Innovation of Entrepreneurial Firms

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ABSTRACT. An empirical test is provided of the effect of the degree of obsolescence on the effect of firm size and monopoly profits on a firm's ability to innovate. Recent theory suggests that innovation depends on firm size and monopoly profits only if the firm conducts product improvement as well as new product innovation. This is due to the allocation of limited entrepreneurial attention between improving current products and innovating new products. Current products are subject to obsolescence and innovation requires technological opportunities. The firm conducts product improvement as well as new product innovation only if the degree of obsolescence is sufficiently low relative to the level of technological opportunity. This theory provides an explanation for previously unexplained empirical observations. We find preliminary support for the hypothesis that product improvement reduces the positive effect of firm size on new product innovation and sufficient product improvement may reverse the negative effect of monopoly profits on new product innovations. In addition, product improvement reduces the positive effect of technological opportunity on new product innovation.

I. Introduction

The growing interest in the behavior of small entrepreneurial firms refocuses attention on the role that the entrepreneur plays in the firm and the economy (Brock and Evans, 1989; Acs and Audretsch, 1990a,b). This paper describes recent theoretical research into the function of the entrepreneur and provides an empirical test of the implications of limited attention which must be allocated between maintaining current operations and innovating new products.

One of the implications of the optimal allocation is that innovation depends on firm size and monopoly profits only if the ability to maintain current operations is high relative to the ability to innovate new products. In this case, some attention is allocated to try to improve current products through product improvement or process innovation and away from new product innovation. This diverts attention away from efforts to innovate new products. The inability to maintain the profitability of current operations is defined as obsolescence.

As the firm grows, more attention is diverted away from new product innovation in order to maintain the profitability of a growing number of current product lines. However, greater profits decreases the frequency with which each product must be improved and so increases the amount of attention allocated to new product innovation. Therefore, if the firm conducts product improvement as well as new product innovation, then new product innovation decreases with firm size and increases with monopoly profits. Product improvement is optimal only if the degree of obsolescence of current product lines is not too great. However, if obsolescence is severe, then the firm conducts no product improvement and allocates all attention to new product innovation. In this case, new product innovation is at a constant rate independent of firm size and monopoly profits.

The emphasis of this analysis is on the limits of entrepreneurial attention in carrying out the entrepreneurial role in the economy. The function of the entrepreneur has in the past been defined as risk bearer, manager, innovator and arbitrageur.

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However, the entrepreneur by necessity plays all these roles and while wearing the hat of innovator or arbitrageur, the entrepreneur is not undertaking managerial activities.

This opportunity cost of innovation embodied in the neglect of current operations has significant implications for the innovativeness and growth of the entrepreneurial firm. Because of this opportunity costs of innovation and growth, the entrepreneurial firm is limited in size but may not be limited in innovativeness. Whether an entrepreneurial firm remains innovative as it grows depends on what might be called the degree of obsolescence of its current products. The degree of obsolescence is the degree to which entry of competing products makes current products economically obsolete. The difficulty with testing this determinant of innovation is that the degree of obsolescence has not been measured before.

The limits of the growth of the firm due to this fixed input of entrepreneurial attention has been recognized before. Kaldor (1934) attributes the limits on firm size to the fixed input of the entrepreneur in his role as coordinator.[1] Among the various roles of the entrepreneur, he dismisses the role of risk bearing as the cause of a limit on firm size since the emergence of joint-stock companies makes it possible to spread risk over many individual stock holders. Kaldor also dismisses the managerial, or supervisory, role of the entrepreneur as the source of diseconomies of scale, since an army of supervisors of equal ability may be as efficient as a single supervisor. This leaves the role of "coordinator". Kaldor describes the role of coordinator as "that part of the managerial function which determines what sort of contracts should be entered into" (p. 68). This function limits the size of the firm since, even if this responsibility falls to a board of directors, in all important strategic decisions each member of the board will have to keep all alternatives in his or her mind, which is limited.[2] Thus, it is the boundedness of the entrepreneurial function of "coordination" which limits the span of control and thus firm size.

