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INNOVATION AND MARKET

STRUCTURE: A SURVEY

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INNOVATION AND MARKET STRUCTURE: A SURVEY

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EXECUTIVE SUMMARY

Some critics have pointed to the deterioration in the international competitiveness of several U.S. industries during the past decade and argued that there is an association between these international trade problems and antitrust policy; it is alleged that antitrust policy has an adverse impact on domestic innovative activity. This argument is premised on the belief that the recent trade problems are due primarily to poor R. & D. performance. Obviously, there are other factors that affect the export/import record of U.S. industries (such as exchange rates, commercial policies of the U.S. and its trading partners, and policies by various countries to prop up or subsidize particular industries). More importantly, the argument is founded on the belief that (1) recent R. & D. efforts have been reduced and (2) that this reduction is due to antitrust policy. Are these two beliefs supported by the facts?

Although there is little dispute that labor productivity and number of patents issued in the United States have declined in recent years, particularly since 1974, it is not clear what the root causes of the innovation problem are. Innovation, by definition, is the development and introduction of new products and production techniques. Clearly, decisions to innovate are investment decisions--current expenditures are made with the hope of future payoffs. Furthermore, introduction of innovations often requires the construction of new plants and equipment. Therefore, the same broad factors that have recently inhibited general investment (uncertainty about inflation, high unemployment, and low saving) are also expected to retard innovation activity. However, it is still possible, as some critics claim, that antitrust policy hampers innovation independently of these other factors. In particular, following the lead of Joseph Schumpeter, theoretical arguments have been developed that predict that large firms and monopoly power are conducive to innovation. However, since other theoretical arguments have been offered that contradict the "Schumpeterian" position, empirical study is necessary to resolve the issue.

While there is an extensive empirical literature on the relationship between innovation, firm size and monopoly power, this body of evidence does not support many strong general conclusions. Innovation is a complex process characterized by a high degree of uncertainty and involves a sequence of complementary stages, beginning with invention, proceeding through development and first commercialization, and finishing with diffusion of the invention throughout the economy. It is a very difficult task to sort out the relationships between the successive stages of the innovation process and to identify the market structures that are most conducive to efficient completion of the activities associated with the different stages (assuming such relationships exist).

Economists have been hampered in their efforts by formidable conceptual and measurement problems. These problems are especially severe for econometric studies covering a cross section of industries. One particularly thorny problem is the likely interrelationship through time of market structure and innovation. Several recent theoretical works suggest that innovation and market concentration are highly interdependent, if not jointly determined by other industry characteristics. Unfortunately, econometric studies of this issue are only now emerging.

The conclusions that can be offered at this time are provisional guidelines and rely heavily on the results of case studies of particular inventions or series of inventions in a given industry. First, the Schumpeterian proposition that large firms and/or monopoly power are necessary for or are most conducive for innovation does not generally hold. There are several examples of firms that were initially small and grew due to extremely successful innovations (e.g., Texas Instruments and Xerox). Second, small firms usually provide the best environment for the invention of new products or production processes. However, at least in some cases, small firms need the support of larger organizations to subsequently develop and commercialize their inventions. Third, smaller firms are often more efficient in R. & D. than larger firms for those projects that are undertaken by both small and large firms. But very large R. & D. projects may be beyond the reach of small firms. Fourth, atomistic industries and cartelized industries generally provide unfavorable market structures for the development and commercialization of new products and processes. Finally, after a new product or process has been introduced, relatively small firms are typically more alert to adopting the innovation, thus facilitating the diffusion of the innovation throughout the economy.

These empirical findings suggest that in general, antitrust policy does not hamper innovation since large firms and monopoly are not invariably necessary for innovation. Indeed, by challenging attempts by leading firms to cartelize their industries, it is expected that antitrust policy will promote innovation. However, antitrust policy must be alert to the possibility that in some instances a large firm with significant monopoly power may be a vigorous innovator. Recent antitrust decisions indicate that antitrust authorities are increasingly cognizant of the importance of a firm's innovation performance and, moreover, encourage such efforts.

The implication of these findings for antitrust policy is essentially that the innovational performance of a firm or industry needs to be assessed on a case-by-case basis. While there is no foundation for the presumption that large firms and/or monopoly power are generally necessary for innovation, it is possible that in some instances a dominant firm is a superior innovator. Additionally, it is possible that small and large firms play a complementary role in the innovation process in some industries--small firms are better sources of invention but need the support of large firms to succeed in lengthy and expensive development work. Furthermore, the innovation record of many inventions reveals an intricate interrelationship between vertically related industries where a supplying industry develops new products or techniques that are subsequently purchased and put to use by firms in user industries. An appraisal of innovation performance in some of these cases reveals that the sources of innovation are firms that operate in concentrated industries, but the full benefits of the innovation depend on the interaction between these firms and buyer/user firms that frequently operate in unconcentrated industries. Lastly, antitrust policy should monitor barriers to entry that result from industrywide restrictions created by existing firms or regulatory authorities, since new firms are expected to expedite the diffusion of innovations.

Finally, in antitrust matters that involve international competition and multinational markets, it is particularly important to analyze the merits of the innovation issue on a case-by-case basis. The effect on competition and efficient market operation in international cases can only be determined by recognizing the institutional arrangements abroad, including foreign government policies, that alternatively subsidize or regulate innovational performance by foreign firms. This introduces an additional dimension in analyzing antitrust cases and poses significant challenges, since information about such issues appears to be meager and difficult to obtain.

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I. INTRODUCTION

Concern over the recent decline in productivity and the worsening trade performance of several industries has been linked by critics of antitrust policy to adverse impacts antitrust policy is alleged to have had on the innovative activity of U.S. firms. While there is evidence to indicate that innovative activity has lessened[1] and that foreign countries have narrowed the gap between

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[1] For example, a recent study reports that R. & D. spending relative to Gross Domestic Product (GDP) fell from 2.67 percent in 1960 to 2.32 percent in 1979 and number of patents issued to U.S. nationals fell from 54,600 in 1966 to 41,200 in 1978. In contrast, the ratio of R. & D. spending to GDP rose between 1960 and 1979 in several of the major trading partners of the United States (an exception was the United Kingdom). John W. Kendrick (1981), "International Comparisons of Recent Productivity Trends," Contemporary Economic Problems 1981 (American Enterprise Institute), pp. 158, 165.

their productivity and U.S. productivity[1] it is not clear what the root causes of these changes are.[2] Inflation, high unemployment, a drop in saving as a percent of GNP, tax laws, a decline in Federal Government support for research and development, and an increase of environmental and other costly regulations probably all have contributed to the decline in innovation. Furthermore,

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1 Using one broad measure of labor productivity, real Gross Domestic Product per employed person, Kendrick (1981, p. 136) finds that between 1960 and 1979, Japan and five major European countries increased their labor productivity relative to the United States. He suggests (p. 161) that an important reason for a narrowing of the productivity gap was a result of a catching up by other countries to the technological leadership position achieved by the United States. This catching up was facilitated by several factors, including foreign direct investment and joint projects, licensing of patents, performance of R. & D. abroad by U.S. firms, personnel exchanges, and teaching and training. The narrowing of the technological gap between the United States and other industralized countries largely reflects the diffusion of knowledge and know-how internationally. In the future, with a narrower technological gap between the United States and other industrialized countries, it is likely that foreign countries will find it more difficult to maintain higher productivity growth rates than the United States, because imitation is probably easier than inventing and introducing new products and production methods.

2 Moreover, there are recent indications that the innovation problem has lessened, that innovational activity in the United States is increasing. For example, the Wall Street Journal (3 September 1981, p. 1) reports that several companies are increasng their support for basic research. And the Economist (5 July 1980, p. 79) notes that a survey of 101 U.S. companies suggests that many firms plan to boost R. & D. in large part because the challenges and opportunities opened up by recent developments in microelectronics. One of the areas in which new technological breakthroughs in silicon chips (e.g., the 16-bit microprocessor) are expected to have a significant impact is in production systems and includes new devices like programable robots. General Motors, for example, reportedly plans to spend over $1 billion by 1990 to install more than 14,000 new industrial robots in its production lines (Economist, 29 August 1981, p. 71).

the export-import record of U.S. industries is sensitive to such influences as exchange rates, commercial policies of the United States and its trading partners, and policies of various countries to prop up or subsidize particular industries. The weight to attach to antitrust in the debate about the innovation problem is unclear. Nonetheless, since some critics are persuaded that antitrust policy has been harmful to innovation, it is important to address the issue of how antitrust may affect the incentive and the ability to innovate.

Today's antitrust policy reflects the point made by many commentators: it is vital that antitrust policy not undermine the desire and ability of firms to innovate. As Areeda and Turner (1978) point out,

> The economic objective of a pro-competitive policy is to maximize consumer economic welfare through efficiency in the use and allocation of scarce resources, and via progressiveness in the development of new productive techniques and new products that put those resources to better use.[1]

This economic objective appears to have been the foundation for the rulings in several recent cases. In Berkey Photo v. Eastman Kodak, Judge Kaufman wrote:

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[1] Phillip Areeda and Donald F. Turner (1978), Antitrust Law (Little, Brown and Co.) I:7. Similarly, other antitrust works recognize the importance of progressiveness in the goal of antitrust policy. See Robert H. Bork (1978), The Antitrust Paradox (Basic Books), p. 132, and Carl Kaysen and Donald F. Turner (1959), Antitrust Policy (Harvard), p. 11.

> . . . a monopolist is permitted, and indeed encouraged by § 2 [of the Sherman Act] to compete aggressively on the merits, and any success that it may achieve through the process of invention and innovation is clearly tolerated by the antitrust laws.[1]

And he continued:

> The attempt to develop superior products is . . . an essential element of lawful competition.[2]

Finally, in dismissing a complaint charging du Pont with attempting to monopolize the domestic titanium dioxide market, the Commission observed:

> Actions that promote innovation or improve efficiency, for instance, should generally be encouraged, not inhibited.[3]

While antitrust scholars and antitrust authorities are aware of the importance of innovational activity, critics of current antitrust policies still argue that these policies do not go far enough in their support of innovation. Specifically, critics argue that by preventing firms from growing through merger and discouraging concentration, antitrust policy may undermine the ability of U.S. firms to innovate. A crucial assumption in this argument is that size and market concentration are important to

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1 Berkey Photo, Inc. v. Eastman Kodak Co., 603 F. 2d 281 (1979).

2 Ibid., p. 286.

3 E. I. du Pont de Nemours and Co., 96 FTC 738 (Docket 9108).

the innovation process.[1] Is this assumption valid? It is this question that is the focus of this paper.

The theoretical proposition that large firms having monopoly power are essential for innovation comes from the work of economists following the lead of the late Joseph Schumpeter, who argued that ". . . the large-scale establishment or unit of control . . . has come to be the most powerful engine of . . . the long-run

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[1] This argument also assumes that antitrust policy inhibits firms from growing through merger and prevents markets from becoming more concentrated where these factors are important. However, if the two cases mentioned earlier are indicative of recent and current antitrust policy, then size and concentration that result from successful innovation appear to be encouraged. Furthermore, some antitrust critics may be prone to the view that any innovational activity is desirable or that more innovation is always preferred to less. This position ignores the fact that innovation is costly, that in some instances it is accomplished by means of a possibly inefficient employment of scarce resources, and that antitrust action may be warranted even though innovation may be diminished if it is perceived that on balance consumer welfare is enhanced. This implies that in order to maximize consumer welfare, antitrust is obliged to consider the benefits as well as the costs of innovation. It is conceivable, for example, that a firm with significant monopoly power engages in relatively minor innovational activity. Antitrust action may accordingly be desirable for reducing the extent of wasteful allocation of resources. In such a case, the benefits of the monopolist's innovation are counterbalanced by the potential benefits of ending the monopolist's market power. Antitrust authorities recognize the benefit/cost aspect of innovation. In the words of the Commission,

> . . . the actions of a would-be monopolist may enhance efficiency or product performance, albeit marginally, although the overall competitive effect is decidedly negative. (Du Pont, 96 FTC 738).

Therefore, in contrast to the view which may be held by some antitrust critics that innovation is always desirable, it is important also to consider the cost of innovation and that in particular cases antitrust action may be beneficial even though certain innovational activities are reduced.

expansion of total output . . ."[1] While it is not entirely clear whether the "powerful engines" of the Schumpeterian position combine firm size and monopoly power or refer merely to size, it is important for antitrust purposes to distinguish between size and monopoly power. Size alone, in the absence of monopoly power, traditionally has not warranted antitrust attention, since no adverse effect on consumer welfare is anticipated. Similarly, even though a firm possesses monopoly power, if the firm is small it may not be of concern to antitrust, because the deleterious effect on consumer welfare is slight in relation to the resources that would have to be expended to remedy this problem.[2] A policy dilemma only arises in a case where a large firm possesses monopoly power so that the monopoly power is evidently "significant"

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[1] Joseph A. Schumpeter (1975, 1942), Capitalism, Socialism and Democracy (Harper and Row), p. 106. In Schumpeter's framework, large-scale firms (which he appears to identify with firms having significant monopoly power) have a comparative advantage in the evolutionary process of creative destruction in which new products, processes, or organizations supplant outmoded rivals. However, Schumpeter also states that while the "typical" large-scale firm has access to superior methods of production or organization, ". . . mere size is neither necessary or sufficient for it [superiority]" (p. 101).

[2] This reflects a cost/benefit approach that has long been used as a guiding principle for antitrust policy. For a recent treatment, see William M. Landes and Richard A. Posner (1981), "Market Power in Antitrust Cases," Harvard Law Review 94:953. The exception is precedential cases where antitrust authorities may take action against a firm that does not have significant monopoly power, but the antitrust precedent established applies to many other possible cases and therefore involves a significant cummulative gain in social welfare.

and the prospective improvement to consumer welfare from antitrust action may be sizable, yet the size and resulting concentration are prerequisites for efficient innovation.

