Boone (2001) has examples where the incentive to innovate changes with the degree of competition in an industry. These examples, however, are rather special cases. What is missing is a theory that demonstrates a general tendency for firms to be most innovative in markets that are only moderately concentrated. Perhaps there is such a general theory that follows from principles information asymmetries between owners and managers.

Leibenstein (1966) argued that managers do not apply the effort necessary to reach the frontier of the firm's production function, and this slack is greater for managers who are

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[10] Interview with Steve Jobs, *Business Week*, October 11, 2004, p. 96.

[11] The dynamic model in Aghion et al. (2002) generates such a relationship between R&D and

not exposed to significant competition. In modern terms, managerial slack is the result of asymmetric information in a principal-agent hierarchy. The owner's of firms (the principals) would like managers, acting as their agents, to exert effort to run the firm in an efficient manner. This effort could include investing in and thinking creatively about new processes and products. The activity of invention requires ingenuity, hard work, and risk-taking, and often requires managers to make changes in operating procedures that can be stressful for all and impose severe hardships on some workers. Hicks (1935) said it well when he wrote that "The best of all monopoly profits is a quiet life." Perhaps what is missing in the theories on innovation that we have discussed so far is an articulation of the information gap between managers and firm owners, which affects the ability of owners to implement R&D strategies.

Martin (1993) develops a model of a Cournot-Nash industry in which owners have to offer incentives to privately informed managers to invest in cost-reducing R&D. In other respects the model is similar to that in Dasgupta and Stiglitz (1980b) and indeed the model predictions are also similar. Investment in cost-reducing R&D is a decreasing function of the number of firms in the industry. The greater the number of competitors, the higher is the equilibrium level of the marginal cost. Asymmetric information, alone, does not change the result that competition lowers incentives for cost-reducing R&D in the absence of exclusive intellectual property rights.

Schmidt (1997) develops a richer model of firm governance in which firms face a risk of bankruptcy. Bankruptcy has punitive consequences for a firm's managers, who are at least temporarily out of a job, and they exert effort to avoid this unhappy state. In Schmidt's model, greater competition has two opposing consequences for managerial effort and innovation. By reducing each firm's demand, greater competition lowers the incentive to innovate, as in the models developed by Dasgupta and Stiglitz (1980b) and Martin (1993). However, greater competition also increases the risk of bankruptcy, which encourages manager to work hard (to innovate) to preserve their jobs. Despite

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market concentration, but the model assumes a specific sequential structure for innovation.

these opposing forces, Schmidt's models do not generate predictions that vary sharply from those in models that ignore information costs.[12]

Other Theories and Extensions

We have implicitly assumed that profits depend only on the available technologies and not on the identity of the firms that own the technologies.[13] This assumption is at odds with much of the competitive strategy literature, which emphasizes differences in the ability and desire of firms to exploit technological opportunities. There is also a small economics literature that emphasizes the effects of asymmetric firm characteristics on innovation incentives.

Boone (2001) relates the value of a cost-reducing innovation to firms' pre-innovation marginal costs and the degree of competition in the industry. He shows that firms value innovations differently (and hence will invest differently to compete for innovations), and furthermore these values depend on the degree of competition in the industry. He also correctly faults empirical studies that equate the degree of competition to the number of firms in the industry or the measure of market concentration. Equilibrium industry structure follows from the characteristics of the firms. For example, in a Cournot-Nash oligopoly with constant marginal costs, a firm's size is inversely related to its marginal costs. If firms have different sizes, it is because they have different cost structures. Some of Boone's results reinforce the efficiency effect in Gilbert and Newbery (1982). Under some conditions he finds that the most efficient firm, which is also the largest firm in a Cournot-Nash oligopoly, has the greatest incentive to invest in a new process technology.

Some types of innovations are potentially disruptive to existing organizational structures within industries (see, e.g. Teece (1986)). They introduce radically different technologies

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[12] Schmidt (1997) offers a model in which R&D activity peaks for firms in a duopoly. However, one can generate these results without asymmetric information. See, e.g. Sah and Stiglitz (1987) and Farrell et al. (2004).

[13] Boone (2001) shows that the value of a cost-reducing innovation to a firm depends on the firm's pre-innovation marginal cost and the intensity of competition in the industry.

and are difficult to conceptualize as simple substitutes for existing processes and products. Institutional commitments to existing products or production methods can be as great a factor in the incentive to innovate as the problem of self-induced obsolescence. Such commitments can take the form of firm-specific skills, investments in complementary assets, and a preference for established ways of doing business. Moreover, even if all firms have the same incentive to engage in research and development, it is highly unlikely that all firms are equal in the effectiveness of their innovative efforts. Firms may possess private information about R&D opportunities, or have unique assets that are related to innovation success. Variance in effectiveness also makes it difficult to posit a strong relationship between industry structure and innovation.

Henderson (1993) describes the experience of semiconductor firms that were faced with new photolithography technology for making large-scale integrated circuits. A crucial technology was the optics required to project complex circuit layouts onto semiconductor wafers. Camera companies such as Canon and Nikon had an advantage in these technologies and threatened to take business away from established integrated circuit manufacturers. Although firms in both the optics and semiconductor industries had incentives to introduce the new process technologies, the winner depended in part on the ability of established companies to adapt to new technologies with which they had little experience.

The photolithography example presents a quite different take on the notion of a drastic innovation. Here, the innovation is drastic because it requires a change in the management of innovation within the firm. Henderson calls these "architectural" innovations. An innovation can be drastic in the architectural sense even if it is not drastic in the sense of creating a new monopoly price that is less than the old marginal cost.

There are many examples of architectural innovations. Electronic watches required upscale mechanical watchmakers to emphasize even more the value of their products as jewelry instead of time-keeping devices. The rise of the Internet caused Microsoft to reorganize its research efforts to put more emphasize on browsers and servers rather than desktop software. Camera makers and film companies have had to adapt to digital photography. Some, such as Kodak, managed the transition with partial success, while Polaroid was a casualty of the digital revolution. Other market leaders, such as General Motors, DEC and IBM, have had bureaucratic problems in adapting to new technologies. Henderson (1994) observes that pharmaceutical companies have maintained their dominance for half a century because they have been able to continually remake themselves. Drug companies encourage scientists to publish. In the best companies, eminence is a criterion for promotion. They balanced science and commercial success in ways that enhanced their abilities to respond to new technological opportunities.

Innovation requires hard work, passion, and genius. Management gurus often stress the need to personalize competition to get the juices of innovation flowing. Pearson (1997) claims that companies are more innovative when they focus on beating a particular competitor, not just on improvements in performance. He gives as an example a 40% reduction in engine costs at Cummings Engine in response to Japanese competitors. It is, however, difficult to disassociate Pearson's emphasis on one-on-one competition from the more general role of competition as a stimulus to innovation.