If the entrepreneur has coordinating activities which lead to new product lines and supervisory responsibilities of overseeing the production processes of these products, then one would expect that the number of products the entrepreneur can enter into is limited by the number of products which the entrepreneur can supervise. This is the problem addressed in the model developed in Gifford and Wilson (1995) and Gifford (1992a). This model suggests that if the degree of obsolescence is sufficiently low, then the entrepreneur conducts both new product innovation and supervises product improvement. In this case new product innovation decreases with firm size and increases with monopoly profits. However, if the degree of obsolescence is sufficiently high then the entrepreneur conducts only new product innovation and new product innovation is independent of both firm size and monopoly profits.

Thus the degree of obsolescence has significant implications for the *Schumpeterian Hypotheses* (Schumpeter, 1934) of the relationship between innovation, on the one hand, and firm size and monopoly profits on the other. In addition, the bound on firm size implies that Gibrat's law (Gibrat, 1931) of proportionate effect does not apply to the entrepreneurial firm. Finally, if the degree of obsolescence is sufficiently low, then the size of the firm is bounded away from a larger firm size which would be more profitable if the optimal firm size were derived without modeling the growth process itself.[3]

The purpose of this paper is to test the effect of the degree of obsolescence on the rate of new product innovation and its significance for tests of the *Schumpeterian Hypotheses*. The task of carrying out this test is made difficult by the fact that the degree of obsolescence is difficult to measure. However, since the firm conducts product improvement only if the degree of obsolescence is low, we test the effect of product improvement on the dependence of new product innovation on firm size and monopoly profits. Although these preliminary results are weak, they suggest that product improvement reduces the positive effect of firm size on new product innovation and at least partially offsets the negative effect of monopoly profits on new product innovations. This suggests that the degree of obsolescence may be an important determinant of the validity of the *Schumpeterian Hypotheses*. In addition, product improvement decreases the effect of technological opportunity on new product innovation, which may explain previous mixed results on this relationship.

The main focus here is the decision to attempt new product innovation at all, considering the opportunity cost embodied in the neglect of current operations. By focusing on the implications of limited attention, the model ignores other aspects of the innovation production process, such as patent races, optimal timing of innovation and other decision problems which must be addressed once the firm has decided to try to innovate a new product. The analysis proceeds as follows. Section II briefly outlines the model of the entrepreneurial firm and describes the optimal innovation, firm size and growth rate of the firm. Section III interprets the implications of the model for new product innovation and relates them to the empirical literature. Because of the significance of the degree of obsolescence for the results of the model, section IV describes various possible sources of measures of the degree of obsolescence. Section V presents a preliminary and indirect empirical test of the significance of obsolescence for the *Schumpeterian Hypothesis*.

II. The entrepreneurial firm

Following Kaldor, a firm is defined as a "production combination possessing a given unit of coordinating ability".[4] A firm may be composed of any number of current projects. A current project is denoted by the number of periods since it was last inspected by the entrepreneur. Call this the "age" of the project. Let the sequence $a \equiv \{a_i\}_{i \in Z_+}$ denote the projects currently held by a firm, where a_i denotes the number of current projects of age i. Let a be an element of A, the set of all such sequences. Current projects are either functioning or failed. A project of age i is functioning with probability $p_i = \gamma^i$, where $(1 - \gamma) = \phi$ is the one period probability of failure. The current returns to a project of age i are $r_i \equiv p_i g - (1 - p_i)b$ where, $g > 0$ and $b > 0$. Denote the number of current projects by $N(a) = \sum_{i=1}^{\infty} a_i$. The current state of the firm is completely described by a.