The Schumpeterian position has sparked considerable controversy among economists, which is reflected by the accumulation of a voluminous literature on the subject over the past four decades.[1] On the one hand, the Schumpeterian view has been supported by a number of theoretical arguments that identify characteristics of large firms and monopoly that might favor innovation.[2] The main characteristics cited that favor large firms refer to considerations that concern the ability to innovate and include the following. First, there is the general advantage big firms possess over small firms in being able to secure financial capital and at more favorable interest rates. This is important because innovation may be very costly, particularly when expensive equipment and research laboratories are contemplated. The second characteristic stems from the

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1 This literature has been surveyed on several occasions, recently by F. M. Scherer (1980), Industrial Market Structure and Economic Performance (Rand McNally), ch. 15. See also Douglas F. Greer (1980), Industrial Organization and Public Policy (Macmillan), ch. 23; Leonard Weiss (1977), "Quantitative Studies of Industrial Organization," in Frontiers of Quantitative Economics, ed. M. D. Intriligator (North-Holland), pp. 389-97; Morton I. Kamien and Nancy L. Schwartz (1975), "Market Structure and Innovation: A Survey," J. Econ. Lit. 13:1-37; and Jesse W. Markham (1974), "Concentration: A Stimulus or Retardant to Innovation?" in Industrial Concentration: The New Learning, ed. H. J. Goldschmid (Little, Brown), pp. 246-78.

2 A useful discussion of these points is contained in Scherer (1980), pp. 413-15, 424-26.

riskiness of innovation. A large firm may be more willing to undertake risky innovation projects because it can reduce its own risk (as opposed to society's risk) by undertaking a portfolio of diverse high-risk projects. With a large number of projects there is a tendency for the average gain to be less volatile, less sensitive to a loss on any one project, and thus for the average risk to be lower. By contrast, the existence of a small firm, which may not be able to embark on many different projects and therefore cannot enjoy the advantages of risk pooling, may be more threatened by undertaking a particular risky project. Third, if there are significant economies of scale in research and development, a large firm would tend to have an R. & D. cost advantage over a small firm. This advantage is more pronounced in areas where expensive and specialized staff and laboratory equipment are required.[1]

A firm with monopoly power has two principal characteristics that affect the ability to innovate. First, because of its

[1] Other, probably less significant, advantages of size include the following: (1) large firms may benefit from a cross-flow of information when a variety of projects are mounted, (2) cost-saving advantages come from developing and using methods of production for a large volume of output, (3) a large firm is more likely to be able to use the uncertain results of R. & D. somewhere in its range of operations, and (4) benefits accrue in marketing and distribution arising from well-established sales outlets that facilitate the introduction of new products and increase the appropriability of their benefits. Points (1) and (2) refer to the ability to innovate and may reflect real economies (as opposed to pecuniary economies) and therefore constitute social benefits. Points (3) and (4) relate to the incentive to innovate and may also apply to multiple-product firms. See Scherer (1980), pp. 413-14.

monopoly power, the firm is able to reap excess profits. The internal funds thus generated enable the firm to more easily finance innovational efforts without turning to outside sources for financial capital. This may be a significant advantage when lenders are reluctant to furnish funds for high-risk projects. Second, the firm is able to take a long-term perspective on research projects. To the extent that its monopoly power is not subject to short-term erosion, the firm's position is relatively secure. In cases where projects are expected to have long gestation periods, the firm would be likely to have an advantage over a firm not possessing monopoly power.[1]

On the other hand, many economists maintain that the simple Schumpeterian position is incorrect. They argue that many of the alleged advantages noted above as favoring large firms and firms with monopoly power are weak or are counterbalanced by other factors that are more significant. For example, the economies to scale in R. & D. and the risk-pooling advantages of large firms[2] and the importance of internal sources of finance and an ability

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1 Another advantage of monopoly influencing the incentive to innovate is the ability to internalize most of the benefits from new-product innovations, which promotes the incentive to innovate. See Scherer (1980), pp. 424-25.

2 Scherer (1980, pp. 415-17) is critical of the risk-pooling argument allegedly favoring large firms. He notes that there is considerable scope for risk spreading even among medium-size firms. He estimates that a manufacturing firm that just qualified for the Fortune 500 (with annual sales of $328 million in 1976) would be able to support an R. & D. portfolio consisting of 37 projects.

to take a long view of a monopolist may not be that great.[1] Moreover, they argue that there are other theoretical arguments that explain why large firms and monopoly may not be conducive to innovation.[2] Focusing first on firm size, one disadvantage cited is the tendency of large firms to have long chains of command that prolong and frustrate decisionmaking. This can lead to information-flow problems where major decisions are poorly transmitted to the research labs and where progress or failure in the lab is too slowly filtered up the chain of command to the company's top officials. Another possible disadvantage is that large bureaucratic organizations may not provide the best environment for or make the best use of independent and creative researchers who prize freedom and flexibility. These researchers may eschew the constraints and formalities of a large firm for a smaller firm

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1 One factor that should be highlighted concerns risk and the possibly differing attitudes toward risk taken by large vs. small firms. Greer conjectures that "[t]here are countless little guys who <u>really</u> gamble; there are countless small firms accepting great risks. Conversely, there are many large firms whose bureaucrats seem to shun almost anything short of a sure thing . . . [for example] . . . IBM repeatedly rejected opportunities to develop and produce the Xerox machine, saying it was too risky. But it was not too risky for Haloid, the halfpint company that actually undertook the task and later changed its name to Xerox." Greer (1980), p. 577 [emphasis in original].

2 These points are also discussed in Scherer (1980), pp. 413-15, 425-26.

that provides greater scope for individual initiative.[1] By being more appropriately structured for handling innovative decision-making, small firms may decrease the cost and increase the likelihood of successful innovation effort.[2]

Similarily, critics of the Schumpeterian position suggest that a monopoly may not be very conducive to innovation. One consideration is that a monopolist may have a position that earns handsome returns merely producing his existing product(s) by means of well-established production procedures. Not only may the monopolist be content to continue with this lucrative state, he may also be hostile to change in the form of innovation for fear

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1 The adverse effects of size on inventive initiative are reflected by a statement by the chairman of Texas Instruments.

> As an organization grows in size, exploiting its initial innovation, it finds it must have managers with administrative skills to ensure the organization is efficiently and effectively run as profit margins narrow and the product matures. For the most part, innovators are poor administrators. Therefore, management tends to become more and more administrative in character as it grows, relegating the innovators to relatively low positions or so frustrating them that they leave the organization.

Cited in Brian C. Twiss (1974), Managing Technological Innovation (Longman), p. 19.

2 Another disadvantage of size is a tendency for research in large laboratories to become overorganized so that the bulk of R. & D. projects is aimed at relatively modest advances in the state of the art. See D. Hamberg (1963), "Invention in the Industrial Research Laboratory," J. Pol. Econ. 71:95-115.

it will upset his sinecure.[1] Another consideration is that the monopolist enjoys the luxury of not having to minimize costs and operate efficiently.[2] His potential monopoly profits provide a cushion to sponsor such peccadillos as elaborate and overstaffed research laboratories.[3] As a consequence, whatever fruits grow from this innovational activity are obtained at excessively high costs.[4]

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[1] Furthermore, a monopolist may have an incentive to thwart competition by preemptive patenting. The monopolist can parry potential rivals by supporting R. & D. designed to obtain patents that block effective entry. Moreover, the monopolist may delay commercialization of the patents and accumulate "sleeping patents." For a theoretical treatment of this issue, see Richard J. Gilbert and David M. G. Newbery (1979), "Pre-Emptive Patenting and the Persistence of Monopoly," Economic Theory Discussion Paper no. 15, University of Cambridge.

[2] This point is related to the concept of X-efficiency, which states that when competitive pressures are weak there is a harmful effect on incentives to operate efficiently. This concept was developed by Harvey Leibenstein (1966), "Allocative Efficiency vs. 'X-Efficiency,'" Am. Econ. Rev. 66:392-415.

[3] However, it is conceivable that under monopoly, investment in R. & D. is greater than under competitive profit-maximization. Furthermore, to the extent that private enterprises underinvest in innovation, the larger R. & D. investment of a monopolist may be preferred to the lower investment level resulting from a competitive market structure. But this leaves open the issue of the quality or efficiency of R. & D. activity. That is, X-efficiency problems may be so severe under monopoly that R. & D. investment and activity under a competitive market structure are, on balance, preferable to that arising under monopoly.

[4] Another disadvantage attributed to monopoly is a diminished incentive to adopt process innovations. For a discussion of this point, see Scherer (1980), pp. 427-28, and the references he cites.

Finally, some economists take the view that there is a balancing of the advantages and disadvantages listed above and argue that there is a threshold effect in the relationships linking firm size and monopoly power to innovation.[1] Thus, over some initial range of firm size and monopoly power there are net benefits for innovation, but beyond some point the disadvantages outweigh the advantages, tending to retard innovation.

Given the various and conflicting theoretical possibilities, there have been a large number of empirical studies that have attempted to discern the relationship between market structure and innovation. These empirical studies suggest that there are complex relationships among firm size, monopoly power, and innovation. In particular, the evidence indicates that there is no simple rule that relates innovation to market structure. For example, while the empirical findings contradict the naive "Schumpeterian" claim that markets dominated by large firms and characterized by high concentration are always the best breeding grounds for innovation, there are industries where this may be the case. Furthermore, an evaluation of the empirical research, while suggesting that thresholds may be present in some industries, calls into question whether a simple threshold relationship is present uniformly across all industries, particularly whether they arise at the same levels of size and concentration in different

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1 Jesse W. Markham (1965), "Market Structure, Business Conduct, and Innovation," Am. Econ. Rev. 55:325.

industries. Overall, the richness of the results of the quantitative work in this area suggests that it is premature, if not incorrect, to draw general conclusions about the relationships between firm size or monopoly power and innovation which apply to all industries.

That the empirical literature on innovation and market structure does not support strong conclusions is not surprising, in view of the elusiveness of the concept of innovation and the presence of several fundamental conceptual and measurement problems. Innovation is an intricate sequential process characterized by a high degree of uncertainty that operates over a (possibly considerable) period of time. The process through which new products or processes are brought into productive use can be viewed as multistage. While different scholars have defined these stages slightly differently, they generally recognize four complementary stages: invention, development, marketing, and diffusion.[1] Invention encompasses the theoretical development and novel application of the theory to originate a new product or process. Development includes refinements to the original design featuring iterative testing of the product or process until it is ready to be introduced commercially. Marketing is the phase in which the product or process becomes available for general use in the economy. And diffusion refers to the spread of the product or process throughout the economy, including widespread use of the

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1 See Scherer (1980), p. 411, and section II below.

product or process and imitation of this innovation by other manufacturers.

A complete empirical analysis of the structural question of how firm size and monopoly power affect innovation must not only recognize the phased nature of the innovation process but must also consider the performance implications of large firm size and monopoly power for each of the stages separately. Different stages of the innovation process appear to require different talents, just as different innovations require different skills and insights to make that critical inventive breakthrough. Reviews of particular innovation case histories reveal that creative thinking power and risk-taking tendencies are key to invention, while marketing skills and access to financial resources are key to development and commercialization of inventions.[1] Some economists have concluded that small firms tend to be best suited for invention, while larger firms may have a comparative advantage in development and marketing. However, even if larger firms are more conducive to the development and marketing stages of the innovation process, this does not necessarily imply that the largest firms provide the best vehicles for innovation in many markets. Several empirical studies suggest that conditions vary across industries, but again it is necessary to bear in mind that

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1 Scherer (1980), pp. 416-17.

much of the empirical literature on innovation suffers from significant methodological shortcomings that question the credibility of the conclusions these studies reach.

The most severe methodological problems arise in the empirical studies that use econometric methods to investigate a large number of industries. The main problem is the difficulty of identifying and measuring the relevant concepts to apply to the different stages of the innovation process. For example, most studies use either total research and development data (either spending or inputs such as number of scientists) or number of patents to measure innovation. Input data are poor indicators of efficient R. & D. activity, since they do not capture the productivity of the inputs. The input studies also suffer because research and development data are only available for larger firms and encompass a possibly wide range of activities cutting across all stages of the innovation process. On the other hand, using patent data (such as number of patents issued) groups together inventions that vary enormously in importance and also refers directly only to the first stage of the innovation process. Finally, R. & D. and patent data are usually credited to the industries that initially undertake innovational activity. But this ignores "demand pull" influences in vertically related industries, which may be the principal users of innovations; and these industries are important stimulants for innovation. An overall assessment of innovational performance will frequently need to examine the record of a cluster of vertically related industries.

Another important problem with many of these studies is their use of simple concentration measures (e.g., the share of total industry sales by the four largest firms) as indices of monopoly power. Several recent contributions point out that simple concentration measures are, at least by themselves, unreliable indicators of monopoly power.[1] These measures do not, for example, take account of barriers to entry. If entry barriers are low, high concentration may not generally signify significant monopoly power.[2] Accordingly, it is possible that many econometric studies may fail to discern and, more importantly, may distort the complex interaction between firm size or monopoly power and innovation.

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1 Paul Pautler of the Bureau of Economics surveys the recent literature in "The Economic Basis for Broad-Based Antitrust Horizontal Guidelines," appendix A to Preliminary Report of the Merger Guidelines Review Working Group (15 July 1981), especially pp. 50-51; also see David J. Ravenscraft (1981), "The Relationship Between Structure and Performance at the Line of Business and Industry Level" (unpublished manuscript, Bureau of Economics, Federal Trade Commission).

2 It is possible that an industry consists of a number of closely related segments and that entry into some segments is easy but entry into others is difficult. Moreover, movement by a firm from an easy-entry segment to other segments may be difficult. This is referred to as "mobility barriers" and explains the coincidence of easy entry (into certain segments) and monopoly power when mobility barriers exist. See R. E. Caves and M. E. Porter (1977), "From Entry Barriers to Mobility Barriers," Q. J. Econ. 91:241-61.

To avoid some of these data problems, some empirical studies have focused on the case histories of specific industries or of groups of major innovations. These works provide deeper insight into the structural environment most conducive to the different stages of the innovation process. But they suffer from the disadvantage of being based on possibly unrepresentative cases, making it difficult to generalize about the market-structure/ innovation nexus.[1] Moreover, R. & D. is highly concentrated itself, so case studies may cover the bulk of the activity even if they are not representative.