One of the most influential theories of innovation in the business literature is Clayton Christensen's theory that dominant firms often fail to innovate precisely because they are too concerned with their present customers' needs. In his book, *The Innovator's Dilemma*, Christensen (1997) recounts the history of disruptive innovation in the personal computer disk drive industry. The industry experienced a succession of significant innovations that greatly increased storage capacities and reduced costs. In a classic example of Schumpeterian competition, the sequence of significant innovations generated waves of creative destruction. Each innovator enjoyed a period of temporary industry dominance, but the dominant firm rarely produced the next innovation and was quickly replaced by a new dominant firm. Christensen's explanation for the failures of the dominant firms to maintain their leadership is that they focused too much on the needs of their customers. They stayed within the existing technological boundaries and delivered their customers the extra performance that they desired. However, by doing so, they ignored the potential of new, disruptive technologies. These new technologies were usually inferior to the existing technology when they were first introduced. But the new technologies offered the greatest potential for improvement and ultimately replaced the existing technology.

Christensen's emphasis is on the information flows between the customer and the innovator; his thesis is that too much attention on customers' present needs causes dominant firms to focus on the wrong technologies and miss the next wave of innovation. Bower and Christensen (1997) offer several other examples of once dominant firms that lost their innovative edge. These include Xerox, which lost market share to Canon and other competitors[14], the mechanized excavator market where Caterpillar and Deere took over from Bucyrus-Erie, the decline of Sears and the ascent of Wal-Mart, and DEC's failure to substitute PCs for its once dominant position in minicomputers. What is often lost in the Christensen information-based theory is that these waves of creative destruction are also consistent with competition-based theories of R&D. Christensen suggests that dominant firms should have an advantage over rivals for disruptive innovations. However, market-based theories, such as Reinganum's (1983) model of innovation with exponential discovery probabilities, suggest that dominant firms often have no greater incentives than new rivals to introduce drastic innovations, and their incentive may be distinctly less. An incumbent monopolist could have a greater incentive to innovate that a single competitor if the innovation is non-drastic, even if discovery follows an exponential discovery process. However, in an industry with an incumbent monopolist and several potential entrants, it does not follow that the incumbent should be the most likely firm to introduce a new innovation, even if the innovation is non-drastic so that the incumbent benefits from the efficiency effect. For illustration, the incumbent might invest twice as much as a single potential competitor. But if there are eight potential competitors, and if each has the same discovery technology, the incumbent's probability of being the next successful innovator is only 20 percent. The odds are five to one that a new competitor will be the next innovator.

[14] See also Bresnahan (1985) on Xerox's response to innovation competition.

Innovation Diversity

Competition in R&D is a source of diversity in research paths that can create value and can be difficult for a single firm to duplicate. This is the flip side of the argument that monopoly can avoid the redundant expenditures on R&D that are likely to occur in competitive markets. Oil company mergers may save redundant exploration expenditures. However it is sometimes the case that when two oil companies explore the same area, one may succeed and the other may fail because they take different approaches to the search for oil. In theory, a single firm can pursue multiple R&D paths, but in practice it can be difficult for a single firm to maintain the diversity of inquiry that can characterize truly independent R&D.

Innovation diversity is an elusive concept. It is not obvious that reducing the number of firms in an industry reduces the number of independent R&D paths. That follows if we assume that each firm takes a single R&D path, but that need not be the case. It is common for firms to pursue several research paths. Pharmaceutical research companies test hundreds and thousands of molecular combinations in search of new medicines. Semiconductor companies experiment with different manufacturing processes for wafer fabrication. Sah and Stiglitz (1987) consider a model in which firms can choose any number of independent R&D projects, each of which succeeds with the same probability. They show that under some conditions the equilibrium number of R&D paths is independent of the structure of the industry. Their result requires several strong assumptions. It must be the case that: (i) the value of being the only firm that has a successful project is independent of the number of firms in the market and of the distribution of unsuccessful projects in the market; (ii) the value of another R&D project to a firm is zero if any other firm has a successful project; and (iii) the value of another R&D project to a firm is zero if that firm has another successful project.

In these models, a single firm can make up for the loss of diversity by increasing the number of projects undertaken at that firm. However there is much more to innovation diversity than counting the number of R&D projects in the industry. Anecdotal evidence suggests that organizational factors limit the extent to which a firm can diversify its innovation efforts. Research programs that appear to be redundant may hide important differences, and combining such programs may risk the elimination of an alternative path of discovery. Andrew Grove, the former CEO of Intel, described how he wanted to keep his options open by pursuing active R&D programs for microprocessors that utilized by RISC (Reduced Instruction Set Computing) and CISC (Complex Instruction Set Computing) technology. In the end, Intel abandoned RISC in favor of CISC because it was too difficult to pursue both options simultaneously. Independent researchers develop capabilities and "hunches" that are difficult to replicate within a single organization. It is difficult to model the value of this type of diversity.[15]

Our analysis so far has ignored the effects of scale and market structure on the production function for research and development knowledge. Joseph Schumpeter praised monopoly as a source of innovation because monopoly provides a "more stable platform" to engage in R&D. R&D has large economies of scale, which Schumpeter argued can be more fully exploited by a single firm that dominates an industry. Retained earnings are the source of funds for approximately 70 percent of all R&D investment. R&D investment is risky and monopoly profits can cushion the uncertain payoff of R&D. Furthermore, most firms finance R&D with internally generated funds, so monopoly profits can translate into more dollars to spend on R&D. Firms are likely to know more than investors about R&D prospects. Investors would be reluctant to invest in risky R&D projects if they believe that firms will use internally generated funds for projects that have high expected payoffs and will turn to the capital market only for projects that have low expected payoffs. This raises the possibility that monopoly is beneficial for R&D simply because monopoly profits lower the cost of raising funds for R&D.

These observations are important, but may oversimplify the benefits of monopoly profits for R&D investment. Internal funds are often sufficient to finance R&D investments in many industries, even industries that are workably competitive. Firms can diversify their

[15] Sah and Stiglitz (1985, 1986, 1988) attempt to do so in a series of papers that explore simple models of bureaucracy.

R&D risks by pursuing different R&D programs and stockholders can protect themselves against risky R&D projects by holding a portfolio of firms. Pharmaceutical research is a case in point. About 70% of drug R&D programs fail to pay back the cost of the R&D and the average cost of bringing a successful drug to market is about $300 million. These numbers suggest that the risk, even for a large pharmaceutical R&D firm, is substantial, however shareholders can diversify the risk by holding a portfolio of several pharmaceutical companies.