During any period, the entrepreneur may inspect a new project for possible adoption or inspect a current project to determine whether it has failed. If a current project has failed, it can be restored to a profitable state with probability ρ. Thus, if a current project is evaluated, it is good in the next period with probability $\rho_i = \gamma^i + (1 - \gamma^i)\rho$. If a new project is evaluated, it is good with probability ρ_o and adopted. Let $u \in Z_+$ denote the evaluation decision, where $u = 0$ if a new project is evaluated and $u = i > 0$ if current project i is evaluated. Note that $u = i$ implies $a_i = 1$. The entrepreneur may also freely discard any number of current projects. Let $q \equiv \{q_i\}_{i \in Z_+}$ denote the retained projects, where $q \in A$, $q_i \leq a_i$ and $q_u = 1$ for $u > 0$. The current returns to the firm in state q after discard is $R(q) = \sum_{i \in Z_+} r_i q_i$.

The transition of the state takes place after current projects have been discarded, a project, new or current, has been evaluated and adopted or restored, or not, and all current projects fail with probability ϕ. To denote the adoption or restoration of a project, define $y + a = \{\max(y_i, a_i)\}_{i \in Z_+}$, for $y, a \in A$. Let e_1 denote the sequence with a one in the first position and zeros elsewhere. Then $e_1 + a$ is the addition of a project of age one to the sequence a of projects. This project of age one may be a newly adopted project or a newly restored current project. To denote the discard of a current project, let q_{-j} denote the sequence q' with $q'_i = q$, $i \neq j$, and $q_j = 0$. Thus q_{-j} denotes the deletion of project j. To denote the aging of projects, define the operator $S{:}A \to A$ such that $(Sq)_i = q_{i-1}$ and $(Sq)_1 = 0$. That is, the age of each retained unevaluated current project increases by one unit each period. Then the state in the next period is $e_1 + Sq_{-u}$ with probability ρ_u and is Sq_{-u} with probability $1 - \rho_u$.

If $R(q)$ is bounded and returns are discounted by $\beta < 1$, then there exists a stationary optimal policy $\lambda(a)$ which prescribes the decision rules $\{u_\lambda(a), q_\lambda(a)\}$. The optimality equation for the entrepreneur is

$$F(a) = \max_{q,u}\{R(q) + \beta[\rho_u F(e_1 + Sq_{-u}) + (1 - \rho_u)F(Sq_{-u})]\}.$$

The optimal policy takes two forms:[5] 1) an age-inspection rule which prescribes that each current project is evaluated periodically and a new project is evaluated if no current project requires evaluation; and 2) an innovate-and-discard rule which prescribes that current projects are discarded, unevaluated, upon reaching a critical age and a new project is evaluated every period.

To describe the optimal policy λ, let V_i denote the discounted expected returns to a project of age one which is discarded at age i. Then $V_i = \sum_{v=1}^{i} \beta^{v-1} r_v$. Let d denote the i which maximizes V_i. Then $r_d \geq 0$ and $r_{d+1} < 0$. Let W_i denote the incremental returns from a current project of age one which is evaluated every i periods instead of evaluating a new project. Then $W_i = \sum_{s=0}^{\infty} \beta^{si}(\rho_i - \rho_o)^s V_i = V_i/[1 - \beta^i(\rho_i - \rho_o)]$. Let c denote the value of i which maximizes W_i. Let A^s denote the set of all sequences $\{a_i\}_{i \in Z_+}$ such that $a_j = 0$ for $j > s$. The optimal policy is as follows:

i) If $V_d > W_c$, then, for all $a \in A^d$, $\lambda = \delta$, where $u_\delta(a) = 0$ and $q_\delta(a) = a_{-(d+1)}$.
ii) If $V_d \leq W_c$, then, for all $a \in A^c$, $\lambda = \psi$, where

$$u_\psi(a) = \begin{cases} c & \text{if } a_c = 1 \\ 0 & \text{otherwise} \end{cases}$$

and $q_\psi(a) = a$.

The following statements characterize the implications of the optimal policy.