These qualifications caution against expecting too much from the empirical studies on innovation that are surveyed in the subsequent sections. However, our evaluation of available evidence suggests the following conclusions: (1) generally, the results of a variety of studies are unfavorable to the Schumpeterian proposition that large size and monopoly power are necessary for innovation, (2) small firms play a disproportionately prominent role in the invention and diffusion stages of the innovation process, (3) small firms are typically more efficient in R. & D., at least where small and large firms undertake the same projects (but many large-scale projects are probably beyond the reach of small firms), (4) cartelized industries or industries where there is

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1 However, the case-by-case approach in this research does aline with the case-by-case review employed in antitrust policy.

collusion among the leading firms do not provide a hospitable environment for innovation, and (5) while firm size and industry concentration are positively associated with innovational activity in some industries, the economic significance of this finding is obscure because these results, which derive from econometric studies, have significant methodological problems.

The subsequent presentation is organized as follows. Section II discusses some basic concepts in innovation. This includes an explanation of the different types of innovations, the relationships between the successive stages of the innovation process, a consideration of the economic organization of innovation, and the role of technological opportunity in innovation. Section III reviews the methodology used in the empirical literature, analyzing the ways innovation is measured and the types of economic models that are used to test for the relationship between firm size or monopoly power and innovation. The next four sections review the empirical findings. The presentation is sequenced to correspond broadly to the stages of the innovation process, beginning with invention and ending with diffusion. Ideally, we seek to examine the relationship between each of the innovation stages and firm size and monopoly power separately, but gaps in the literature make this impossible. For example, most studies combine the development and commercialization (and even the invention) stages. These works are reviewed under the broad rubric "innovation." The specific order is as follows: In section IV the evidence concerning invention and firm size is surveyed. Section V turns to the empirical work on firm size and innovation, while section VI discusses the evidence on monopoly power and innovation. The connection between market structure and diffusion of innovation follows in section VII and the concluding section (VIII) summarizes the findings and contains suggestions for further research.

II. INNOVATION: BASIC CONCEPTS

Innovation is a dynamic process that embraces those activities of individuals and firms aimed at discovering and developing new methods of production, products, raw materials, and forms of organization. According to Scherer (1980, p. 405), the two most commonly studied types of innovation are process innovation and product innovation. Process innovations are new methods of production that enable firms to improve the productivity of making existing products and permit the economy to expand its total output from a given input of resources such as labor and machinery. Product innovations involve the discovery of new products.

New products can increase consumer welfare by providing consumers with a better and more varied collection of goods and services. In terms of the innovative activities of major industrial firms, greater attention is given to bringing out new products than to developing process innovations. Scherer, for example, estimates that 75 to 80 percent of industrial research-and-development spending is oriented toward devising new or improved products.[1]

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1 Scherer, lecture to staff of the Bureau of Economics, 13 October 1980. Note, however, that the distinction between product and process innovations is blurred when final consumer products are not involved. This happens when one firm introduces a new product that is used as a productive input by another firm. From the standpoint of the originating firm, the innovation is a new or improved product it sells to other firms. From the standpoint of purchasing firms, the new development is a process

(footnote continues)

While most economic research has focused on product and process innovations, economists have recognized that the discovery of new sources of raw materials and the introduction of new types of organizations are also important.[1] Historically, the discovery of major mineral deposits (such as petroleum in Pennsylvania in 1859) and the experiment with a new organization (like the first self-service grocery store in 1930, predecessor of the supermarket) played important roles in this country's development. However, due to the difficulty of quantifying the contributions of these innovations, economists have typically devoted their attention to the study of process innovations and the introduction of new products. This practice will be adopted here.[2]

(footnote continued)

innovation and thus it affects their production and cost conditions. It appears that these mixed product/process innovations are relatively numerous. Scherer has examined nearly 15,000 patents issued to U.S. firms or individuals between June 1976 and March 1977 and finds that only about 3,500 of the patents could be designated as involving consumer goods.

[1] Joseph A. Schumpeter (1961; 1934), The Theory of Economic Development (Oxford), p. 66.

[2] It should be noted, however, that considerable attention has been devoted to the theory of development of economic organizations; in particular, an analysis of the organizational structure and efficiency of large corporations. This literature includes contributions by several economists, including Armen Alchian, Harvey Leibenstein, Robin Marris, Herbert Simon, and Oliver Williamson. However, economists are only now starting to conduct empirical investigations to test alternative hypotheses. Consult the articles by Robin Marris and Dennis C. Mueller (1980), "The Corporation, Competition, and the Invisible Hand," J. Econ. Lit.
(footnote continues)

The process by which industrial product and process innovations are discovered and put to use is recognized to consist of a sequence of functional stages. These stages may be characterized as:[1]

(1) invention--the theoretical conception of the possibility of a new product or process together with the first practical demonstration that it is workable;

(2) development--the testing and refinement of the invention to the point that it is ready for commercial use;

(footnote continued)

18:32-63, and Richard R. Nelson (1981), "Research on Productivity Growth and Differences," J. Econ. Lit. 19:1029-65. The recent interest by economists in the efficiency and productivity of alternative forms and sizes of organizations has built on an old and immense literature on organizational theory and structure by a host of scholars in other disciplines (e.g., business management, public administration, and sociology). For example, see Hall (1972) and the works he cites. Richard M. Hall (1972), Organizations: Structure and Process (Prentice-Hall).

[1] While there is general agreement that the innovation process involves several steps or stages, various analysts have characterized these stages somewhat differently. This is a reflection of complex nature of the process and the fact that the process varies for different innovations. A useful discussion is given by Edwin Mansfield, John Rapoport, Jerome Schnee, Samuel Wagner, and Michael Hamburger (1971), Research and Innovation in the Modern Corporation (Norton), pp. 111-15. Also see Scherer (1980), p. 411; Douglas F. Greer (1980), Industrial Organization and Public Policy (Macmillan), p. 572; Edward Ames (1961), "Research Invention, Development and Innovation," Am. Econ. Rev. 51:370-81; Edwin Mansfield (1968), Industrial Research and Technological Innovation (Norton), pp. 83 and 133; Morton I. Kamien and Nancy L. Schwartz (1975), "Market Structure and Innovation: A Survey," J. Econ. Lit. 13:1-37.

(3) marketing--the first commercial introduction of the new product or process, which may include finding and cultivating possible customers and markets;

(4) diffusion--the subsequent adoption and widespread use, both in vertically related industries and horizontally within a given industry of the new product or process, which may be accompanied by imitation by other firms.

It is important to distinguish among the four stages of the innovation process, because different talents and skills may be required for each stage. Thus, it is possible that the optimal structure and size of the firm units undertaking basic research can be quite different from those of the units conducting development or marketing. Additionally, the possibility of common inputs to two or more stages, possible advantages of internalizing information flow between successive stages, and the prospect of serendipity between stages will influence the size and scope of the innovation effort within a firm. The importance of the advantages of integrating two or more stages of innovation may vary from industry to industry.

Economists have come to recognize that innovative activity must be studied in the context of the surrounding environment. For example, as Phillips[1] and Rosenberg[2] point out, the role of

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1 Almarin Phillips (1966), "Patents, Potential Competition, and Technological Progress," Am. Econ. Rev. 56:301-10.

2 Nathan Rosenberg (1970), Technology and American Economic Growth (Harper and Row).

prior developments in basic science, or the extent of "technological opportunity" may be especially important in explaining interindustry differences in the amount and success of innovative activities. Others, such as Schmookler,[1] argue that inventions are stimulated either by technical problems or by the prospect of economic gain. The Phillips-Rosenberg position has led to an examination of interindustry differences in innovation and has contributed possible classifications of industries into high-technology, medium-technology, and low-technology industries,[2] or alternatively, into technology-intensive and mature industries.[3] Schmookler's view has been employed in studies by Schmookler and Brownlee (1962), Schmookler and Griliches (1963), and Scherer.[4]

That the optimal size of the innovation unit depends on the innovation, the stage of the innovational process under study, and the environment in which the innovative activity is undertaken is illustrated by a wide range of innovation experiences. The

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1 Jacob Schmookler (1966), Invention and Economic Growth (Harvard).

2 Statement by Bruno O. Weinschel (1978) to the Senate Subcommittees on Science, Technology and Space and International Finance, in Export Policy, Hearing, Part 7, 95th Cong., 2d sess., p. 184.

3 Raymond Vernon (1974), "Competition Policy Toward Multinational Corporations," Am. Econ. Rev. 64:276-81.

4 Jacob Schmookler and Oswald Brownlee (1962), "Determinants of Inventive Activity," Am. Econ. Rev. 52:165-76 and Schmookler and Zvi Griliches (1963), "Inventing and Maximizing," Am. Econ. Rev. 53:725-29. F. M. Scherer, presentation to a seminar at the Justice Department, 30 September 1981.

organization of innovation may be viewed as the coordination of a sequence of complementary steps. All the steps of innovation (up to imitation) may be undertaken by the same firm, as was the case with Du Pont's introduction of nylon.[1] Or the steps may be undertaken by different organizations, as with the invention of xerography. The basic patents for xerography were obtained by one individual, but significant support was subsequently provided by a subsidiary of the Battelle Institute. Later, the Haloid Corporation (later renamed the Xerox Corporation) stepped in and assumed the responsibility for development work.[2] The size of the firm can also vary, even when the innovation is sizable. When Xerox was a small firm, it introduced the copier. Yet the development of new jet engines seem to require firms of considerable size. The coordination of the several functions in the innovation process can, in short, be organized in several ways.[3]

From an economic perspective, a key issue about innovation concerns the efficiency of alternative forms of organization that relate to one or more of the functional stages of the innovation process. That is, there may be efficiencies from the integration

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1 Edwin Mansfield (1968), The Economics of Technological Change (Norton), pp. 48-50.

2 Scherer (1980), p. 412.

3 The ". . . functions need not be performed by the same person or even by the same organization . . ." Scherer (1980), p. 411.

of two successive functional stages (e.g., development and marketing) or from the horizontal combination of efforts of two or more firms centering on a particular stage (e.g., basic research).[1] These issues do not appear to have been studied very extensively by economists, in substantial part because of empirical or measurement difficulties. Nonetheless, further research is desirable to attempt to produce useful guidelines for antitrust policy.[2]

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[1] Furthermore, the optimal organization and size of innovational efforts may be influenced by the extent of vertical integration of various sequential stages of a production process. In a recent paper, Armour and Teece posit that vertical integration may promote innovation by means of a sharing of technological information common to separate production stages of an industry, because this facilitates the implementation of new technology when complex interdependencies are involved. They find a strong (statistical) relationship between vertical integration and innovation in the U.S. petroleum industry. Henry Ogden Armour and David J. Teece (1979), "Vertical Integration and Technological Innovation," Center for the Study of Organizational Innovation, University of Pennsylvania, Discussion Paper 56 (unpublished), August 1979.

[2] However, tentative efforts to provide antitrust guidelines regarding mergers (both horizontal and vertical) and joint-venture arrangements have been offered. Donald F. Turner and Oliver E. Williamson (1971), "Market Structure in Relation to Technical and Organizational Innovation," in International Conference on Monopolies, Mergers, and Restrictive Practices (HMSO), ed. J. B. Heath, pp. 127-44. Turner and Williamson break down the innovation process into three stages: invention, development, and production marketing. Their basic argument is that the stages may be separable and that the efficient firm size for one of these stages need not be the most efficient for the others. Their policy recommendations are based on empirical studies undertaken in the 1950's and 1960's (several of which are reviewed in section IV below), which have several qualifications that are also discussed below.

III. MEASUREMENT AND MODELING OF INNOVATION

A. Measurement of Innovation

Ideally, to assess the economic performance of innovational activities in an industry, empirical information is desired for relevant industries, firms, or lines of business giving the value of the final innovation and the value of the inputs invested to make the innovation possible. Furthermore, knowledge about the investments at each stage of the process (invention, development, marketing, and diffusion, including adoption of an innovation by vertically related industries), and the length of time taken in each stage, are information necessary to assess innovation performance fully. Unfortunately, with the exception of a few in-depth case studies,[1] available information falls far short of the ideal and it becomes necessary to resort to studying aggregative measures and proxies for key variables. Two principal approaches to measuring innovative activity have been used. The first proxies innovation by measuring inputs in innovative activities (the "input approach"); the second proxies innovation by measuring innovation outputs (the "output approach").

The input approach measures innovation by such indicators as total expenditure on research and development or the number of scientists or engineers employed by firms. The principal sources of such data are company reports for leading U.S. firms, typically

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[1] For example, by Mansfield et al. (1971) on the drug industry and Almarin Phillips (1971) Technology and Market Structure (D.C. Heath), on the aircraft industry.

the largest firms as listed in the Fortune 500. These data are drawn from firms that have sustained R. & D. efforts. Although these firms are expected to account for the vast bulk of R. & D. activity, the exclusion of many small firms represents a major omission, because an understanding of the role of small companies in innovation is central to an assessment of how size of firm influences the efficiency of innovation. Another problem with these data is that R. & D. subcontracting is not reported.[1] This deficiency hampers attempts to appraise the effectiveness of alternative types of organizations and prevents an examination of the possibility that small firms may be able to overcome economies-to-scale obstacles in R. & D. by turning to specialist R. & D. subcontractors. Additionally, many of the companies that support large R. & D. programs are conglomerate firms, and all their R. & D. expenditures and employment are lumped together. Efforts to collect more meaningful R. & D. data at the establishment or product-line level are relatively recent. A notable example is the Commission's Line of Business (LB) reporting program.[2] Efforts to analyze LB data are just beginning. The bulk of empirical work by economists over the past 20 years has been forced to rely on more aggregated data. Finally, while many

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1 The Commission's Line of Business program may remedy this deficiency, because information is collected, for each product line, on R. & D. billed to other companies.

2 Another potential source of useful disaggregated data of large corporations is the PIMS (Profit Impact of Market Strategy) data set. See Scherer (1980), p. 271.

empirical studies of innovation use total R. & D. spending or employment, it is possible, the case of R. & D. spending, to break out R. & D. by three functional categories, as defined by the National Science Foundation:[1]

> basic research--original investigation for the advancement of scientific knowledge,
>
> development--reduction of research findings to practice,
>
> applied research--research expected to have a practical payoff.

While the distinctions between categories are not always sharp, particularly between basic and applied research, and they do not conveniently correspond to the four stages of the innovation process discussed in the previous section,[2] nonetheless, attempts to study one or more of NSF R. & D. categories could represent an improvement over using total R. & D. spending. Unfortunately, research investigating individual R. & D. categories appears to be rare, a notable exception being a recent paper by Mansfield (1980), who sought to determine whether the rate of productivity

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1 National Science Foundation (1978), National Patterns of R. & D. Resources (NSF 78-313), p. 25.