Nearly all economic models that relate market structure to incentives for innovation assume that the firm's capacity for R&D is either generated through its own expenditures or purchased in the market, for example by licensing technology from others. These models typically ignore the fact that research output depends on the human capital of the people who work for the firm, which in turn depends on their education and experience. There are well-known stories of innovative firms that were founded by scientists and engineers who owed their experience to employment in other, technologically progressive firms. An example is the sequence of innovation in semiconductor technology that began at Bell Laboratories and then moved to Shockley Semiconductor. Key executives at Shockley departed to form Fairchild Semiconductor, and subsequently left Fairchild to start successful new firms such as AMD, Intel, Intersil, and National Semiconductor (which ultimately bought and then sold Fairchild). Studies of market structure and innovation in this industry should account for the market conditions that created the human capital that went on to found these other successful enterprises. For example, suppose that there is a highly innovator and competitive telecommunications sector, and suppose further that many of the management teams in these companies trace their employment histories to a giant such as Bell Laboratories or IBM. Is it correct to conclude that competitive markets promote innovation in this example? Perhaps a better interpretation is that competitive markets were useful only in a more limited sense to exploit innovations whose seeds were sown at Bell Labs or IBM.

Gompers, Lerner and Scharfstein (2005) is one of a very few attempts to systematically examine how corporate experience has shaped innovation. The authors trace the employment histories of founders and key executives in a database of firms formed with venture capital financing from 1986 to 1999.[16] They use the term "entrepreneurial spawners" to describe companies that are at the roots of the corporate histories of key executives at many new startups. Working backward through the resumes of key executives, the authors find that 70 of the startup companies in their database had management teams with prior experience at IBM, 60 at AT&T, 55 at Sun Microsystems, and so on; 48 publicly-traded companies had employees who became key executives at more than 10 different startups.

The authors consider two anecdotal explanations for entrepreneurial spawning, which they call the Xerox story and the Fairchild story. In the Xerox story, key employees leave because the bureaucracy does not recognize the market potential for ideas that fall outside their core business. In the Fairchild story, key employees acquire human capital and form entrepreneurial networks that facilitate new startups. They find evidence that is consistent with the Fairchild story. In particular, they find that companies, many of which were located in Silicon Valley, spawned other startups when their growth rates slowed, suggesting that expected rewards at these companies were not sufficient to retain their top executives.

This type of research is very different from studies that relate R&D to present market structures. Yet the history of human capital formation is an important component in the understanding of innovative companies and markets. While there is clearly much more that needs to be done on this important topic, the analysis in Gompers, Lerner and Scharfstein identifies some of the building blocks for a theory of corporate experience and its effects on innovation.

[16] The total number of venture-capital financed startups in their database increased from 221 in 1986 to 804 in 1999. The number of technology startups was 144 in 1986 and 232 in 1999, peaking at 372 in 1996.

III. Empirical Studies of R&D

The previous section attempted to tease out some theoretical conclusions about the relationship between innovation and market structure. It is a difficult though not entirely unrewarding task. To the extent that the literature yields any predictive results, they depend on the characteristics of innovations, the R&D technologies, and the industries in which R&D occurs. The details matter.[17] In this section we turn to empirical studies of market structure and innovation. What does experience tell us about the most fertile environment for generating inventions and for developing their potential? How do R&D expenditure and outcomes vary with market structures?

A very large number of empirical studies test the relationship between firm size or industry concentration and R&D. Indeed, Aghion and Tirole (1994) call this the second most tested hypothesis in industrial organization, after the relationship between profits and firm size/concentration. We summarize many of these studies and their key observations in Tables 1 and 2. The first table lists studies that relate R&D to firm size, and the second table does the same for market concentration. There is no compelling evidence from the studies listed in the first table that R&D increases with firm size above some minimal threshold. Although some studies show a relationship between R&D spending or output and market structure, these effects disappear after controlling for technological opportunities and other industry-specific factors, with no single firm size being optimal for R&D in every industry. Freeman (1982) identifies a threshold size for effective R&D in non-U.S. industries. However, the specific thresholds vary widely across industries. An early study by Mansfield (1968) concluded: "…little evidence that industrial giants are needed in all or even most industries to promote rapid technological change and rapid utilization of new techniques. Baldwin and Scott (1987), summarizing many studies, conclude that: "the preponderance of evidence ...indicates that economies of scale in industrial R&D, of both the firm and the research establishment, are in most cases exhausted well below the largest firm and research establishment size examined. The studies that have found a pervasive positive relationship between size and R&D

[17] Carlton and Gertner (2002) and Katz and Shapiro (2004) reach similar conclusions in the context of antitrust policy to promote innovation.

intensity are those drawing on samples including companies of widely ranging sizes and with little or no control for industry effects....The Schumpeterian hypothesis relating innovation to firm size appears to hold up if interpreted as a threshold one, but does not imply that giant corporations are essential for vigorous R&D in most fields." (p.87)

The studies of the relationship between market concentration and R&D spending or innovative outputs are similarly inconclusive. Although early studies showed some tendency for R&D intensity to be larger for moderately concentrated industries, these effects typically disappeared in more refined statistical studies that controlled for industry effects and technological opportunities. Of course if R&D spending did vary with firm size or market structure, this would not justify restructuring the industry to enhance innovation. We should not forget that observed market structures and innovation are equilibrium outcomes. There is no assurance that exogenous changes in market structure would result in different, and more innovative, outcomes.

Nearly all of the studies listed in these two tables are plagued by severe methodological and data problems that undermine their usefulness. I discuss some of these difficulties below, but first I offer a brief case study that illustrates why it is so hard to discern a relationship between market structure and innovation. My example is the market for built-in residential dishwashers. Home dishwashers changed little in terms of functional characteristics or appearance from 1960 to about the mid-1980s. Starting in the mid-1980s, a number of new models appeared with features such as water-efficient engineering, quiet operation, and sophisticated controls. Patenting in the product classification for dishwashers accelerated rapidly about this time. The number of patents awarded in this classification held steady at about 80 per year from 1975 until about 1985, after which the number of patents awarded increased steadily, reaching about 300 per year in 2004. (See Figure 1)

What happened to the dishwasher industry over this time period? In 1974, Consumer Reports listed ten different brands of dishwashers, several of which were manufactured by the same company. The leading suppliers of dishwashers at the time were General

Electric, Whirlpool, and Maytag, with a few smaller producers such as KitchenAid.[18] A reasonable estimate is that for the decade from 1975-85, during which time the rate of patenting was relatively low and steady, there were three major suppliers of residential built-in dishwashers and a few fringe suppliers. The major suppliers were also in the market in 2000 (and had gobbled up some of the smaller suppliers). With respect to U.S. manufacturers of dishwashers, the market in 2000 was not very different from the market in 1975. Two other major factors distinguish the market before and after 1985, when the rate patenting began to skyrocket. One factor is the advent of microprocessor controls, which allowed manufacturers to design in (and patent) much more functionality in their products. The other major factor was the entry of foreign manufacturers, particularly from Europe. In 1998, Consumer Reports listed thirteen dishwasher brands offered by distinct manufacturers. Of these, at least five were European firms. Thus, over the time period shown in Figure 1, the increase in patenting coincided with both an increase in the number of independent suppliers and an increase in the variety of these suppliers (domestic and foreign).