1) Firm size is bounded by c if $V_d \leq W_c$, and by d if $V_d > W_c$ and $c \leq d$. That is, if the innovate-and-discard rule is optimal then the bound on firm size is greater than if the age-inspection rule is optimal.
2) If $V_d \leq W_c$, then $\rho_c \geq \rho_0$. This implies that, if effort to maintain current projects is optimal then the probability of restoring a current project is greater than the probability of adopting a new project.
3) If $V_d \leq W_c$, then c i) is non-decreasing in ρ_0, ii) is non-decreasing in $(1 - \rho)$, and iii) is non-decreasing in g/b. When the optimal rule is to evaluated current projects then the bound on firm size is increasing in the level of technological opportunity, the degree of obsolescence, and monopoly profits.
4) If $V_d \leq W_c$, then for any $a \in A_c$, there are unattainable states $a' \in A_d$ for which $N(a') > N(a)$ and $F(a') > F(a)$. If the age-inspection rule is optimal, then there are larger, more valuable, firm sizes which are unattainable under this rule.
5) If $\rho = 1$, then $V_d \leq W_c$ and firm size approaches the steady state $a^c \in A_d$, in which there are c projects of ages 1 to c, and $u(a^c) = c$. If maintenance of current operations is certain, then current projects will be evaluated and a steady state is reached in which a current project is evaluated every period and new product innovation ceases.
6) If $V_d \leq W_c$, then the rate if innovation decreases with firm size and increases with monopoly power.
7) If $V_d > W_c$, then the rate of innovation is constant and equal to ρ_0, the level of technological opportunity.
8) The rate of growth decreases with age for young firms.
9) For any $\rho_0 < 1$, there is a ρ large enough such that $V_d \leq W_c$. For any level of technological opportunity less than certainty, there is a level of endurance for which evaluating current projects is optimal.
10) For any $\rho < 1$, there is a ρ_0 large enough such that $V_d > W_c$. For any level of endurance less than certainty, there is a level of technological opportunity for which the innovate-and-discard rule is optimal.

Both rules imply bounds on firm size which depend positively on the level of technological opportunity. The age-inspection rule ψ implies a smaller bound on firm size than does the innovate-and-discard rule δ, even though current projects may never become obsolete. The age-inspection rule also implies a rate of innovation that is decreasing in firm size and increasing in monopoly profits, while the innovate-and-discard rule implies a constant rate of innovation. Thus, the validity of the *Schumpeterian Hypotheses* depends upon which rule is optimal. Since this depends upon the degree of obsolescence, the most significant result is the effect of the degree of obsolescence on the innovative ability of the firm and its dependence on firm size and monopoly profits.

To make this clear, call ρ the endurance of current projects; that is, the probability that a failed current project can be restored through product improvement upon evaluation. Then $(1 - \rho)$ is the degree ofobsolescence. The age-inspection rule holds if endurance is sufficiently high (the degree of obsolescence is low) relative to the level of technological opportunity, ρ_0. For any level of technological opportunity, there is a level of the degree of obsolescence low enough that the age-inspection rule holds. If the degree of obsolescence is sufficiently low, then innovation decreases with firm size and increases with monopoly profits and new product innovation is negatively related to product improvement. Otherwise, innovation is constant and equal to the level of technological opportunity and there is no product improvement. Thus, even though two firms may face the same technological opportunity for innovation, the same monopoly profits and the same frequency of failure, if the degree of obsolescence of its products is sufficiently greater for one firm than the other, the first firm may have a constant rate of innovation independent of firm size and monopoly profit while the rate of innovation of the other firm may increase with monopoly profits and decrease with firm size.

The intuition of this result is that current projects less subject to obsolescence represent a higher opportunity cost to the innovation of new products. If endurance is high relative to the level of technological opportunity, then this opportunity cost is high enough to distract the entrepreneur from evaluating new projects. On the other hand, innovation represents an opportunity cost to maintaining current projects. If the level of technological opportunity is sufficiently high relative to endurance, then this opportunity cost is high enough to distract the entrepreneur's attention from maintaining current projects. A firm with a sufficiently high endurance of its products, relative to the level of technological opportunity, eventually reaches a level of operation at which maintaining valuable current operations distracts the entrepreneur from efforts to innovate and grow. A low endurance reduces this opportunity cost of innovation and results in a high level of innovative effort and output, although firm size remains bounded.