2 For example, it is possible that much development R. & D. in some firms represents imitative research and reverse engineering responding to a significant innovation by rival firms. Furthermore, in some industries (possibly automobiles), routine testing may be classified as development. It is not even clear that this is R. & D. activity.

change of an industry or of a firm was related to the amount of basic research.[1]

The output method of measuring innovation has been approached in two ways. First, several economists have used the number of patents issued as a measure of innovative productivity. The advantages of using number of patents to reflect innovation are that their temporal and technological coverage is virtually complete and that they indicate some minimal standards of technical novelty (in contrast to R. & D. spending or employment).[2] However, this measure is also somewhat suspect, because patents vary in importance. A raw count of patents issued treats all patents as having the same importance. Clearly there is a substantial economic difference between a diaper-for-parakeets patent and the original patents covering xerography.[3] According to Scherer (1980, p. 411, fn. 30), many patents issued are no more than ". . . a mass of trivia that sometimes pass for inventions under the patent system." That is, many (if not most) patents are not subsequently developed and commercialized and therefore probably have no economic impact. Additionally, not all inventions are patented (e.g., Kodak's formulae for making color film). In spite of these limitations, several economists (in particular

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1 Edwin Mansfield (1980), "Basic Research and Productivity Increase in Manufacturing," Am. Econ. Rev. 70:863-73.

2 F. M. Scherer (1980), "The Propensity to Patent," (forthcoming, J. Indus. Econ. (p. 1 of typescript).

3 Greer (1980), pp. 602, 606.

Scherer and Schmookler) regard patents issued as a usable indicator of inventive output.

The second line of approach to measuring innovative output includes such measures as number of significant inventions, as judged many years after the date of invention, or as reflected by sales volume of inventions 1 or 2 years after their first introduction. These measures attempt to recognize the varying economic importance of different patents and by not necessarily confining attention solely to patented inventions, can also incorporate important innovations that bypass the patent procedure. However, these measures have two main drawbacks. First, they represent only a sample of innovations that may not be representative, and second, it is very difficult to assign economic weights to inventions and to obtain sales data that relate to specific inventions. For these reasons, very few empirical studies have used this approach.[1]

B. Empirical Testing Methods

1. Case Study Approach. Empirical studies of innovation have largely been concerned with the Schumpeterian hypothesis that large-scale firms possessing monopoly power provide the most conducive institutional environment for innovation. The studies

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[1] Two notable contributions are Edwin Mansfield (1968), Industrial Research and Technological Innovation (Norton), covering the iron and steel, petroleum-refining, and bituminous-coal industries, and Mansfield et al. (1971), Research and Innovation in the Modern Corporation (Norton), covering the ethical pharmaceutical industry.

have been conducted with case-study methods of specific innovations or industries and with econometric models covering a number of industries. Case-study methods trace an industry's evolution and allow wide scope for studying the timing and impact of major innovations and also permit consideration of unique events and personalities. Potentially, case studies provide a vehicle for reaching a reasonably full analysis of the unfolding innovation process in specific instances. Unfortunately, this method suffers from the disadvantages of not being objectively verifiable (i.e., no two economists studying the same industry would necessarily conduct the investigation in the same way or reach the same conclusions). And it is difficult to generalize on the basis of the results on one or a few industries or innovations.

2. Econometric Testing. By contrast, econometric models of innovation attempt to meet these criticisms of the case-study method and have attracted considerable attention among economists. But unfortunately, the econometric models that have usually been adopted are very simple, in part due to the measurement problems noted above. Moreover, these attempts have applied simple regression models to a complex, dynamic, interactive phenomenon.

Two types of models have been used. The first model tests for the relationship between firm size and innovation. A variant of a single-equation regression equation of the following form is typically estimated

(A) $I_i = a + bS_i + cS_i^2 + u_i$

where S_i is firm i's size (measured, for example, by sales or employment),

I_i is firm i's measured innovation (or innovational intensity, I_i/S_i),

u_i is a random variable, and

a, b, and c are constant coefficients.

Separate regressions for each industry may be performed on the basis of the argument that technological opportunity varies across industries. Primary interest resides in the estimated value of the c coefficient, which captures whether I_i (innovation) increases more than proportionately with S_i (firm size). If c is positive, measured innovation is relatively greater in large firms--which lends support to the Schumpeterian position. On the other hand, if the estimated coefficient c is negative, measured innovation does not increase proportionately with firm size and the Schumpeterian position does not hold.

The second type of model tests for the connection between monopoly power and innovation. The format for the single-regression equation fitted is basically

(B) $I_i = e + fM_i + gT_i + v_i$

where M_i measures monopoly power in industry i,

T_i is an index of technological opportunity in industry i,

v_i is a random variable,

e, f, and g are constant coefficients, and

I_i measures industry i's innovation or innovational intensity.

In this model, the focus is on the estimated coefficient f. If f is positive, this implies that innovation increases with monopoly power, which accords with the Schumpeterian view. On the other hand, if the estimated f is negative, innovation is reduced as monopoly power increases.

While the estimation of these models may shed some light on the relationships between firm size or monopoly power and innovation, there are several reasons for believing that the results of these models are not definitive. First, as discussed earlier in this section, the measures of innovation are flawed. For example, if innovation is measured by R. & D. expenditure or inputs, then regression results that would lead one to believe the Schumpeterian position was correct may not be warranted. The broad innovation measure may merely mean that the largest firms and/or the leading firms in the most concentrated industries had research labs geared primarily to imitating innovations introduced by other firms or to keeping abreast of progress in the sciences, with the aim of making minor modifications to current production processes or products. On the other hand, if the number of patents issued is the measure of innovation used, then once again the regression results may signal a Schumpeterian result. But on closer examination, the results may reveal that the leading firms tend to seek patents on relatively more of their research results than small firms, or that a larger share of patents issued to leading firms were not put into commercial practice. In short, and as suggested earlier, using broad measures of innovation makes it impossible to examine the activities of firms at successive stages of the innovation process and accordingly makes it difficult to evaluate the innovative performance of different firms.

Second, even if there were no qualms about the measurement of innovation, the estimation of equation A using the input approach may not be a suitable test of the Schumpeterian proposition that large firms have a comparative advantage in innovation over small firms. This point is made by Fisher and Temin (1979) in a recent methodological comment on empirical studies of innovation.[1] According to Fisher-Temin (F-T), even if the estimate of the c coefficient in equation A is negative, there may still be increasing returns in innovation, which thus favors large firms.[2] F-T argue that economies to scale in innovation requires that an increase in firm size, given innovation input, is associated with higher average return in R. & D. per R. & D. worker. Thus, while

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1 Franklin M. Fisher and Peter Temin (1979), "The Schumpeterian Hypothesis: Reply," J. Pol. Econ. 87:386-89. See also Carlos Alfredo Rodriguez (1979), "A Comment on Fisher and Temin on the Schumpeterian Hypothesis," J. Pol. Econ. 87:383-85, and the original article by Fisher and Temin (1973), "Returns to Scale in Research and Development: What Does the Schumpeterian Hypothesis Imply?" J. Pol. Econ. 81:56-70.

2 Fisher and Temin concentrate on the size elasticity of innovation, e.g., (dI/AS) (S/I), where I is innovation and S is firm size. In equation A, this elasticity is [b + cS] (S/I). For large S, the elasticity depends on the sign of the coefficient c. If c is positive, the size elasticity of innovation is always positive, while if c is negative, as size increases eventually the elasticity will be negative.

a big firm may seek a much larger value of R. & D. output than a small firm, the number of R. & D. workers hired may not differ markedly for the two firms. Therefore, the ratio I/S (innovation/size) may be smaller in the large firm. Accordingly, results of efforts to estimate equation A using inputs to measure innovation are not expected to indicate whether large firms have an advantage in innovation. Since the F-T argument rests on a particular theoretical formulation, it may not necessarily be fatal to studies that use input data in equation A. But the F-T contribution does pose a challenge to empiricists who rely on input data to examine possible economies to scale in innovation.

Third, many studies of the innovation/monopoly-power relationship use the domestic concentration ratio to measure monopoly power. A major reason for using concentration (and this measure in particular) is convenience--the sales or capacity share of the top four or eight firms is usually easy to calculate and available on a U.S.-area basis. Additionally, at the time several of these studies were conducted, especially in the 1960's, economists were more receptive to using domestic concentration as an index of monopoly power. However, a growing skepticism has emerged regarding the use of simple concentration ratios for this purpose.[1] Not all of the skepticism about concentration ratios is of recent

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[1] See Pautler (1981), pp. 53-68, for a recent survey of the literature.

origin. For example, economists have long been aware that monopoly power also depends on entry conditions. If entry into an industry is relatively easy, a high concentration ratio does not signify significant monopoly power. But recent research has found that simple concentration ratios--i.e., the four-firm concentration ratio--are not always a reliable indicator of monopoly power, because they conceal information about the relative positions of the top (four) firms. That is, asymmetry of market shares and the the positions of the top two firms may be more important in determining monopoly power.[1] Another issue concerns the definition of the relevant market. Several studies have used three-digit SIC industries, which are probably too broad in many cases. A similar market definition problem arises when four-digit SIC codes are used to define the product market. These classifications may bear little relationship to the actual product markets, which can be smaller. Furthermore, the (growing) importance of competition between firms in different countries is invariably ignored. The simple domestic concentration ratio is probably a poor measure of monopoly power in industries like automobiles and steel, where foreign producers export to the United States and the relevant market is apparently broader than the United States alone. While foreign-manufactured autos and

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[1] John E. Kwoka (1979), "Does the Choice of Concentration Ratio Really Matter?" FTC working paper no. 17, and Kwoka (1977), "The Effect of Market Share Distribution on Industry Performance," Rev. Econ. Stat. 61:101-9.

steel have increased in importance in the past decade, even by the end of the 1950's imports of autos and steel were approaching or exceeding 5 percent of domestic consumption and therefore were probably exerting a significant influence on U.S. firms. Finally, other markets may be local rather than national, so that national concentration understates monopoly power.

Fourth, the simple innovation/firm-size and innovation/monopoly-power models presented above presume that the direction of causality flows from firm size or monopoly power to innovation. While this direction of causality may be appropriate for tests of the Schumpeterian-type hypothesis, some economists have argued that causality is much more complex and that innovation and firm size or monopoly power are interrelated, if not simultaneously determined. For example, Phillips (1971) maintains that innovation and market structure need to be studied over time; innovations tend to alter market structure, for example, as successful innovators increase their market share. He points out that some rivals adversely affected by the innovation may be forced to exit the industry, while other rivals, as well as the initial innovators, may be stimulated to further R. & D. activity.[1] To the

[1] Note that several economists have proposed that the evolution of an industry's structure over time can also be studied in the context of a pure random-growth phenomenon, where all firms face the same probability distribution of growth rates, so that the actual growth rate record of an individual firm is a matter of luck. Those models generally predict that an industry's concentration will increase over time. See Scherer (1980), pp. 145-50, for a review of this literature.

extent this view of innovation is valid, the statistical results of single-equation models will be biased and misleading. The bias arises because the correct model is a system of equations in which both innovation and market structure are endogenous. The single-equation models are also expected to be misleading if Phillips' argument is correct, because as these models have been applied, they utilize cross-section data (e.g., observations for different firms or industries at a point in time or over a short time). Accordingly, these models do not allow for changes over time in innovational activity and market structure. The thrust of Phillips' line of argument as well as similar recent theoretical efforts[1] therefore casts a cloud of doubt over the results of econometric studies that employ single-equation models and use cross-sectional data. Finally, to the extent that variables, and perhaps entire relationships, are missing from the equations, the statistical estimates will be biased. There may be leads and lags that are not captured. Variables such as barriers to entry may be omitted. And equations that define how these variables are determined may be omitted also.

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[1] For example, Partha Dasgupta and Joseph Stiglitz (1980), "Industrial Structure and the Nature of Innovative Activity," Econ. J. 90:266-93; Carl A. Futia (1980), "Schumpeterian Competition," Q. J. Econ. 94:75-695; Glen C. Loury (1979), "Market Structure and Innovation," Q. J. Econ. 93:395-440; Richard R. Nelson and Sidney G. Winter (1979), "Forces Generating and Limiting Concentration Under Schumpeterian Competition," Bell J. Econ. 9:524-48.

IV. INVENTION AND FIRM SIZE

Economic study of the invention phase of the innovation process has been rather limited. The literature has focused almost exclusively on the relationship between invention and firm size.[1] Furthermore, attention has been confined to measures of inventive output, such as number of patents issued or number of significant inventions.

There appears to be broad agreement, regardless of the inventive-output measure employed, that there is little (if any) perceptible connection between firm size and rate of invention. Indeed, to the extent that experts in the area have drawn any summary finding, they have concluded that small firms appear to be favorably structured for inventive efforts. For example, Scherer (1980, p. 417) offers the generalization that ". . . small firms and independent inventors play a prominent and perhaps even disproportionate role in generating new ideas and concepts. . ." Supporting Scherer's summary are a few studies of a variety of

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[1] It appears that there are no studies that focus on the relation between invention and concentration, although attempts have been made to assess the inventive performance of small firms in concentrated industries--e.g., Williard F. Mueller (1962), "The Origins of the Basic Inventions Underlying du Pont's Major Product and Process Innovations, 1920 to 1950," in the National Bureau of Economic Research Conference Report, The Rate and Direction of Inventive Activity (Princeton), pp. 323-46.

[2] John Jewkes, David Sawers, and Richard Stillerman (1969), The Sources of Invention, 2d ed. (Norton). Also see Daniel Hamberg (1963), "Invention in the Industrial Research Laboratory," J. Pol. Econ. 71:95-115.

inventions. For example, the work of Jewkes, Sawers, and Stillerman,[2] who studied the record of 70 important 20th-century inventions, discovered that most inventions were attributable to the efforts of independent investigators, although many were subsequently acquired by large firms. While it is hazardous to reach conclusions on the basis of such limited data, current findings imply that there are a wide variety of environments hospitable to invention and that with due regard to instances where a large laboratory or organization is conducive to basic research, it is expected that antitrust policy will not, as a general matter, necessarily disrupt inventive output. In fact, antitrust may promote inventive efforts in some markets.