What can we make of this? Not much, because the technology changed so dramatically over this time period. Indeed there is a further complication. The entry of the European firms not only increased the number of independent dishwasher suppliers in the US, it also brought new ideas to the US market. Miele, a German brand sold in the US since 1984, was the first to use microprocessor controls for dishwashers sold in the US. Bosch and other European manufacturers brought energy saving and quieter designs to the US market. We can only speculate whether US manufacturers would have introduced similar designs if the European manufacturers had not entered the US market.

This simple story illustrates the complexities of trying to assess the influence of market structure on innovation. In particular it shows how exogenous factors, such as the entry of foreign suppliers who design products for different types of consumers facing different constraints (e.g. smaller kitchens) and different factor prices (e.g. higher energy costs)

[18] Dishwashers sold under the brand name Sears Kenmore, a popular brand at the time, were manufactured by Whirlpool.

can influence the direction of technological developments. It is plausible that complications, such as those that affected the US market for dishwashers, are present in many, if not most, industries.

Returning to the empirical studies identified in Tables 1 and 2, most of them suffer from one or more of the following problems.

Poor data on innovative activity

Many of the studies that relate market structure to innovation rely on R&D expenditures, often at a highly aggregated level. R&D expenditure is an input to innovation. As we have seen from models of innovation with non-exclusive property rights, greater R&D expenditures do not translate directly into greater innovative output and indeed the opposite can be true. Market environments with non-exclusive intellectual property rights may generate redundant R&D expenditures that increase industry costs with no additional benefits for innovative output.

As an alternative, several studies focus on patent awards as a measure of innovative output. Unfortunately, the correspondence between patents and useful new products or processes is also weak in many industries. In industries such as semiconductors patenting is often done for defensive purposes and is not a particularly good indication of the direction of new technology.[19]

Ideally, a structural model of R&D would include estimates of the expected values of discoveries. This corresponds to the demand side of conventional models that relate production decisions to the characteristics of market demand. By its very nature, estimates of the value of discoveries are difficult to obtain; these are products or processes that have not yet been invented. Even if values of individual discoveries could be estimated, this would not be sufficient to estimate the value of an R&D program because many discoveries open opportunities to additional valuable innovations.

Furthermore, a complete analysis of innovation activity would require data on the R&D activities of all potential innovators. It is well known that innovations often come from unexpected sources, including from firms in unrelated industries and sometimes from individual inventors. Henderson's (1993) example of innovation in photolithography is an example of one industry (optics) generating innovations for use in another industry (semiconductor fabrication). Culbertson and Mueller (1985) note that most innovation in food processing came from firms in other industries, foreign firms, and individual inventors. It is exceedingly difficult to identify all of the potential sources of innovation for many new products and processes. The sources of invention are numerous, scattered, and varied.

Firms often purchase rights to innovations made by others.[20] The effects of market forces can differ significantly for investment in own-R&D and for purchases of innovations from others. For example, in a study of R&D investment behavior by German firms, Cyzarnitzki and Kraft (2004) found that new entrants into industries invested more in R&D than incumbents. However, in a companion study the authors found that incumbents spent more than entrants to license technologies from others (Cyzarnitzki and Kraft (2005)).

Failure to distinguish product v. process innovations

The economic theory demonstrates that incentives to invest in innovation can differ depending on whether the innovation is a new product or a new cost-reducing process. Yet few of the many empirical studies of R&D attempt to distinguish the two. There are some exceptions. For example, Link and Lunn (1984) examined the rate of return to R&D separately for product and process innovations. They found that returns to process R&D increased with market concentration. This is consistent with theoretical relationship between competition and R&D in models with non-exclusive intellectual

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[19] See, e.g., Hall and Ziedonis (2001)

[20] Brock (1975) observed that IBM originated only 7 of 23 major early innovations in computing.

property rights (e.g. Dasgupta and Stiglitz (1980b)). For R&D directed to new products, they found that the rate of return was independent of market concentration.

Failure to distinguish exclusive v. non-exclusive property rights

The economic theory of the incentive effects of different market structures for innovation clearly demonstrates the importance of the exclusivity for innovation incentives. With exclusive rights, the theory suggests that competition promotes innovation. There are models that predict differently, such as the preemption models in Gilbert and Newbery (1982) and Fudenberg et al. (1983), however these models require particular assumptions about market structure and the dynamics of innovation competition and do not generalize to many other reasonable market settings. Explicit empirical tests of preemption do not generally sustain the view that incumbent firms invest in ways that effectively preempt competitors. Examples of these tests include the cross-sectional analysis in Cyzarnitzki and Kraft (2004) and industry case studies such as Bresnahan's (1985) study of competition in xerography, Cockburn and Henderson's (1995) study of R&D competition for pharmaceuticals, and the studies of competition in the computer disk drive industry by Lerner (1997) and Christensen (1997).

Differences in technological opportunities across industries and time

Early studies of the relationship between market structure and R&D identified intriguing patterns, such as the inverted-U-shape in which expenditures on R&D increase with market concentration up to a point and then decrease.[21] More recent analyses done at the level of an individual industry or sector have, however, challenged these conclusions.[22] Using Federal Trade Commission 1974 line of business data for 437 firms, Scott (1984, 1993) found no significant relationship between market structure and R&D intensity after controlling for effects that were specific to firms and their industries. Also using FTC line of business data, Levin et al. (1985) show a statistically significant "inverted-U" relationship between industry concentration and both R&D intensity and the rate of

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[21] See. e.g., Scherer (1967) and Scherer (1984).

[22] Carter and Williams (1957) appear to be among the first to establish the importance of

introductions of innovations. The relationship peaked at a C4 index (the share of the largest four firms in the industry) of about 0.5-0.6; this is consistent with Scherer's earlier results. The authors then included eight variables constructed from the Yale R&D survey to measure technological opportunity and appropriability for each firm. These included, for example, the effectiveness of appropriation mechanisms such as secrecy, lead time, and ease of imitation. Inclusion of these variables dramatically lowered the significance of the concentration variables in the R&D regression. At the same time, technological opportunity and appropriability were significant, with the expected signs. These inter-industry econometric studies suggest that whatever relationship exists at a general economy-wide level between industry structure and R&D is masked by differences across industries in technological opportunities, demand, and the appropriability of inventions, all of which are so important to the process of innovation. As Baldwin and Scott (1987) note, "The most common feature of the few R&D and innovation analyses that have sought to control for the underlying technological environment is a dramatic reduction in the observed impact of the Schumpeterian size and market power variables."