III. Interpretation of the model

To relate the results of the model to the empirical literature, it is necessary to interpret the model and indicate how the values of the parameters and variables may be estimated. The endogenous variables of the model include the number of current projects, which represents firm size and may be proportional to employment or sales, and changes in firm size, which reflect firm growth. The crucial aspect of firm size in the model is that increases in firm size may increase the demands on the entrepreneur's attention and that firm size can reach a critical maximum level at which innovation ceases. This should be kept in mind when choosing a measure of firm size.

Also among the endogenous variables are the two forms of innovation, new product innovation and current product improvement. New product innovation is the adoption of an evaluated new project. Current product improvement or process innovation restores current projects that have failed. Process innovation and product improvement affect current projects while product innovation occurs only with new projects. Note that in the model, the rate of process innovation is negatively related to the rate of product innovation. That is, they are alternative activities. The rate of evaluation of new projects reflects innovative effort, usually measured by R&D expenditures. The rate of adoption of new projects is the innovative output, usually measured by patents numbers.[6] The ratio of the rate of evaluation to the rate of adoptions reflects the productivity of R&D expenditures. This is a common measure of technological opportunity.

The distinction made here between product innovation and process innovation is not uncommon. For example, Scherer (1982) states that "A new process in the sense used here is a technical improvement in one's own production methods, whereas a new product is an improvement sold to others, either to other business enterprises or to consumers" (p. 227). However, in the analysis above, the significance of the distinction is that process innovations increase productivity while product innovation changes the total mix of goods and services available. This has significant implications for the measurement of real growth (Scherer, 1978). However, as pointed out by Gomulka (1990) this distinction is not always clear cut. A new product innovation requires new combinations of inputs that constitute process innovations. And process innovations often result in modifications of the product characteristics to such an extent as to imply new product innovation. In addition, a product innovation for one firm may result in process innovation by a firm downstream.

The distinction between product and process innovation made in the analysis of this paper avoids these issues by emphasizing the implications for the demands on the entrepreneur's attention. Product innovation adds to the number of subunits of the firm which would require the entrepreneur's attention to maintain their profitability, if those efforts were justified. On the other hand, process innovation, though it may increase the production of a current product, does not increase the demands on the entrepreneur's time, even if maintenance efforts are justified.

The composition of innovative effort and inter firm differences have been empirically tested only recently. However, most of these investigations do not distinguish between product and process innovation. The first empirical investigation of the determinants of the composition of R&D expenditure was provided in Mansfield (1981). Mansfield found that inter firm differences in the composition of R&D increased with the concentration of the industry. However, Mansfield distinguished between basic, applied and new product or process innovation but not between product and process innovation. Scott (1984) found significant firm-specific influences on the level of R&D spending, but did not consider its composition. Link (1982) tests the effects of profits, diversification, concentration, federal R&D spending and ownership control on the mix of innovative effort between basic research, applied research and development.

Other empirical studies of process innovation or product improvement have been conducted in Kraft (1990) and Lunn (1986, 1987). However, these studies compare the determinants of process innovation which occurs in the development of new products. That is, process and product innovation are complementary activities. Mansfield (1981) considers the effects of size and concentration on the composition of R&D but lumps new product and new process innovations in the same category. Link (1982, 1985) distinguishes between basic R&D, applied R&D and development. Link (1985) estimates separate regression models for new product innovation and for process innovation. The coefficients of the various determinants have opposite signs in the two regressions, although these coefficients are insignificant. To capture the results described above for the negative relationship between product innovation and product improvement, measures of R&D activity must be separated by whether it is related to new products or the improvement of established products of the firm.