V. FIRM SIZE AND INNOVATION

While little is known about the inventive stage of the innovative process, even less is known about the development and commercialization stages of the innovation process. Economists simply have not broken their studies down so that they focus on these stages individually. Instead, they typically have studied these two stages simultaneously, often employing aggregative measures that mix in the behavior of other stages of the innovation process. This section and the next review empirical works that have studied innovation using aggretate measures of innovation.

Empirical investigations of the possible relationship between firm size and innovation typically focus on research and development by industrial firms. This implies that innovation is viewed rather broadly, since R. & D. may be devoted to a wide range of activities, from basic research to final development of new products and processes (and even imitation).

Two types of approaches may be distinguished: (1) studies of firm size and innovative input, and (2) studies of firm size and innovative output. These approaches may be viewed as complementary, since both attempt to determine whether bigness is necessary for (or at least conducive to) innovation. The general questions addressed by these studies are whether large firms are better able to undertake innovation and whether they have significant incentives to innovate. Specifically, the issue is whether a given percentage expansion in firm size leads to an even greater expansion in innovation. Input studies--presuming that there is a constant linear relationship between inputs and outputs--focus on the question, Does the intensity of innovational activity, measured (for example) by R. & D. employment divided by total employment, increase with firm size? Output studies try to circumvent the assumption of equal and constant efficiency of innovative efforts by studying whether innovative output increases more than proportionately with firm size.

A. Firm Size and Innovative Input

Studies of innovational input and firm size generally do not support the notion that large firms have a disproportionate advantage in innovation. According to a review by Weiss, ". . . most studies show strong positive effects of size on R. & D. employment or expenditures within broadly defined industries but weak, and often negative effects of size on R. & D. intensity."[1,2] That

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1 Leonard Weiss (1977), "Quantitative Studies of Industrial Organization," in Frontiers of Quantitative Economics, ed., Michael D. Intriligator, p. 390.

2 Weiss references several works published in the 1960's that closely overlap with the works surveyed by Kamien and Schwartz, and Scherer (1980). They include Henry Grabowski (1968), "The Determinants of Industrial Research and Development," J. Pol. Econ. 76:292-306; Daniel Hamberg (1966), R and D, Essays on the Economics of Research and Development (Random House); Ira Horowitz (1962), "Firm Size and Research Activity," S. Econ. J. 28:298-301; Edwin Mansfield (1968), Industrial Research and Technological Innovation (Norton); F. M. Scherer (1965a), "Size of Firm, Oligopoly, and Research: A Comment," Can. J. Econ. Pol. Sci. 31:256-66; and J. S. Worley (1961), "Industrial Research and the New Competition," J. Pol. Econ. 69:183-86.

is, larger firms employ more innovative inputs, but they do not employ disproportionately more inputs. However, there are qualifications to this summary. Most important, the statement applies to most, but not all, industries investigated. For example, several of the studies found the chemical industry to be an exception displaying increasing R. & D. intensity with size.

Case studies of the chemical industry give further insights into the innovative process. Researchers suspect that the results for the chemical industry are strongly influenced by the industrial giant Du Pont. A study by Mueller (1962) of Du Pont's 25 most important product and process innovations between 1920 and 1950 revealed that at most 11 were initially discovered in Du Pont's laboratories.[1] However, while Du Pont was not the initial inventor of the majority of the 25 innovations, it is possible that its development and commercialization activities were significant and explain Du Pont's disproportionately large R. & D. effort in relation to its size. Finally, a more recent examination of the chemical industry finds that Du Pont's R. & D. performance has been distinctive and that generally, large size does not insure technological progressivness in chemicals.[2]

While Kamien and Schwartz (p. 18) concur in Weiss' summary, they point out a second qualification. Studies of firm size and

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1 Also see Scherer (1980), p. 416.

2 Edwin Mansfield, John Rapoport, Anthony Romeo, Edmond Villani, Samuel Wagner, and Frank Husic (1977), The Production and Application of New Industrial Technology (Norton), ch. 3.

innovative inputs typically only include firms that have sustained R. & D. efforts. However, the vast majority of small firms probably do not have such programs. Since small firms without research programs are excluded from the studies, the results may be biased in favor of finding that small firms are more intensive in R. & D.[1]

Researchers also recognize that these results may be biased in favor of a positive relationship between firm size and innovation intensity because a high proportion of the research of some large firms is financed by the Government.[2] To the extent that the Government subsidizes the research efforts of large firms more than it does smaller firms, the input studies confound subsidies with an indicator of efficient firm structure. Finally, R. & D. subcontracting may artifically inflate R. & D. activity of a large firm when it hires subcontractors to perform R. & D. and the financing is attributed to the large firm as R. & D. expenditure for its own research effort. This may mask the comparative inefficiency of undertaking R. & D. in large firms and distort assessments of scale economies of R. & D. with firm size.

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1 Offsetting this bias, to some extent, is the fact that small firms are less likely to formalize their budgets. To the extent that workers in small firms informally suggest and undertake innovative efforts more than in large firms, the R. & D. expenditure figures taken from income statements will understate the level of activity in small firms.

2 Weiss, ibid. Also see Scherer (1980), p. 418.

On balance, these qualifications suggest that insofar as antitrust policy focuses on possible monopoly problems involving large enterprises, it is expected that for many (if not most) industries, innovational advantages would not be lost by restraints on the formation of bigger firms. This statement cannot be transformed into a stronger guideline, because excepttions have been found. In actual investigations, therefore, it may be necessary to assess innovational activity in cases where innovation is a significant dimension of an industry's performance.

B. Firm Size and Innovative Output

Innovative output can be measured in several ways, e.g., in terms of total patents issued, significant patents issued, sales of new products over a period after their introduction. In an extensive study of patents and firm size, Scherer (1965b) used a main sample of 448 firms from the 1955 Fortune 500 largest industrial companies and performed a number of statistical tests.[1] Initial tests of patenting and firm size were performed first for all firms together and second for firms grouped within 14 two- and three-digit (SIC) industries. The results were inconclusive.[2] Next, firms were organized into four categories that attempted to

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1 F. M. Scherer (1965b), "Firm Size, Market Structure, Opportunity and the Output of Patented Inventions," Am. Econ. Rev. 55:1097-1125.

2 These tests encountered severe multicollinearity problems, which means that the coefficients in the regression model cannot be meaningfully estimated. See Scherer (1965b), p. 1106.

reflect what Scherer regarded as differences in technological opportunity.[1] Two types of tests for the four industry groupings were conducted. One test used raw data for firm size (measured by total sales), while the second test used the logarithm of firm size. Apparently Scherer utilized the logarithmic formulation to attempt to adjust for heteroskedasticity.[2] Both types of tests showed that patenting increased with firm size in all four industry groupings. But the two types of tests differed about returns to scale in patenting. When size of firm was measured by absolute sales, increasing returns to scale eventually prevailed in all four industry groupings.[3] In contrast, measuring firm size by the logarithm of sales produced results that implied diminishing returns to scale in all four groupings. The contrast in these

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1 The four groups were (1) the so-called unprogressive industries, which include five industries: food and tobacco products, textiles and apparel, paper and allied products, miscellaneous chemicals (e.g., soap, paints, and fertilizer), and primary metals; (2) what Scherer termed moderates, which include six industries: petroleum, rubber products, fabricated metal products and miscellaneous (e.g., ordnance, watches and clocks, optical equipment), machinery, transportation equipment except aircraft, and aircraft and parts; (3) stone, clay, and glass, and general chemicals (e.g., inorganic, organic, and drugs); and (4) electrical equipment and communications. Scherer (1965b), pp. 1101, 1107.

2 The presence of heteroskedasticity in a single-equation regression model reduces the statistical significance of the coefficients of firm size in the estimated model.

3 Scherer estimated a cubic equation in firm size and found that the coefficient of size squared was negative and the coefficient of size cubed was positive. This resulted in an initial region for firm size over which there were decreasing returns to size. After some point, the positive cubic coefficient dominated and gave rise to increasing returns to size.

results is important and cannot be resolved based on the information supplied in the article. Scherer observes that the results of the absolute firm size test ". . . are dominated to some extent by the observations for large firms."[1] But no information is furnished about the behavior of the residuals in the regression runs. An examination of the residuals would greatly aid in choosing between the absolute-size and the logarithm-of-size tests.

While Scherer's statistical results are contradictory on the issue of whether there are increasing or decreasing returns to scale in patenting, it should be noted that there are several qualifications about using patents as a measure of innovational output. First, there is some indication that very large firms do not commercially develop as high a percent of their patents as do small firms. Second, giant firms tend to seek patents for a higher proportion of their inventions, which may be related to advantages that very large firms possess in supporting internal staffs of patent attorneys rather than the productivity of their R. & D. effort.[2] Third, Hamberg (1966) reported that the output of large industrial laboratories tends to consist mainly of minor inventions. However, he also pointed out that while very large firms may issue relatively large numbers of minor inventions, they

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1 Scherer (1965b), p. 1108. He reports that there were 11 large firms--1 in electrical, 2 in chemical, 3 in moderates, and 5 in unprogressives.

2 These two points are noted by Scherer (1980), p. 418.

may also be the primary sources of many of the few really significant innovations.

While the general direction of the biases in patent data appear to push studies in the direction of finding that large firms are more productive innovators, resolution of this question really requires closer examination of the quality of patents.[1] In an attempt to control for quality of innovational output, Mansfield (1968) secured the cooperation of trade experts to rank by importance the major innovations during 1919 to 1938 and 1939 to 1950 in three industries--bituminous coal, petroleum refining, and steel.[2] Mansfield found that the four largest companies in the coal and petroleum industries accounted for a greater share of innovations than their respective shares of industry capacity. But in the steel industry the opposite conclusion was reached. Mansfield considered several factors that could account for his findings. Apparently a key difference between the steel and the petroleum refining industries is the cost of innovation. Mansfield found that the investment outlays required to innovate compared to the average size of firms were appreciably higher in petroleum than in steel. (Because of inadequate data, the cost of innovations in the coal industries could not be determined.)

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1 Weiss (1977), in his survey (p. 391, fn. 25), concluded that on balance total patents issued were a better indicator of R. & D. input than R. & D. output.

2 Edwin Mansfield (1968), Industrial Research and Technological Innovation, ch. 5.

This assumes that the top four firms in petroleum had a sharper comparative advantage in being able to bear the cost and risk of innovation.

Subsequently, Mansfield et al. (1971) studied the pharmaceutical industry and, as in steel, the four largest firms were comparatively unprogressive.[1] In commenting on the first Mansfield study, Weiss pointed out that there were reasons to have severe reservations about the validity of the results. In particular, he noted that only a limited number of observations were used.[2] Further, Scherer observed that in the Mansfield study the company credited with an innovation was not necessarily the firm that ultimately developed and introduced the innovation.[3]

Unfortunately, efforts to construct data for significant innovations have been limited, apparently because these efforts are very costly. For example, in his 1980 survey, Scherer

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1 Edwin Mansfield et al. (1971), Research and Innovation in the Modern Corporation, ch. 8. See also, Walter Adams and Joel Dirlam (1966), "Big Steel, Invention and Innovation," Q. J. Econ. 80:167-89. The Big Three U.S. firms were the last, for example, to adopt the BOF furnace.

2 Weiss (1977), p. 391.

3 Scherer (1980), p. 423, fn. 47. Scherer comments that "Particularly in the coal mining industry, new machinery is typically developed by specialist machinery makers, not by mining firms."

mentions only two other recent studies, both of which concern specific industries.[1]

To summarize, attempts to relate firm size to innovational output have used patents issued and significant innovations as measures of output. The evidence of two principal studies of U.S. firms, by Scherer and Mansfield, suggests that the importance of firm size for innovation varies across industries. In some industries giant firms may be very progressive, while in others small or medium-size firms hold this distinction.

C. The Quality or Efficiency of Innovative Effort

Neither input nor output studies present the full picture of the effectiveness of R. & D. efforts relative to firm size, since both approaches fail to control for the efficiency of their R. & D. activity. Firms can devote substantial amounts of their resources to R. & D. efforts without producing much output, if the "quality" of the R. & D. efforts is substandard. Similarly, focusing on substantial R. & D. output may overlook the fact that this output was produced at excessive cost. Only by taking a closer look at R. & D. efforts than do the typical R. & D. input

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[1] Scherer (1980), p. 421. The two industries are computers and pharmaceuticals. In the former, IBM was reported to be responsible for only 28 percent of 21 major computer industry innovations, but its share of industry sales during the relevant period ranged between 66 and 78 percent. See Gerald Brock (1975), The U.S. Computer Industry. Major drug companies were reported to be responsible for a disproportionate share of major drug innovation after the mid-1960's, when development and testing costs rose sharply, partly owing to stiffer regulations. Henry Grabowski (1976), Drug Regulation and Innovation.

and output studies will the researcher be able to analyze the efficiency of the R. & D. activity.

Direct analysis of the efficiency of a firm's operations by relating inputs to outputs is relatively rare. Most studies take the form of the input and output studies described above. As a result, they fail to distinguish between two conceptually different types of scale economies: (1) the effect of firm size on the efficiency of a given size of R. & D. facility, and (2) the effect of the scale of the R. & D. facility for a given firm size.[1]

Several studies have focused on the question of how firm size affects the efficiency of a given size of R. & D. facility. An illustrative example is the interview study conducted by Cooper (1964). He attempted to find the costs involved in comparable projects in large and small firms in the electronics and chemical industries.[2] He reported that a given project would cost 3 to 10 times more to develop in a large company than in a small firm. Cooper found that innovation was hampered by the bureaucracy of some large firms and that better personnel were attracted to smaller companies. This suggests that beyond some point, firms encounter negative returns for their R. & D. activity when they reach substantial size.

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1 Kamien and Schwartz (1975), p. 8.

2 A. C. Cooper (1964), "R. & D. is More Efficient to Small Companies," Harvard Business Review, May/June and September/October.

Studies that have focused on economies of scale in R. & D., holding firm size constant, have been rarer. The few studies that are of this genre provide indication that there may be economies of scale in R. & D., given firm size--at least in some industries. For example, Mansfield et al. (1971) found that ". . . there was a significant tendency among the chemical companies for a firm's ranking [of the effectiveness of major firms' R. & D. programs] to increase with the level of its R. & D. expenditure . . ." However, ". . . in petroleum, the evidence for this tendency is not statistically significant."[1]

Other studies have examined the issue of the coordination between the development and commercialization phases of the innovation process and the relationship of the coordination to successful innovation, but the role of firm size is somewhat in doubt. There has also been a suggestion that small and large firms play complementary roles, with large firms better suited to undertaking innovations that require large-scale R. & D., while small enterprises have a relative advantage with smaller, specialized equipment or products.[2] Finally, the importance of marketing and the interrelationship and communication between

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[1] Mansfield et al. (1971), Research and Innovation in the Modern Corporation (Norton), p. 45.