Lack of structural models of innovation

Few statistical studies of innovation use a structural economic model of the determinants of innovation. Although this is a reflection of the highly unsettled state of the economic theory, it poses serious problems for the reliability of econometric estimates. Given that we expect innovation incentives to bear a highly nonlinear relationship to industry characteristics, regression analyses that merely include plausible determinants of innovation are likely to generate biased estimates. Unfortunately, it is difficult to "nest" different theoretical models of R&D in ways that would allow the econometrician to reject some models as having weak explanatory effects. Empirical studies of the relationship of prices to market structure are often constructed on "standard" models, such as Bertrand-Nash pricing for static games with differentiated products. The economic theory of innovation competition does not establish a clear favorite model for empirical analysis. A case could be made for the replacement effects models of Arrow (1962) and Reinganum (1985) when innovations enjoy exclusive intellectual property

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technological opportunity as a main determinant of R&D expenditures, based on 152 case studies.

rights, and for a model such as Dasgupta-Stiglitz (1980b) when intellectual property rights are non-exclusive, but these models clearly are not appropriate descriptions for all market situations.

The lack of a structural model of innovation also invites estimation errors because we should expect that few variables in an econometric analysis of innovation determinants are truly exogenous.[23] Empirical studies do not make a clear case that market structure affects R&D, but there is little doubt that R&D is a cause of market structure, and this endogeneity greatly complicates the analysis. For example, Phillips (1971) notes that the technology that made early commercial aircraft largely came from exogenous sources and neither size nor market power explained the relative R&D performances of the industry's firms. However, relative success in innovation was the primary cause of the growth of some firms and the decline of others, and hence of growing concentration. Mansfield (1983) found that process innovation led to radical increases in minimum optimal scale in steel and cement, and less dramatic increases for other industries. Thus, R&D caused higher concentration in these industries. In other industries, Mansfield found that product innovations were concentration decreasing.

Failure to control for other confounding factors

With the many factors that influence the opportunity and incentives for innovation, the need for "natural experiments" that enable empirical researchers to filter out the effects of unobserved covariates is particularly important for studies that relate innovation to observed market characteristics. Most of the empirical studies of market structure and innovation use large cross sections or panels, for which many factors vary in the population that are inadequately controlled for by the econometrician.

Natural experiments are difficult to find for studies relating market structure and innovation. Changes in import policies, which cause relatively rapid changes in market structure without changing technological opportunities, are plausible candidates.

[23] See, e.g., Salinger's (1980) study of concentration and profits, which suggests that both concentration and profits are likely related to innovation success.

Significant increases in competition resulting from changes in import penetration or other industry shocks have triggered the major restructuring of some industries to achieve lower manufacturing costs and to develop new and more competitive products.[24] MacDonald (1994) confirmed these observations by analyzing the determinants of the rate of growth of labor productivity (output per hour of labor) in 94 industries during the period 1972 through 1987.[25] He found that increases in import penetration had large positive impacts on labor productivity in highly concentrated industries. Using labor productivity as an indicator, albeit imperfect, of technical change, these results suggest that a sudden increase in competition had significant beneficial impacts for technical progress in markets that had been highly concentrated.

Failure to account for "outliers"

The objective of a statistical analysis is to identify the main determinants that influence the variables of interest. Econometric models assume that there are unobserved, latent influences that are conveniently lumped into the "error term". However these latent factors could be major determinants of innovative outcomes. When we think of innovation, we think of individuals or companies that are outliers in some sense. They exhibit flashes of brilliance, choose a different path, and push the frontiers of technological progress. We must be careful not to suppress the role of the true innovators by burying them in the econometric error term.

Early studies, such as Jewkes et al. (1969) and Schmookler (1966) emphasized the role of the individual as the source of innovation. Some of the most commercially important discoveries have come from independent inventors with little or no contact with the industry that they have revolutionized, and hence whose influences on technology would be very difficult to capture with a regression on market structure. Chester F. Carlson, the inventor of xerography, was a patent lawyer. Gillette, the inventor of the safety razor, was a traveling salesman. J. B. Dunlop was a veterinary surgeon when he invented the pneumatic tire. An undertaker invented the automatic telephone dialing system, and the

[24] *See, e.g.,* Dertouzos (1990) (describing the experience of Xerox, domestic steel and chemical producers, and commercial airline manufacturers to increased competition).

inventor of the ballpoint pen was a sometimes sculptor, painter and journalist. Even with the growth in corporate patenting and the importance of scale to the development and exploitation of innovations, we should not ignore that discoveries come from people, and not all people make discoveries.

Outliers come in many varieties. The story of innovations in dishwasher technology is consistent with a vital role played by foreign manufacturers, who designed dishwashers for consumers facing constraints that differed from the typical installation in an American home. While these models may have been initially ill suited for the American consumer, they had features, such as quiet operation, that American consumers valued and that stimulated innovation by US suppliers. The history of innovation in the US automobile industry shares a common thread.

Industry case studies are sources of evidence on the relationship between market structure and innovation with advantages and disadvantages compared to typical cross-sectional econometric studies. Based on an international study of the sources of competitive advantage, Michael Porter concluded that "[R]ivalry has a direct role in stimulating improvement and innovation..."[26] He concluded that "A group of domestic rivals draws attention to the industry, encouraging investments by individuals, suppliers, and institutions that improve the national environment, and creates diversity and incentives to speed the rate of innovation..."[27] Porter's thesis is that firm structure and rivalry interact with the supply of industry factors of production and demand in complex ways that are conducive to technological progress. The presence of these interdependencies likely contributes to the difficulty of uncovering clear conclusions from statistical studies of the relationship between market structure and R&D. At the same time, Porter's analysis is essentially a cross-section statistical study, and suffers from many of the data and modeling problems that affect the other studies listed in tables 1 and 2.

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[25] MacDonald (1994).
[26] Porter (1990), p. 143.
[27] *Id.* at 144.