There are, however, two empirical investigations of the composition of innovative activities between product and process innovation and the dependence of this composition on firm characteristics. Not surprisingly, neither specifically tests the results of the above analysis. Pavitt (1984) explores sectoral influences on the level and composition of firms' innovative activity. He finds that the mix of product and process innovation depends on the source of technical change and the scale of production. For example, in traditional manufacturing, such as textiles, technical change comes predominantly from the suppliers of equipment. These firms conduct mostly process innovation using the product innovations of other firms. Large scale production intensive firms, such as motor vehicles, tend to produce their own process innovations, and few product innovations. However, small scale mechanical and instrument engineering firms tend to concentrate on product innovations for use in other sectors, such as large scale production intensive firms. Science based firms, such as chemicals and electronics, produce a mixture of process and product innovations. Therefore, large, scale intensive producers emphasized process innovation, either produced in house or provided by suppliers. However, small-scale high tech firms emphasize new product innovation and are not concerned with producing the innovations in large scale operations themselves.

Link (1985) also considers the determinants of changes in the mix of product and process innovation, as well as basic and long term R&D from 1970 to the early eighties. Among the determinants investigated are changes in company strategy from defensive to offensive, and vice versa, the existence of a central lab, and changes in diversification. Only the classification of the firm's product is significant for the mix of product and process innovation. Firms in producer goods industries are found to increase their process innovation over time while those in consumer goods industries increase their product innovation over time. In addition, the coefficients for all the variables for new product innovation have the opposite sign from the coefficients for process innovation.

The adoption of new projects can also be interpreted as the acquisition of other firms or as expansion of products into new markets and/or through new plants, as long as projects are acquired one at a time. These alternative interpretations are possible because the R&D process itself is not modeled explicitly. Thus the model can be used to explain growth (or lack thereof) through any activity which requires the entrepreneur's attention.[7]

The parameters of the model also require interpretation. The model of the allocation of entrepreneurial attention contains three dimensions of competition: 1) monopoly profits from current projects, 2) the frequency of failure from the entry of competition, and 3) the degree of obsolescence. Because of these three measures of competition, the vagueness of the term "monopoly power" is avoided. Monopoly power can be reflected in high current profits, entry barriers or a low degree of obsolescence. Monopoly profits reflect the degree of price competition from current competitors. This is usually captured by concentration ratios. The frequency of entry of competition is the per-period probability of failure of a current project. Failure can be due to the introduction of an innovation or the imitation of the current product by another firm, either within the industry or not. Measures of firm entry are not sufficient. Measures of innovations themselves is the best way of capturing this form of entry (Acs and Audretsch, 1990b).

The third dimension of competition is the degree of obsolescence which is the probability of failing to restore the profits of a current project through product improvement or process innovation. The degree of obsolescence reflects the extent to which efforts at product improvement or process innovation fail. Firms with a lower degree of obsolescence conduct product improvement. For example, Link (1985) shows that firms in producer goods industries have increased their process related R&D while firms in consumer goods industries have been increasing their new product R&D. The implication of the analysis above is that producer goods industries have a lower degree of obsolescence than consumer goods. Measures of the degree of obsolescence are discussed in the next section.

The probability of adopting an evaluated current project represents the level of technological opportunity for innovation and so is an indication of R&D effectiveness in producing new products. It can be increased by scientific breakthroughs that have applications in the industry and by spillover effects from the R&D of other firms and from government expenditures on R&D. Questions concerning the productivity of R&D expenditures and the relative value of basic research, versus other research, have been tested empirically (Griliches, 1986).

It should be noted that the degree of obsolescence and the level of technological opportunity may be correlated. The success of product improvement or process innovation may increase or decrease with the level of technological opportunity. This depends on whether new technological opportunities can be adapted to current products. If new technologies can be adapted, then the degree of obsolescence may decrease and product improvement may increase with technological opportunities. However, if these technological improvements cannot be adopted, then the degree of obsolescence may increase and product improvement cease. This interaction between technological opportunity and the degree of obsolescence is not analyzed in the current paper but should be considered in future research, since this interaction may affect the evolution of the industry.