[2] By K. Pavitt and S. Wald (1971), "The Conditions for Success in Technological Innovations" (OECD).

parts of an organization and with potential users[1] have also been noted.

D. Thresholds in the Relationship Between Firm Size and Innovation

It is generally recognized that there are both advantages and disadvantages of firm size for innovation. These theoretical possibilities were discussed earlier (pp. 7-12). Some economists have suggested that there may be an optimum firm size that occurs where the advantages of firm size are just balanced by the disadvantages. A few empirical studies have attempted to discover whether there is a threshold in the relationship between firm size and innovation--that is, whether there is a critical value (or range) for firm size at which innovational performance is maximized. Furthermore, the remarks of some economists suggest that the threshold is uniform across many industries.[2]

The evidence for a firm size threshold is limited and is based primarily on research conducted during the 1960's. The principal contributions from that period are those of Scherer (1965b) and Mansfield (1968). However, the evidence in these

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1 By Mansfield et al. (1971) and by Christopher Freeman (1973), "A Study of Success and Failure in Industrial Innovation," in Science and Technology in Economic Growth, ed. B. R. Williams (Wiley), pp. 227-45.

2 For example, while Scherer (1980, p. 422) is careful to qualify his remarks, he suggests that "A little bit of bigness--up to sales levels of $250 to $400 million at 1978 price levels--is good for invention and innovation. But beyond the threshold further bigness adds little or nothing, and it carries the danger of diminishing the effectiveness of inventive and innovative performance."

studies is somewhat contradictory, making it hazardous to draw strong conclusions. The main problem centers on the question of measuring firm size. If firm size is measured by the logarithm of firm sales, then, Scherer's and Mansfield's results suggest, there is a threshold. On the other hand, if firm size is measured by the absolute level of sales, then either no threshold is found or else it is at a level corresponding to the very largest firms in the industry.[1] While there may be a good case for using the logarithmic-size measure over the absolute-size measure, neither author develops an argument supporting this view.[2]

New evidence about thresholds is furnished in a recent paper by Scherer (1980), which utilizes an extensive sample of firms, drawing on the Commission's Line of Business data base.[3] Scherer presents results for both innovational output measured by patents,

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[1] Mansfield (1968), Industrial Research, pp. 98-99, reports that there is an exception in the steel industry, where the threshold occurs at a level for very small firms.

[2] In a private conversation, Scherer mentioned that his regression runs encountered severe multicollinearity problems and that a comparison of the results of measuring firm size by absolute sales against the log of sales was a type of sensitivity analysis. Furthermore, as discussed earlier (p. 48, fn. 2 above), a key issue turns on the possibility of heteroskedasticity when absolute size is used. To examine this issue, we need to have the residuals of the regression equations. In the absence of this information and in view of a more substantive recent paper, there is limited value in devoting further attention to these earlier contributions.

[3] F. M. Scherer (1980), "The Propensity to Patent" (forthcoming, J. Indus. Econ.).

and for innovational input measured by R. & D. spending. Unfortunately, Scherer uses only a linear regression model and does not consider the logarithmic format. But this deficiency is probably more than offset by working with a superior data base. Specifically, size is measured by absolute sales of firms in each LB industry. For the relation between patents and size, Scherer investigates 124 Line of Business industry categories. He finds that for 70 industries there are diminishing returns in patenting, which implies that a threshold applies.[1] For the other 54 industries, increasing returns are reported, suggesting that a threshold does not exist.[2] A similar mixed pattern is found for the relation between R. & D. spending and firm size, which covers 196 Line of Business industry categories. In 92 cases, the statistical results imply a threshold,[3] while in 104 LB industries no threshold is evident.[4]

Scherer's latest findings support the view that the "optimal" environment for innovation varies widely across industries. These latest results warrant special weight, because they draw on a much

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[1] Of the 70 industries, the (negative) quadratic regression coefficient is statistically significant (at the .05 level) in 17 cases.

[2] Of the 54 industries, there are 14 statistically significant (positive) quadratic coefficients.

[3] Only 16 (negative) quadratic coefficients are statistically significant, out of 92 cases.

[4] Forty (positive) quadratic coefficients in the 104 LB industries are statistically significant.

more extensive and carefully designed data base, as compared with the samples used by the earlier studies conducted in the 1960's. Scherer's new findings are also in accord with the view that the balancing of advantages and disadvantages of firm size for innovation vary over industries. For example, the cost of a major innovation can vary enormously from industry to industry and accordingly, can influence the size of firm most conducive to innovation.[1] At this time, therefore, there appears to be a diversity of firm sizes most conducive to innovation across industries. But unfortunately we must await further research to learn the specific industries where thresholds may or may not be relevant and to obtain the appropriate size thresholds where they apply. Scherer's paper does not identify the industry groups that reported increasing vs. decreasing returns to scale in patenting and R. & D. spending.

E. Conclusion

Overall, the empirical evidence concerning firm size and innovation does not paint a very simple picture. In part, this is due to problems with the data. A number of contributions have examined the association between firm size and innovational input (e.g., R. & D. employment or expenditure). But the interpretation

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[1] For example, the cost of developing the IBM 360 series of computers in the mid-1960's was apparently in the region of $5 billion. By contrast, the innovation cost of the integrated circuit, introduced in 1959 by Texas Instruments, was put at $100,000. B. C. Twiss (1974), Managing Technological Innovation (Longman), p. 22, and Economist, 27 Dec. 1980, p. 64.

of the results of these studies is in doubt because they beg the question of the efficiency of R. & D. programs. Output studies suffer from the difficulty of measuring the value of innovative output. Accepting the measures that are adopted, there appear to be marked differences among industries. In some industries (chemicals, and possibly petroleum), a few large firms are comparatively progressive; in others (steel), large firms are less innovative than medium-sized enterprises. Similarly, an optimal size threshold for innovation appears to exist in some industries, but no general threshold level appears to apply in all industries. Indeed, even the presence of a threshold is open to question in some other industries. Apparently there are significant differences underlying the structural characteristics of markets, although further testing is needed to substantiate this conclusion. It may also be due to the fact that the relationship between R. & D. and firm size involves two distinct scale economies: the scale effect on R. & D. efficiency as R. & D. increases, given firm size, and the efficiency of R. & D. as firm size increases, given an R. & D. program. While several studies appear to be concerned with the latter or a combination of both types of scale economies, little work appears to be available about the former.[1] Before strong conclusions can be reached, it

[1] Note that the scale effect on R. & D. efficiency (given firm size) is important to the analysis of joint-venture R. & D. programs.

is important that these two factors be separated. Only further study with improved data sets will provide a firm basis for conclusions.

VI. EVIDENCE CONCERNING INNOVATION AND MONOPOLY POWER

A fundamental challenge to traditional antitrust policy is the proposition that greater monopoly power is necessary to increase innovation in a given industry. Attempts to study this challenge have focused on exploring the relationship between market concentration and innovative activity. Unfortunately, these studies have not reached any universal conclusions. This ambiguity is largely attributable to the complexity of both the subject and the empirical task. Not only are satisfactory measures of monopoly power and innovative activity difficult to obtain, but also there are complex, simultaneous processes that confound the measurement effort. Specifically, it is difficult to distinguish whether the monopoly power surrogate (concentration) impacts innovation, whether innovation impacts concentration, or whether the two are simultaneously determined. Because of the need for detailed data to unravel these relations, some scholars have focused their efforts on case studies. A review of both the case-study evidence and the statistical evidence follows, to indicate our current knowledge of these relationships.

A. Evidence from Case Studies

While attempts to generalize from the results of a few case studies must be regarded cautiously because of special or unique circumstances in the cases surveyed, economists have detected several themes in the case studies. For example, Scherer (1980, pp. 430, 431) offers three tentative guidelines.

First, vigorous innovation appears to be incompatible with an industry that features a sustained atomistic structure.[1] Scherer cites as examples the home construction and fertilizer industries.[2] Note that innovation here emphasizes the origination, development, and marketing of new products and processes. The diffusion aspect of innovation is examined in the next section (VII).

Second, and more important for antitrust policy, there is evidence that effective cartelization has retarded innovation. Examples include the U.S. electric lamp industry and the radio industry before the Second World War, and the alleged conspiracy of U.S. auto manufacturers to delay the development of emission control devices.[3]

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[1] Here I focus on the initial stages of the innovation process, rather than the diffusion of innovations. Atomistic industries, such as agriculture, often employ innovations developed by larger suppliers that are in more concentrated industries.

[2] However, Scherer notes some possible exceptions, including unconcentrated segments of the electronics industry. But it is possible this industry's structure is still evolving. It is also possible that this young industry is strongly influenced by earlier development in science and that as the industry matures, the market structure may change, as several small firms become unable to keep abreast of rivals and are forced to exit. See Scherer (1980), p. 430. The statements about the building trade and fertilizer industries draw on studies by Charles Foster (1964), "Competition and Organization in Building," J. Indus. Econ. 12:163-74, and Jesse Markham (1958), The Fertilizer Industry (Vanderbilt).

[3] Scherer (1980, p. 431) cites the studies of Arthur Bright, Jr. and W. R. Maclarin (1943), "Economic Factors Influencing the Development and Introduction of the Fluorescent Lamp," J. Pol. Econ. 51:449, and W. R. Maclarin (1949), Invention and Innovation in the Radio Industry (Macmillan). There is a question, however, concerning the significance of the delay in the development of (footnote continues)

Third, the innovation record of dominant firms appears to be mixed. In several instances--including Gillette (stainless steel razor blade), IBM (digital electronic computing equipment), and United Shoe Machinery (sole-cementing devices)--dominant firms were slow innovators but reportedly reacted strongly to upstart innovators by becoming aggressive followers. But in other industries, dominant firms were significant innovators, including RCA (color TV) and Alcoa (energy-efficient smelting method).[1]

Scherer concludes his review of the evidence from the case studies by pointing out that

> The main lesson to be drawn from a review of the qualitative evidence is that no simple, one-to-one relationship between market structure and technological progressiveness is discernible.[2]

He suggests that the search for a simple market-structure/innovation rule may miss the important role played by technological opportunity across industries. Furthermore, and as stressed

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(footnote continued)

the fluorescent lamp. While GE was the first company to secure a patent for the lamp and may have sought to delay its development, another firm, Sylvania, quickly obtained other patents for the fluorescent lamp and pushed its promotion. Consult the FTC staff report by Robert P. Rogers (1980) of the Bureau of Economics, Development and Structure of the U.S. Electric Lamp Industry, pp. 113-30. The R. & D. performance of auto firms is analyzed by Louis Silvia (1980), "Technological Suboptimization and the U.S. Automobile Industry" (Ph. D. dissertation, Michigan State University).

1 According to Scherer (1980), pp. 431, 432.

2 Scherer (1980), p. 432.

by Phillips (1971), it is possible that technological opportunity, innovation, and market structure are interrelated. If this is true, then the quest for a simple monopoly-power/innovation rule is probably not very meaningful, because in principle innovation is not simply explained by or determined by narrow market characteristics such as concentration.

B. Evidence from Econometric Studies

Several statistical studies have sought to measure the relationship between market structure, usually reflected by industry concentration, and innovation. These studies frequently make allowance for differences in technological opportunities between industries. Generally, econometric studies show that innovation varies widely from industry to industry. Typically, innovation is found to be positively related to industry concentration, although the statistical relationship is often insignificant.[1] In what follows a distinction is drawn between studies that measure innovation by inputs, as opposed to outputs. A final section will consider efforts to find a threshold concentration ratio for innovation.

1. Monopoly Power and Innovative Input. One group of studies has relied on concentration as a measure of monopoly power

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[1] According to Markham (1974, p. 274), who had surveyed the literature to the early 1970's, there were no studies that had found a negative statistical relationship between industry concentration and R. & D. effort. Jesse Markham (1974), "Concentration: A Stimulus or Retardant to Innovation?" in Industrial Concentration: The New Learning, ed. Harvey Goldschmid et al. (Little, Brown and Co.), pp. 247-78.

and tested the hypothesis that concentration determines innovative activity, measured by inputs to the innovation process. Two early works found that concentration was positively related to innovation, but the relationship was described as weak.[1] A larger scale investigation was mounted by Scherer (1967), which covered 56 manufacturing industry groups in 1960, most at the three-digit level of aggregation.[2] Scherer tested two empirical formulations, using three different measures of innovational input for each. In the first (logarithmic) formulation, innovation was explained by industry size, concentration, and several other variables designed to capture technological opportunity and product characteristics. The second formulation sought to explain innovational intensity, the ratio of innovational input to industry size, by the same independent variables. The econometric results show that innovational input is positively related to concentration in all cases. For the logarithmic formulation, concentration is statistically significant; in the ratio formulation, it is not.

Scherer also detected a positive association between an industry's concentration and the degree of its technological opportunity, particularly in the "technically vigorous" electrical

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1 Daniel Hamberg (1964), "Size of Firm, Oligopoly, and Research," Can. J. Econ. Pol. Sci. 30:62-75, and Ira Horowitz (1962), "Firm Size and Research Activity," S. Econ. J. 28:298-301.

2 F. M. Scherer (1967), "Market Structure and the Employment of Scientists and Engineers," Am. Econ. Rev. 67:524-31.

and chemical industry groups. He suggested that the interrelationship between technological opportunity and concentration could be explained by two alternative causal chains: "The electrical and chemical classes might be more progressive on average because they are more concentrated, or they may be more concentrated because in the past they have been more progressive."[1] He argues that the latter interpretation has more support, because science had achieved strong breakthroughs beneficial to these two industries in the past century and (more generally) was also likely to be important in explaining the high concentration in other industries (because they lead to patent and/or know-how barriers to entry). However, this line of argument about alternative causal chains raises basic questions about the meaning of statistical results obtained in simple econometric models of the type used by Scherer. This issue was discussed above in section III, in connection with the modeling of innovation.[2]

In another paper, Comanor (1967) took a different approach and examined the connection between innovation and industry concentration, allowing for the effects of product differentiation

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1 Scherer (1967), p. 529.