Given the great importance of technological opportunity and industry-specific factors in R&D, it is not surprising that some of the most useful studies focus on a single industry, or even a single research program. Unfortunately, there are few such detailed studies, and even fewer that focus on the dynamics of R&D. Cockburn and Henderson (1995) examine R&D expenditures by pharmaceutical firms at the therapeutic program level, in this case drugs in the class of ACE inhibitors used to treat hypertension. Their data set is close to ideal for testing models such as Reinganum's (1985) patent race, or the preemption models in Fudenberg et al. (1983) and others. The authors have detailed data on R&D expenditures for products that enjoy relatively strong patent protection. The firms are investing to patent new ethical drugs, one of the few classes of products for which patents are a primary means to appropriate value. Their conclusions provide valuable insights for studies of dynamic investment behavior. First they note that firms do not appear to adjust the intensity of their research programs in response to changes in R&D by their competitors. This is an important result, because the ability to monitor rivals' research progress is crucial to some models of preemptive R&D, such as those in Fudenberg et al. (1983). If the data revealed firms' reactions to changes in rival investments, one would expect an increase in R&D at the program level by one firm to induce responses (either higher or lower) by rival firms. Cockburn and Henderson do not observe this behavior. However, as they explain, this could merely reflect that observed R&D programs are equilibrium responses to market conditions. They observe equilibrium strategies, not R&D levels along a reaction function. When changes in equilibrium R&D intensities occur, these are responses to market shocks that affect all competitors.

A second interesting finding in their analysis is that even in the search for ethical drugs, where patent protection is key to commercial success, the competition is not "winner take all". A discovery by one firm in a therapeutic category does not cause rival firms to abandon their R&D programs in the same category. Indeed, several of their empirical specifications find the opposite. Discoveries by one firm tend to increase R&D spending by rival firms. They explain this by noting that discovery is often cumulative and does not foreclose new products by other firms. For example, they observe that nine different pharmaceutical firms patented ACE-inhibitor drugs in the eight years after Squibb patented the first drug in this category in 1977. There was, however, still a significant early-mover effect; in 1990 the first two innovators (Squibb and Merck) accounted for 90 percent of US sales of ACE-inhibitors.

Cockburn and Henderson's analysis suggests that drug research has large positive spillovers. Discoveries (in the form of patents) by one company tended to expand the technological opportunities of other firms and stimulated R&D spending. Although most of the theoretical patent race literature assumes that a discovery by one firm spells doom for the profits and R&D programs of rival firms, Cockburn and Henderson instead find that for ethical drugs in this category, research had substantial positive spillovers and drug discoveries by one firm did not foreclose additional discoveries by other firms in the same therapeutic category.

Lerner (1997) focuses on technology races in the market for computer disk drives. Lerner applies statistical rigor to the question of whether current industry leaders are more or less likely than other firms to develop improved disk drive technologies. The R&D racing literature typically assumes that the reward to the winner of the race is a valuable patent that excluded competitors. Patents were not important as an appropriation mechanism in the disk drive industry during the period studied by Lerner (1971-1988). Nonetheless, the market had some of the qualitative features of a "winner-take-all" competition. Leading-edge disk drives commanded much higher mark-ups than did lower performance drives. Many firms exited the industry and some of the survivors earned substantial profits, although perhaps for reasons other than pure technological prowess. Although the innovation competition that Lerner studied in the disk drive industry was clearly much more complex than a simple winner-take-all market, it had some similarities, perhaps more so that the market for ACE-inhibitors in which some follow-on innovators were highly profitable.

Lerner used storage density as a proxy for the state of a firm's disk drive technology and measured innovation in three different ways. For each firm in the industry over the sample period, Lerner measured: whether the firm introduced drives with higher density than it had shipped earlier; the extent of the improvement in density; and the time between shipment of drives with improved density. According to all of these measures, the greatest amount of innovation occurred for firms whose best drives in any year had densities within 25 and 74% of the best drive in the industry. The firm that was the market leader was less likely to introduce a better drive, made smaller improvements if it did introduce a better drive, and took longer to introduce a better drive than did firms whose technologies lagged the market leader.

Lerner argues that these results contradict claims that a leading firm has an incentive to preempt rivals by investing more to improve its technology. That does not necessarily follow. The costs and benefits of technological improvements depend on a firm's location on the technological frontier. It should be easier for a firm to add another rung on the technological ladder if it is half way to the top than if it is already at the top. Furthermore, a firm that is far enough ahead might be able to sustain its lead for some time without investing as much as its technologically less advantaged competitors. Lerner also found that the number of competitors did not affect the rate of technological improvement for leaders or followers. This is not surprising given the large number of firms that supplied disk drives over this period. He did find that firms with greater sales and those specializing in disk drives were more likely to innovate, however it is difficult to disassociate firm size from past R&D success.

Lerner does not analyze whether the firm that is the technological leader in disk drives at date t is more likely than other firms to be the leader at date $t + \tau$. This question is more closely related to the preemption hypothesis, but it is presumably difficult to test because one would expect a high degree of autocorrelation in firms' technological positions. Christensen (1997) observed that firms in this industry frequently lost their technological leads as other firms leapfrogged their technological capabilities. He attributed this to an informational bias that encourages leading firms to make only incremental innovations that better serve their existing customer base, foregoing more radical innovations because they are ill-suited for their present customers. However, one does not need informational distortions to explain this type of behavior. The theoretical models we have reviewed make the point that a monopolist has a lower incentive than a new competitor to introduce a drastic innovation when the innovation can be protected from imitation. The efficiency effect that drives monopoly preemption requires non-drastic (i.e., incremental) innovations. Thus it should not be surprising that new leading firms specialize in incremental innovations while major innovations come from new entrants. Informational biases could explain this behavior, but they are not the only explanation.

The observed pattern of destructive competition that has occurred in the disk drive industry is consistent with a stochastic technology race, whether or not leading firms have some preemption incentive. Lerner's data show that over the sample period, each firm that supplied disk drives faced an average of about 25 other drive manufacturers. If each firm invested the same amount in R&D and had identical technological capabilities, the probability that any one firm would emerge as the technological leader or maintain its technological edge is only about four percent. If leading firms had an incentive to preempt their rivals due to the efficiency effect from non-drastic innovation, the probability that leaders would emerge victorious is still rather small even if they invest at a much greater rate than any one of their competitors. As noted previously, suppose that a leading firm faced eight potential competitors and, due to preemption incentives, invests twice as much in R&D as any single competitor. With equal technological capabilities, the probability that the leader would retain its technological edge is still only twenty percent.

IV. Concluding Remarks

We have surveyed economic theory on the relation between horizontal market structure and incentives to invest in process and product innovation. The theory does not support a conclusion that monopoly necessarily promotes R&D. Highly concentrated markets, at least in some circumstances, retard incentives for R&D. The evidence is clearly mixed and theoretical predictions depend on particular industry circumstances and technological opportunities.

While it is difficult to make general conclusions about R&D incentives in different market structures, the analysis does permit some broad characterizations. For both exclusive as well as non-exclusive rights to innovations, the incentive to invest in R&D:

- *Increases with the scale of the demand for the innovation.*
- *Decreases with the profits that a firm can earn if it does not innovate.*
- *Increases with the monopoly profits that a firm can protect by innovating.*

The relationship between market structure and innovation incentives differs, however, for inventions that are protected by exclusive and non-exclusive intellectual property rights.