IV. The *Schumpeterian Hypothesis* and the degree of obsolescence

The model of Section II has significant implications for the role of obsolescence in testing the *Schumpeterian Hypotheses* of the relationship between innovation, on the one hand, and firm size and monopoly profits on the other. Therefore, this section describes this literature and the implications of the model for future research.

The empirical literature on the *Schumpeterian Hypothesis* can be divided into two groups: that investigating the effects of monopoly profit and that investigating the effects of firm size on innovation.[8] The results on the effect of monopoly profit on innovative effort are inconclusive. Monopoly profit appears to be necessary but not sufficient to induce R&D expenditure. The results appear to depend on some measure of technological opportunity. The effect of monopoly profit on innovative output is even less satisfactory. Kamien and Schwartz (1982, p. 93) conclude that "even 'technological opportunity class' may not be enough to sort out the underlying relationship sought; a deeper study of components of industrial structure may be required". The implication of the allocation of attention is that it is not just the absolute level of technological opportunity that matters, but its size relative to the endurance of current projects.

Recent empirical investigations of the relationship between innovation and monopoly profit have found that this relationship is more complex than previous tests have assumed. For example, Levin *et al.* (1985) offer stylized facts concerning the effects of concentration on R&D and innovation. They show that these effects are mitigated by the inclusion of the effects of technological opportunity, appropriability and imitation. They conclude that "R&D spending appears to be encouraged in youthful industries where a strong science base is present and where the government makes substantial contributions to technological knowledge" (p. 23).

In tests of the effect of firm size on innovative activity, there is little support found for the hypothesis that large firms exhibit greater innovative effort or produce more innovative output. Kamien and Schwartz (1982, p. 103) conclude that "R&D activity measured either by input or output activity, appears to increase with firm size up to a point, then level off or decline". There is no accounting for inter industry differences. It appears that the hypothesis may be true up to some firm size and then fail. Until now, there was, however, no explanation for this result in the theoretical literature.

This result is seen again in Cohen, Levin and Mowery (1987). They find that firm and business unit size explain only a "negligible fraction" of the variance in R&D while industry characteristics, such as technological opportunity, appropriability and demand conditions, are significant in explaining R&D intensity. Their results do suggest, however, that business unit size does affect the probability of conducting R&D and they conclude that, if firm size matters at all, it matters only in industries with low technological opportunity.

Acs and Audretsch (1988) interpret their results on the effect of firm size on innovation to imply that "the greater extent to which an industry is composed of large firms, the greater will be the innovative activity, but that increased innovative activity will tend to emanate more from the small firms than from the large firms" (p. 687).

The lack of a conclusive test of the *Schumpeterian Hypotheses* may be due to the fact that the hypotheses themselves are insufficiently well formulated. Acs and Audretsch (1990b) suggest that "[t]heory should perhaps develop further how firms of varied size may have disparate innovative responses to different economic environments, rather than focusing on which firm size is uniquely endowed to best promote technological progress" (p. 59). One of the difficulties with formulating a coherent model of innovation is the ambiguity of the arguments behind the *Schumpeterian Hypotheses* of the effects of firm size and monopoly profits on innovation.

The motivations to innovate from monopoly profit in the market for the innovated good are unambiguous. However, the effect of monopoly profit in the current product markets is ambiguous. The motivations come from the financial advantages stemming from current monopoly profits. These profits allow the firm to internally finance its R&D projects which may be advantageous for two reasons. First, it may be very difficult to convince an external source of financing of the probability of success of the project because of the vast amount of knowledge required to properly evaluate its prospects. The second reason external financing may be difficult is in the development stage. If the invention cannot be patented then the information required to obtain external financing may expose the invention to imitation. However, there are also disincentives to innovate stemming from monopoly profits in the current market. Current monopoly profit is an opportunity cost if innovation requires resources to be diverted from current production or if the innovation is a substitute in use for the current product.