2 Where a more complex model of innovation is appropriate that allows for direct and feedback effects between technology, market structure, and innovation, the statistical results of single-equation models of the type used by Scherer may be biased.

and technical barriers to entry.[1] Comanor used 1955 and 1960 data for a sample of firms that were grouped into 21 three-digit industries. First, he found that innovation was positively (but weakly) related to industry concentration. Second, he formed two categories of industries based on his assessment of whether product differentiation was significant.[2] Comanor hypothesized that innovation in terms of new or improved products would be stimulated in industries with significant product differentiation.

In this context, there is a question about the meaning and significance of R. & D. activity. R. & D. may be a competitive strategy used by leading firms to bolster their monopoly power. For example, existing firms could use innovation as a device to strengthen their positions in the industry by heightening product-differentiation entry barriers. Thus, in some instances it is possible that increases in innovation are not socially desirable.

Comanor's statistical tests gave support to the hypothesis that product differentiation stimulates innovation. For industries with significant product differention, research levels

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[1] William Comanor (1967), "Market Structure, Product Differentiation, and Industrial Research," Q. J. Econ. 81:639-57.

[2] The industry groups judged to have significant product differentiation were consumer durables (autos, trucks, and parts and rubber industries) and investment goods (machinery, electrical machinery, transportation equipment [other than autos], and other metalworking industries). The two industry groups judged to have weak product differentiation were material inputs (iron and steel; nonferrous metals; paper and pulp; petroleum refining; and stone, clay, and glass industries) and consumer nondurables (food and beverages, and textiles industries). This listing is given in Comanor (1967), p. 647.

(measured by number of research personnel) were about twice as large as for industries where differentiation was judged to be minor. Comanor also tested for the interaction of industry concentration and product differentiation. His results weakly supported the proposition that concentration was not important when product differentiation was significant and where instead ". . . competition in research is an important element of market behavior . . . ."[1] Conversely, concentration was found to play a possibly important role for innovation in industries where product differentiation was less important. In these industries, Comanor noted that research efforts were likely to emphasize process innovations as opposed to product innovations, and he suggested that for this class of industries the Schumpeterian hypothesis that ". . . a positive relationship exists between concentration and industrial research may well be correct."[2]

Finally, Comanor also attempted to test for the influence of technical barriers to entry based on (1) scale economies, and (2)

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1 Comanor (1967), p. 651. Unlike other studies, which used a concentration variable that was continuous, Comanor divided industries into two categories. Industries in which the eight-firm concentration ratio exceeded 70 percent were considered highly concentrated; concentration was considered low in other industries.

2 Comanor, ibid. However, Comanor later qualified this statement (p. 652), observing that he had not incorporated the influence of technological opportunity for innovation, so that the influence of concentration on innovation may have been overstated.

absolute capital requirements.[1] While the results were not conclusive, it appeared that industrial research spending was strongest when entry barriers were moderate. When entry barriers were high, research was low. Comanor attributed this to a low incentive for innovational activity in this situation. Similarly, when entry barriers were low, research was low. This was also explained by a low incentive to innovate because of the prospect of easy imitation.[2]

Comanor's approach is significant because it attempts to detect the importance for innovation of several dimensions of market structure, as opposed to industry concentration alone. More recently, an attempt has been made to extend Comanor's

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[1] Comanor (1967), p. 653, ". . . assumed that economies exist at the plant level . . . [, that] . . . minimum efficient scale was defined as the average plant size within each industry among plants which account for the top 50 percent of industry output . . . [, and] . . . the ratio of . . . [MES] . . . to total industry shipments . . . [represented] . . . the entry barriers created by scale economies." As with his technique to measure concentration, Comanor used dummy variables to measure scale economies and absolute capital requirements. For example, when the ratio of minimum efficient scale to industry output exceeded 7 percent, the entry barrier was defined as high. When the ratio was below 4 percent, the barrier was defined as low. For a ratio between 4 percent and 7 percent, the entry barrier was defined as being moderate.

[2] Comanor (1967), p. 656.

approach and also to incorporate differing technological characteristics of industries, in response to suggestions by Scherer that technological opportunity is important for innovation.[1]

Shrieves (1978) sought to estimate the influence of concentration (C4) on innovative input, while controlling for both product-market and technological characteristics, using a sample of 411 large firms in 56 (three-digit) industries. He employed a statistical technique to determine product-market and technological variables, in contrast to judgmental methods used by Scherer and Comanor.[2]

This raises a methodological question. The analyses by Comanor and Scherer use a priori assessments of conditions in each industry to assign technological or product-market classifications, while Shrieves relies on a statistical technique to furnish summary descriptions of technology and product-market factors. Therefore, Shrieves' summary descriptors may not be economically meaningful--which makes it difficult to compare Shrieves' results with the earlier findings of Comanor and Scherer.

Shrieves first found, for all firms (and industries) combined, that concentration was positively (and significantly)

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1 Ronald Shrieves (1978), "Market Structure and Innovation," J. Indus. Econ. 26:329-47.

2 Shrieves used the technique of factor analysis to determine statistically independent descriptors of product market and technology. Scherer and Comanor used dummy variables applied to characteristics judged important for technological classes and product differentiation classes of industries.

related to innovation. However, second, when industries were stratified into four groups on the basis of product-market factors, the role of concentration changed somewhat. Shrieves discovered that for industries producing consumer products and material inputs, the role of concentration continued to be positive and significant. On the other hand, for two other industry groups, nonspecialized producer goods and specialized durable equipment, concentration was not significantly related to innovation.[1]

These results for the role of concentration differ from Comanor's findings reported earlier because industries are grouped differently in the two studies. For example, according to Shrieves there is a significant relationship between concentration and innovation in the consumer products industries, while Comanor finds no such relationship for consumer durables. Shrieves does not distinguish between durable and nondurable consumer goods and furthermore, does not follow Comanor in treating automobiles as a consumer good.

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[1] Shrieves (1978), p. 342. Another issue is Government support of R. & D. Shrieves' dependent variable (R. & D. employment) does not distinguish between research financed from public and research financed from private sources. This may impart a bias to the R. & D. concentration relationship, although Shrieves argues (p. 333) that the influence of Government-supported R. & D. on privately funded R. & D. is indeterminate a priori. However, Shrieves reports (p. 341, fn. 25) that where Government financing exceeded 20 percent of an industry's R. & D. effort, increases in the industry's concentration were associated with larger R. & D. employment. For smaller Government support of an industry's R. & D., the partial correlation between concentration and R. & D. employment was negative but not significant.

The contradiction between Shrieves' results and Comanor's reflect, as noted above, different approaches to a classification of industries according to product-market characteristics. On balance, it appears that Comanor's approach is more meaningful, because he uses a priori knowledge of products to form his classifications, while Shrieves relies on a statistical technique that can lead to economically arbitrary classifications of products.

Empirical studies of the innovation/monopoly-power nexus started by using industry concentration as the single indicator of monopoly power and proceeded to incorporate other possible dimensions of monopoly power. As a general rule, the Schumpeterian-type argument that monopoly power is necessary for innovation does not receive strong support from the limited number of statistical studies that have examined the relationship between monopoly power and innovational input. While a few studies find a positive association between concentration and innovation, this relationship does not apply to all industries. However, it is possible that the concentration ratios employed in several studies are not meaningful, because industries are defined too broadly (i.e., using three-digit industries). There are also other significant questions that may be raised about the empirical methodology adopted by the studies covered in this section. In particular, innovation is measured by innovational inputs, e.g., R. & D. employment or number of scientists and engineers. The comments raised about input measures of innovation in the previous section (concerning firm size) also apply here. Overall, the weak conclusion the evidence points to is that concentration may be associated with innovational efforts in a few industries, notably the industries in which product differentiation is not important (e.g., steel, petroleum refining, and textiles). However, even in these industries the influence of concentration may be overstated because the role of technological opportunity has not been adequately accounted for; and it is possible that high innovation is due to significant technological opportunity and not to high concentration.

2. Monopoly Power and Innovative Output. Statistical studies of the relationship between monopoly power (as proxied by industry concentration) and innovational output are limited in number. Using patents issued to measure innovational output, Scherer found that higher concentration was associated with greater innovation, but the result was not statistically significant.[1] Scherer also noted that there were questions about the reliability of patent data for 8 of the 48 industries in the study's sample, arising from uncertainties about patent classification and assignment. Removing these industries from his sample led to a marginal improvement in the positive partial correlations between concentration and innovational output. But the correlation remained statistically insignificant.

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1 Scherer (1965b), p. 1119.

Different results were obtained by Williamson.[1] Williamson's study covered three industries--steel, petroleum refining, and coal--over the periods 1919-38 and 1939-58 and found a significant negative correlation between innovation and concentration.[2] However, as suggested by Weiss, the usefulness of Williamson's statistical findings are marred by a very small sample size.[3]

The question of whether concentrated industries are more progressive in terms of recording higher productivity trends has also been addressed in the literature.[4] One contribution, by Allen, undertook to update an earlier parallel effort by George

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1 Oliver Williamson (1965). "Innovation and Market Structure," J. Pol. Econ. 73:67-73.

2 Williamson used Edwin Mansfield's (1963) data in "Size of Firm, Market Structure, and Innovation," J. Pol. Econ. 71:556-76.

3 Weiss (1977), p. 395.

4 There have also been attempts to examine the productivity of R. & D. in recent years. Two studies have reported that the productivity of R. & D. collapsed in the United States in the 1970's (Griliches 1980 and Link 1981). Link (ch. 4) found that this collapse was attributable to poor R. & D. productivity of small firms. However, recent research by F. M. Scherer (reported in a seminar at the Justice Department on 30 September 1981) challenges these findings. Scherer argues that the econometric models used by Griliches and Link are misspecified and that the industry definitions adopted are too broad. Scherer's empirical results do not support the notion of a collapse in R. & D. productivity in the mid-1970's. See Zvi Griliches (1980), "R. & D. and the Productivity Slowdown," Am Econ. Rev. 70:343-48, and Albert N. Link (1981), Research and Development Activity in U.S. Manufacturing (Praeger).

Stigler.[1] Allen's sample included 19 manufacturing (three- and four-digit) industries for the period 1939-64. Productivity was measured by output per man-hour. Allen found that productivity trends were not significantly different among three groups of industries classified by concentration levels and trends.

By contrast, in a more comprehensive effort, Greer and Rhoades reported that industry concentration was positively related to long-run industry productivity growth.[2] They analyze three time periods, 1914-40, 1954-71, and 1958-69, for a broad collection of industries, in the last period covering 394 (four-digit) industries. Their results are consistent over the time samples and show that industry concentration is positively related to productivity growth, measured by annual percent changes in output per production worker man-hour. The relationship was also significant.

In a recent comment on the Greer-Rhoades paper, Scherer is perplexed by their results and suggests that concentrated industries may have greater opportunity to improve productivity. For example, labor-saving technical change may favor industries in which minimum optimum scale is large in relation to market size.[3]

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1 Bruce Allen (1969), "Concentration and Economic Progress," Am. Econ. Rev. 59:600-604.

2 Douglas Greer and Stephen Rhoades (1976), "Concentration and Productivity Changes in the Long and Short Run," S. Econ. J. 43: 1031-44.

3 Scherer (1980), p. 434.

However, it is not clear that Scherer's suggestion distinguishes between firm size and concentration and therefore explains why concentration alone would produce the effect reported by Greer and Rhoades. Large capital-intensive firms may have a strong inducement to introduce labor-saving devices, but this is not the same as finding that increased concentration produces higher productivity growth.[1]

Finally, the Greer-Rhoades results are also expected to encompass the diffusion of new products and processes in industries. To the extent that productivity growth is attributable to the acceptance and widespread use of innovations, the Greer-Rhoades results appear to conflict with evidence concerning the speed of diffusion and concentration. The evidence concerning diffusion is discussed in section VII.

3. <u>A Threshold for Concentration in the Relationship Between Industry Concentration and Innovation</u>. Some attempt has been made to determine whether there is a threshold concentration ratio, or range for the ratio, where innovational intensity is maximized. If a threshold for concentration could be established empirically, then antitrust policy could promote innovational efforts by focusing attention on industries with concentration ratios higher than the threshold level. While there is some support for the

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[1] Moreover, Greer and Rhoades have attempted to control for capital intensity by including the capital/output ratio among their independent variables.

existence of a threshold for industry concentration, the statistical evidence is both meager and weak. That such an important policy issue as a possible threshold for concentration has received so little attention by economists may reflect an appreciation of the problems involved in using simple econometric models and crude empirical measures of innovation to estimate thresholds.[1] Despite possible methodological shortcomings, in view of its significance for antitrust policy it is important to examine the outcomes of efforts to estimate concentration thresholds.

The principal contribution appears to be an article by Scherer (1967).[2] He discovered that increases in concentration (C4) up to 50-55 percent were conducive to progressiveness, but beyond that concentration range, progressiveness dimmed. The concentration ratio for a beneficial influence on innovation to commence was reported to be somewhere above a C4 range of 10 to 14 percent. In conducting this examination, Scherer relied on the variable "technological employment per 1,000 employees," a measure of innovational input intensity. In other words, innovational

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1 Qualifications and problems with these approaches were discussed in section III, above.

2 Two other economists have tested for concentration thresholds. See Thomas Monroe Kelly (1969), "The Influences of Size and Market Structure on the Research Efforts of Large Multiple-Product Firms" (Ph. D dissertation, Oklahoma State University), especially ch. III, pp. 69, 71-79; and John T. Scott (1981), "Nonprice Competition: Theory and Evidence," Bureau of Economics, FTC (unpublished).

intensity was found to achieve a maximum when industry concentration was between 50 and 55 percent.

It is important to note, first, that Scherer's results are of doubtful statistical significance and therefore do not lend strong support to the argument that the concentration threshold ranges between 50 and 55 percent. Scherer estimated four equations, two each for traditional industries and for mechanical industries.[1] There were too few observations to estimate thresholds for the electrical and chemical industry groups. In only one of the four regression equations (for "traditional" industries) were the results statistically significant at the customary .05 level. The exact statistical significance of the coefficients in the other three estimated equations cannot be determined, because the estimated coefficients and their standard errors are not reported.