- *With exclusive rights, investment in R&D is higher in more competitive markets for drastic innovations. Investment is also higher in more competitive markets for non-drastic innovations if the necessary conditions for preemption do not hold (e.g., if the pre-innovation market is not close to monopoly).*
- *With non-exclusive rights, the output of process R&D is lower in more competitive markets, although total industry expenditures on R&D can increase with more competition.*

For process innovations that lower constant marginal production costs, innovation incentives are lower for a monopoly that is protected from both product and R&D competition than for a competitive firm, provided that the innovator maintains exclusive and permanent rights to the innovation. Allowing for competition in R&D can reverse this result. Under some conditions a firm that has a monopoly in an existing product may have an incentive to preempt rivals by investing more in R&D for a non-drastic process innovation than the rivals would gain from the innovation. These broad characterizations apply as well to product innovations, but the conclusions are not as sharp. A monopolist that is protected from both product and R&D competition could have a greater incentive than a competitive firm to invest in a non-drastic product innovation. The general result in Arrow's (1962) model that a monopolist has a low incentive to invest in process innovations does not necessarily extend to non-drastic product innovations. For drastic innovations, relative investment incentives in monopoly and competitive market are similar for process and product innovations.

Economic theory suggests that monopoly preemption in R&D is unlikely to occur in many if not most circumstances and this appears to be borne out by the empirical evidence. The economic models of preemption require assumptions that are often do not apply. These include invention that is not drastic, a monopoly pre-innovation, exclusive intellectual property rights that foreclose competition, no alternative entry paths, and a predictable relationship between R&D spending and the award of exclusionary rights. Monopoly preemption also can occur with stochastic discovery if a firm that is ahead in a race to win an exclusive intellectual property right can monitor the R&D activities of rivals and invest to maintain its lead. Furthermore, with stochastic discovery of a non-drastic invention, an incumbent monopolist may invest more than challengers, although the incumbent would not win the R&D race with certainty.

Empirical evidence suggests that preemption is unusual, except perhaps for acquisition of licenses for exclusive intellectual property rights (Cyzarnitzki and Kraft (2005)). Case studies of dynamic R&D competition offer no support for preemptive R&D expenditures by incumbent firms.

If we drop the strong assumption that innovations are protected by exclusive and permanent rights, we can no longer conclude that incentives to invest in process innovations are higher in competitive markets than in monopoly markets. Competition decreases the market available to each firm and therefore lowers the return from innovation. In addition, competition results in redundant expenditures. Costs would be reduced if a single firm invested in R&D that others could share.

On balance the theoretical and empirical evidence does not support a strong conclusion that competition is uniformly a stimulus to innovation. We remain far from a general theory of innovation competition, although the large body of theoretical and empirical studies is beginning to yield some conclusions, however meager. Specific industry characteristics and technological opportunities determine the equilibrium relationship between market structure and innovation. To the extent that we can learn more about innovation incentives from industry studies, it appears that new learning could emerge from individual case studies that isolate specific industry factors and technological opportunities such as Cockburn and Henderson (1995) for pharmaceuticals, Lerner (1997) for computer disk drives, and Bresnahan (1985) for the plain paper copier industry.

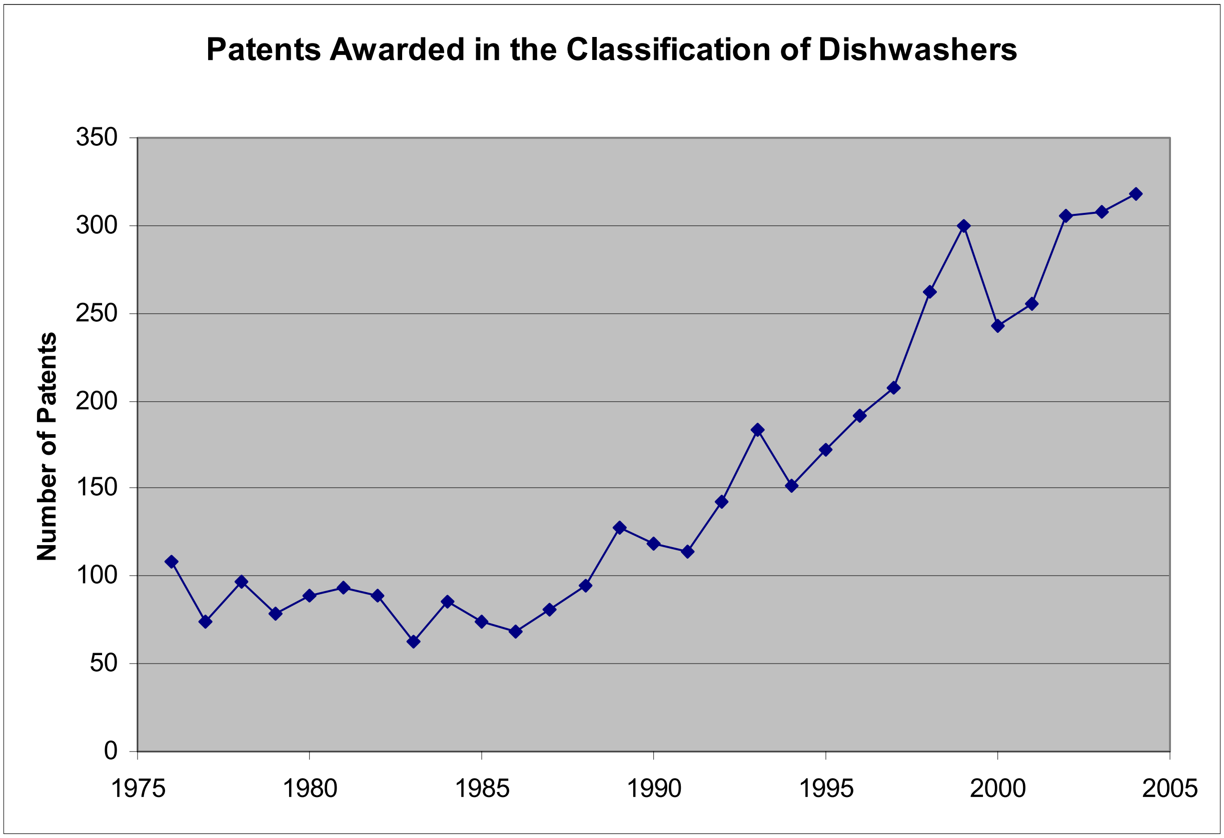
Patents Awarded in the Classification of Dishwashers
Number of Patents
350
300
250
200
150
100
50
0
1975
1980
1985
1990
1995
2000
2005