A second concern is that while Scherer regards innovational input intensity as a signal of greater or lesser innovation from industry to industry, it is not clear that the intensity variable can validly serve its intended purpose. For example, as noted in the last section, input measures of innovational activity raise questions about the quality or efficiency of innovation efforts. There may also be scale economies in innovation (which are likely

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1 Scherer had 25 industries classified as having traditional product technologies, while 24 industries were classified as having general and mechanical technologies. Scherer (1967), p. 528.

to differ across industries) that relate to firm size as opposed to concentration, implying there would be a variety of "optimal" concentrations, ranging from high C4's in small industries to low C4's in large industries. In sum, it appears that Scherer's search for an optimal industry concentration for innovation involves some problems.[1,2]

C. Conclusion

Empirical investigations of the connection between monopoly power and innovation have produced a variety of results, but they generally do not support the proposition that significant monopoly power is necessary for innovation. It is important to distinguish between the findings of case studies and the results of econometric investigations, because the latter may have significant methodological problems. The case studies suggest three tendencies: (1) atomistic industries are frequently not conducive to significant innovation, (2) effective cartelization and conspiracy appear to retard innovation, and (3) the innovational performance of

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1 Another broad-scale effort was mounted by Kelly (1969). It covered 181 large firms (all among the leading 1,000 firms) in 6 two-digit SIC industries (food and kindred products; chemicals and allied products; petroleum extraction and refining; stone, clay, and glass products; primary metals; and motor vehicles and transport equipment). Kelly discovered a threshold range similar to that reported by Scherer (1967). But Kelly's statistical results, the coefficients for C4 and C4 squared, were not statistically significant. (The t-value for C4 squared was only -.74.)

2 Scott (1981) uses 1974 and 1975 data from the Commission's Line of Business Program. His results suggest that a concentration threshold is not meaningful because the role of concentration in explaining company-financed R. & D. intensity in LB's is extremely weak.

dominant firms is mixed--some are leaders in innovation, others are not but may be aggressive followers. Econometric studies indicate a weak positive relationship between concentration and innovation. However, these empirical studies have a number of deficiencies, so that the amount of credibility to assign to this empirical literature is not clear. Finally, while there has been some attempt to estimate thresholds for industry concentration, these efforts are best regarded as exploratory. The results reported by the very limited number of studies that have estimated threshold are of doubtful statistical significance.

VII. DIFFUSION AND MARKET STRUCTURE

Diffusion is the final stage of the innovation process and is important because the impact of a new product or process on economic welfare depends on the speed with which the innovation spreads through the economy. Studies of diffusion have dealt almost exclusively with process innovations. They have analyzed diffusion as an information dissemination and experimentation process, in which knowledge about a new process gradually spreads to potential users as these firms evaluate and (possibly) modify the original innovation.[1]

Just as the time lag between invention and first commercial introduction of an innovation varies widely from case to case,[2] so also, diffusion varies considerably for different innovations. For example, Mansfield (1968) found that it took 15 years for half of the major pig-iron producers to adopt the byproduct coke oven,

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[1] For example, see the studies by Edwin Mansfield (1968), Industrial Research and Technological Innovation (Norton), chs. 7, 8, and 9; Anthony A. Romeo (1977), "The Rate of Imitation of Capital-Embodied Process Innovation," Economica 44:63-69; John E. Tilton (1971), The International Diffusion of Technology: The Case of Semiconductors (Brookings); Edwin Mansfield, John Rappaport, Anthony Romeo, Edwin Villoni, Samuel Wagner, and Frank Husic (1977), The Production and Application of New Industrial Technology (Norton), ch. 7: and Richard M. Duke et al. (1977), The United States Steel Industry, A Staff Report by the Bureau of Economics to the Federal Trade Commission, pp. 482-503.

[2] Edwin Mansfield (1968), The Economics of Technical Change (Norton), p. 101, drawing on the findings of an earlier study by J. Enos, reports lengthy time lags between invention and first commercial introduction for such products as nylon (11 years), television (22 years), the zipper (27 years), and the fluorescent lamp (79 years).

while only 3 years were needed for half of the major coal producers to use the continuous-mining machine.[1] Part of the delay in the spread of innovations is inherent in what Mansfield (1981, p. 33) refers to as a "learning process," which consists of evaluation and decisionmaking regarding the profitability of adopting new innovations. However, diffusion has also been reported to be influenced by market structure. While the evidence is not as extensive as one would like, the broad statistical studies by Mansfield et al. and Romeo, and the case studies by Tilton and Duke et al., suggest that high concentration or large firm size is not necessary for rapid diffusion.

Mansfield et al. (1977) and Romeo (1977) both analyze the diffusion of numerical control methods (NCMs) among 10 manufacturing industries.[2] NCMs are a means of regulating a machine tool by using numerical instructions expressed in coded form, usually on cards or tapes. As explained by Mansfield et al. (1977,

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[1] Ibid., p. 115. Mansfield attempts to explain differences in diffusion rates among innovations. One important influence is that the probability of adoption of a new innovation is smaller for innovations requiring relatively large investments. Firms are expected to be more cautious in committing themselves to expensive projects, and financing problems are also expected to be more important for large innovations. Ibid., p. 120.

[2] Mansfield and Romeo study the same industries and (probably) utilize the same data, namely, a sample of 140 firms. The industries, apparently defined more narrowly than the four-digit SIC code (Mansfield et al. 1977, p. 127, fn. 2), include (1) aircraft engines, (2) airframes, (3) coal-mining machinery, (4) digital computers, (5) farm machinery, (6) industrial instruments, (7) large steam turbines, (8) machine tools, (9) printing presses, and (10) tools and dies.

p. 127), the ". . . cards or tapes are put on a control unit which interprets these instructions, and the machine is led through some desired sequence of movements and operations." The range of possible application of NC methods is very wide, and the suitability of NC machines for different industries is also expected to vary, from one industry to another and possibly also by size of firm. Accordingly, the econometric results of the Mansfield et al. and Romeo investigations should be interpreted with caution.[1]

Romeo and Mansfield use different measures of diffusion, giving their common findings more support. Romeo's measure is derived from the number of firms that adopt NC machines, while the measure used by Mansfield et al. is based on the replacement of conventional machines by NC machines. Across the 10 industries, both studies find that diffusion was more rapid when there were more firms in the industry and when the variance of firm size in an industry was smaller. The combination of more firms and lower

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[1] According to a study by Gebhardt and Hatzold (1974) there are three types of machines: (1) manually operated, (2) NC machines, and (3) mechanically automatic machines. The first type are reported to be most suitable for small batches, while the third type are most efficient for long production runs. Therefore, the suitability of NC machines, which are said to be most efficient for medium-size batches, may vary from industry to industry, and within industries according to size of firm or type of output program. This can, accordingly, influence the maximum possible extent of use of NC machines across and within industries. These considerations apparently were not taken into account by the Mansfield et al. and Romeo studies. See A. Gebhardt and O. Hatzold (1974), "Numerically Controlled Machine Tools," ch. 3 (pp. 22-57) in The Diffusion of New Industrial Processes: An International Study, ed. L. Nabseth and G. F. Ray (Cambridge University).

variance of firm size implies a lower industry concentration. Both studies report statistically significant results (Romeo's at the .10 level) and this mitigates somewhat the fact that the sample size was so small (only 10 industries).

The opportunities opened up by an important innovation may not be fully grasped by established firms and may spur entry into the industry. An apparent deficiency of the Mansfield and Romeo contributions is their failure to consider the influence of entry and entry conditions on diffusion. In contrast, entry plays a prominent role in Tilton's case study of semiconductors.

Tilton (1971) traces the development of semiconductor technology from the invention of the transistor in 1948 (by Bell Laboratories) to the late 1960's. Tilton's work is not confined to diffusion, since he surveys the major innovational achievements sparked by the transistor. The interplay between diffusion and the development of further innovations is a major theme of the industry's development. But the rapid diffusion of technology, aided by AT&T's liberal patent-licensing policy, combined with low economies-to-scale barriers to entry and high mobility of scientists and engineers, led to the formation of a number of new enterprises, some of which achieved considerable success.[1] The

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[1] Webbink, in his report on the industry, concludes that in at least the early stages of the industry's growth, patents played a small role in inhibiting entry, in part because there was a substantial amount of unchallenged copying. He also cites the practice of "second sourcing," which probably promoted diffusion. Second-sourcing is ". . . the practice of producing a device (footnote continues)

two leading semiconductor firms in 1966, Texas Instruments and Fairchild, were new to the industry.[1] Tilton concludes that ". . . new firms with little or no previous experience in the active-components industry have been the most aggressive diffusers of new semiconductor technology (p. 161)."[2]

(footnote continued)

electrically and physically identical and, hence, interchangeable with a device produced by another company." Webbink (1977), p. 97. One of the reasons second-sourcing was important was reported to be due to the purchasing policies of the Defense Department and of large original-equipment manufacturers, which required at least two independent manufactures of any semiconductor before they would design it into their equipment (to protect the buyer against a disaster which might befall one supplier). Douglas W. Webbink (1977), The Semiconductor Industry, Staff Report to the Federal Trade Commission, pp. 96-101.

1 Texas Instruments was a small geophysical services company with annual sales of less than $6 million when it entered the semiconductor industry in 1949. Tilton (1971), p. 51. Fairchild Semiconductor was formed in 1957 by two engineers as a subsidiary of Fairchild Camera and Instrument Co. Economist, 27 December 1980, p. 65.

2 This conclusion is also supported by a more recent study of the semiconductor industry by Wilson et al. (1980). They find that large firms displayed organizational inflexibility that retarded their innovation performance. This tendency also applied to new firms (like TI and Fairchild), which had become large firms by the mid-1970's. (In 1976, TI's sales were $655 million; Fairchild's revenues had grown to $307 million.) An industry executive interviewed by Wilson and his colleagues summarized this point as follows:

> A management style that permits geniuses to contribute is important. If you were to look at why GE and RCA have failed, it is because their organization was too disciplined and unable to respond quickly to true innovation.

(footnote continues)

In summary, the evidence points in the direction that relatively small (and possibly new) firms play a disproportionate role in diffusion. However, it is important to bear in mind that diffusion is part of the innovation process and that large--even dominant--firms (in some instances) may be significant for basic research and development of inventions. Thus, as in the case of the semiconductor industry, large firms (like AT&T) and small firms may play complementary roles in innovation. This suggests that antitrust policy should be concerned with the inventive and/or development/commercial performance of large firms, while also striving to keep obstacles to new entry low, so that newcomers to the industry can stimulate the diffusion of innovations.

(footnote continued)

> What is required is a balancing act--the organization must be loose and flexible, but not too loose. In the 1960's Fairchild was too loose. Today both Intel and Mostek are killing TI in new technology, in part because TI is too structured. Fairchild also seems to be lagging behind the leaders for the same reason.

Robert W. Wilson, Peter A. Ashton, and Thomas P. Egan (1980), <u>Innovation, Competition, and Government Policy in the Semiconductor Industry</u> (A Charles River Study, Lexington [Mass.]), p. 55.

VIII. CONCLUSION

During the past 40 years, there have been an extensive number of attempts to examine the connection between innovation and size of firms and monopoly power. Prompted in substantial part by the "Schumpeterian" challenge that large firms and/or monopoly power are a stimulus for innovation, these studies have ranged from intensive investigations of particular industries to broad-scale econometric surveys encompassing hundreds of industries. To date, while this research supports a few provisional conclusions, the principal lesson to be learned from a survey of the literature is that the economic theory and measurement of innovation is still very primitive and does not usually provide a useful foundation for empirical work. When theory and measurement are deficient, we cannot expect empirical investigations to provide definitive results.

The principal conclusions that appear to be supported by empirical research are: (1) the Schumpeterian proposition that large firms and/or monopoly power are necessary for innovation does not generally hold, (2) small firms usually provide the best environment for the invention of new products or processes, although they may need the support of larger organizations to subsequently develop and market the inventions, (3) smaller firms are usually more efficient in R. & D. than larger firms when the same projects are undertaken by small and large firms, but very large R. & D. projects may not be possible in small firms, (4) atomistic industries and cartelized industries generally provide unfavorable market structures for new products or processes, and (5) after a new product or process has been introduced, small firms are typically quicker off the mark to adopt or imitate innovations and to facilitate the diffusion of innovations throughout the economy.

Our survey of the literature has paid special attention to several of the econometric contributions that estimate the relationship between innovation and firm size and innovation and industry concentration. Potentially, these broad-scale studies could identify the firm size and industry concentration most conducive for innovation. However, the significance of the statistical results of these efforts leaves open questions. More important, these studies encounter severe measurement and conceptual problems that imply that their results, even when statistically significant, may not be meaningful economically.

The methodological problems most sharply revealed by the econometric studies of innovation and market structure point to issues that warrant further research. We conclude by discussing two issues that are particularly important. One concerns the efficiency of alternative methods of organizing innovation. The innovation process is a sequence of related functional stages (from invention to commercialization and later imitation/ diffusion), but the literature usually does not compare firm size or monopoly power to individual stages and therefore does not allow for differing economies to scale in individual stages or for economies that may derive from explicitly integrating adjacent stages. In brief, it appears that too little attention is given to the organization of innovation, to the comparative efficiency of alternative organizations, and to possible obstacles of relying on the marketplace to coordinate adjacent stages.

Second, there is a question about the usual approach taken in econometric studies of innovation and monopoly power. There are two concerns. One is that monopoly power is typically measured by domestic concentration. Even setting to one side objections that may be raised against using concentration generally, there is the possibility that the wrong concentration measure is being used because the relevant geographic market is broader than the United States. Thus, for some industries a world market may be appropriate, and domestic concentration (the share of U.S. output accounted for by the leading four domestic producers) may seriously overstate monopoly power. The other issue concerns causation. Most studies treat concentration across industries as given and examine variations in innovation across industries. However, concentration and innovation may be interdependent. To the extent that this is the case, the empirical results will be biased, and the direction of the bias is unknown without further information. There have been, it may be noted, several recent theoretical contributions that treat innovation and concentration as interrelated. However, at this time empirical work in this area is just starting.[1]

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[1] Two recent efforts to test for interaction between concentration and innovation are by Stephen Farber (1981), "Buyer Market Structure and R. & D. Effort: A Simultaneous Equations Model," Rev. Econ. Stat. 63:336-45, and by Richard C. Levin (1980), "Toward an Empirical Model of Schumpeterian Competition," Yale University (unpublished).

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