Table 1. Statistical Studies of R&D and Firm Size

Author	**Measures of R&D**	**Conclusions**
Scherer (1965)	Patents, R&D employment	No evidence of R&D intensity increasing with firm size. Some evidence of lower R&D intensity for largest firms. Substantial inter-industry differences. No correlation with profits or liquid assets.
Mansfield (1968)	R&D expenditures	Some evidence of declining R&D intensity for largest firms.
Mansfield (1977)	R&D expenditure, Innovations (patents?)	No correlation between size and R&D intensity above a threshold level. Some evidence that small firms account for a disproportionate share of initial inventions.
Link (1980)	Rate of return on R&D	No effect of size above a moderate threshold level for 101 chemical firms.
Mansfield (1981)	R&D expenditures	Larger firms spent proportionally more on R&D for entirely new products and processes.
Scherer (1983)	R&D expenditures, patents	R&D/sales and patents/sales roughly constant for most industries.
Bound et al. (1984)	R&D expenditures	Considerable variation in the elasticity of R&D spending with respect to sales
Scott (1984)	R&D expenditures (Line of Business data)	No correlation between size and R&D intensity after controlling for fixed effects.
Culbertson & Mueller (1985)	R&D employment, expenditures, patents	No effect of size on R&D intensity above a moderate threshold level.
Lunn & Martin (1986)	R&D expenditures (Line of Business data)	R&D/sales increased with line of business size.

Table 2. Statistical Studies of R&D and Market Concentration

Author	Variables	Results
Scherer (1965)	Patents, R&D employment	No correlation between R&D intensity and concentration.
Scherer (1967)	R&D employment	Positive correlation with concentration, then falling after C4 of 50-55% after controlling for industry effects.
Comanor (1967)	R&D expenditures	R&D intensity greatest with moderate barriers to entry. Entry barriers measured by absolute capital requirements and product differentiation.
Mansfield (1977)	R&D expenditure, Innovations (patents?)	Some evidence of positive correlation at low levels of market concentration, but none above moderate levels.
Mansfield (1981)	R&D expenditures	Concentrated industries spent less on basic research; otherwise concentration had no significant effect on R&D. Larger firms spent more on R&D for entirely new products and processes.
Scott (1984)	R&D expenditures (LOB)	No correlation between concentration and R&D after controlling for fixed effects.
Link & Lunn (1984)	Rate of return on R&D	Returns to process R&D increased with concentration. Returns to product R&D independent of concentration.
Levin and Reiss (1984)	R&D expenditures	No statistically significant correlation with concentration.
Culbertson & Mueller (1985)	R&D employment, expenditures, patents	Positive correlation with concentration up to a threshold C4 of about 60%.
Levin et al. (1985)	R&D expenditures, innovations	No effect of concentration on R&D after accounting for differences in appropriability.
Angelmar (1985)	R&D expenditures	Concentration positively related to R&D intensity in industries with low barriers to imitation, negatively related to R&D in industries with high barriers to imitation.
Lunn (1986)	Patents (Line of business data)	Process patents in low-tech industries positively related to concentration. No effect of concentration on product patents, or process patents in high-tech industries.
Lunn & Martin (1986)	R&D expenditures (Line of business data)	R&D/sales increased with market share and C4 index in low-tech industries.

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Appendix 1. Example of a market in which the incentive to invest in R&D is greater for monopoly than for a competitive firm.

A total of N consumers are uniformly distributed along a line whose length we normalize to one. Each consumer desires one unit of a good. Firm A is located at the left end-point of the line. If a rival Firm B enters, it locates at the right end-point of the line. As this is only an example, we simplify even further and assume that both firms have zero marginal production costs. A consumer located at point x incurs a disutility of tx if she buys from Firm A and incurs a disutility of $t(1-x)$ if she buys from the rival. Either firm can sell a good that all consumers value at v_0, or invest in R&D and sell a good that all consumers value at $v_1 > v_0$.

Suppose Firm A is a monopoly. If it sells a product with value v_A at price p, its share of the total market is $x(p,v_A) = \min[\frac{1}{t}(v_A - p),1]$ and its profit is $\pi(v_A) = \max_p Npx(p,v_A)$. If $v_A \geq 2t$, the monopoly serves the entire market and earns

$$\pi_A(v_A) = N(v_A - t).$$

Now suppose the rival firm enters at the opposite end of the line. Let p_A and v_A be the price and product choice for Firm A and p_B and v_B for Firm B. Consumers located at $x < \hat{x}$ will purchase from the Firm A and those located at $x \geq \hat{x}$ will purchase from Firm B, where

$$\hat{x} = \frac{1}{2t}[t + (v_A - v_B) + (p_B - p_A)],$$

provided that $p_A + p_B < v_A + v_B - t$, so that all consumers make a purchase. If each firm maximizes its profit by choosing a price assuming that its price does not affect its rival's price (the Nash assumption), then there is an equilibrium with $p_A = t + \frac{1}{3}(v_A - v_B)$ and $p_B = t + \frac{1}{3}(v_B - v_A)$, provided that $v_A + v_B > 3t$. In this equilibrium, Firm A earns

$$\pi_A(v_A, v_B) = \frac{N}{2t}[t + \frac{1}{3}(v_A - v_B)]^2$$

and Firm B earns

$$\pi_B(v_B, v_A) = \frac{N}{2t}[t + \frac{1}{3}(v_B - v_A)]^2 .$$

Assume $v_1 > v_0 > 2t$. The monopoly incentive to invent is

$$\Delta\Pi^m = \pi_A(v_1) - \pi_A(v_0) = N(v_1 - v_0)$$

and is the same as the marginal social return from the innovation.

The competitor's profit is

$$\pi_B(v_0, v_0) = \frac{Nt}{2}$$

if it enters with the old technology and

$$\pi_B(v_1, v_0) = \frac{N}{2t}[t + \frac{1}{3}(v_1 - v_0)]^2$$

if it enters with the new technology. Monopoly yields a greater incentive to invest in R&D than competition if

$$\pi_A(v_1) - \pi_A(v_0) > \pi_B(v_1, v_0) - \pi_B(v_0, v_0) ,$$

or if $v_1 - v_0 < 12t$.

In this example, the incentive to invest in R&D is greater under monopoly unless v_1-v_0 is very large relative to t. Note that the social value of technology v_i is $W(v_i) = N(v_i - \frac{1}{2}tL)$ and $\Delta W = N(v_1 - v_0) = \Delta\Pi^m$. The monopolist appropriates the entire social benefit from the innovation. The return to innovation for a competitor is less for two reasons. First, competition between the competitor with the new product and its rival with the old product limits the benefit from innovation. Second, unlike the case of process innovation with constant marginal costs, the competitor earns a profit even if it does not innovate because $\pi(v_0, v_0) > 0$ and this lowers the incremental return to innovation.