Firm size is also a source of both motivations and hindrances to innovation. Motivations stem from several aspects of firm size. A large operating staff (non research) may be better able to market a new product and/or to perceive market demand for innovations. A large research staff may have the advantages of a greater specialization of its members and greater ability to engage in parallel projects and to exploit specialized equipment. Product diversification of large firms provides greater incentive to undertake R&D projects which have a large number of expected applications. Diversification also allows a large firm to better exploit the unforeseen outcomes of R&D. This reduces the risk involved in R&D. High sales volume may imply a large distribution system for the innovation. Large assets may provide the ability to undertake the high risk involved in R&D.

Large firm size can also result in hindrances to innovation. The effectiveness of communication between operating staff and research staff can diminish with firm size. A large research staff may have difficulty viewing the research project as a whole (with proper gestalt) and may have problems coordinating the activities of its members. Also, large operating and research staffs may result in costs due to monitoring their activities. Extensive assets of a firm represent opportunity costs if the innovation causes resources to be diverted from these assets.

To resolve these ambiguities, the conditions affecting innovation can be separated into two types: demand-pull and technology-push. Demand-pull manifests itself in greater expected revenues from innovation. Some examples of demand-pull effects are a large market and competitive bidders for the innovation. Technology-push manifests itself in the increased ability to innovate successfully. The only motivation or disincentive mentioned above which is of the demand-pull type is monopoly profit in the market for the innovated good. This is a demand-pull effect because it affects the market value of innovations, not the ability of a firm to produce innovations. The demand-pull effect has an unambiguous effect on innovation. Greater monopoly profit in the market for the innovation has an unambiguously positive effect on the expected revenues from innovation.

However, most of the technology-push conditions have ambiguous effects on innovation. Monopoly profit in current markets can imply financial advantage or opportunity costs. There may or may not be economies of scale in research staff. A large operating staff may better perceive market demand and be better able to market the innovation but be unable to communicate well with the research staff. Diversification can result in a greater ability to exploit the results of R&D but may also result in obsolescence of current products. Assets can allow greater risk-taking or represent opportunity costs. Because of these ambiguities, generalizations, such as monopoly profit and large firm size promote innovations, are unjustified. The effects of these conditions depend on the particular circumstances of the firm and a more detailed model of the determinants of innovative ability is needed.

The model presented above is an attempt to address these problems by modeling the effect of the scarce resource of attention on the innovative ability of the firm. The results offer an explanation of the empirical observations above. One implication of the model is that it is not the absolute level of technological opportunity which affects innovation, but the relationship between technological opportunity and the degree of obsolescence. In youthful industries with a strong science base, the level of technological opportunity may be sufficiently larger than the degree of obsolescence to promote innovation. In addition, innovation does decrease with firm size, but only if the degree of obsolescence is sufficiently low or technological opportunity is sufficiently low. The observation that greater innovation takes place in markets with large firms but is performed by small firms is consistent with the result that industries with high technological opportunity will grow large firms but with low obsolescence, smaller firms in those industries will be more innovative.

The model above implies that the effects of firm size and monopoly profits on product innovation depend on the degree of obsolescence. However, one must be careful how the term obsolescence is used. It is clear that the electronic calculator made the slide rule obsolete. In this case, slide rules were discarded from the producers' product lines. The technology of electronic calculators could not be adopted to the design of slide rules. One might also legitimately say that the IBM-PCXT made the IBM-PC obsolete. However, the IBM-PC continued to be produced by IBM and cloned by other companies. Therefore, it was not discarded from firms' current product lines. In everyday usage, the term obsolete often means only that the product is no longer on the cutting edge of technology. This is technological obsolescence. However, in the analysis above, a product is not economically obsolete as long as it is produced. Obsolescence in this analysis refers to economic obsolescence, not technological obsolescence.[9]

The measure of the degree of obsolescence may depend on the scale of the analysis. Obsolescence can result from business cycles or such technological phenomena as the industrial revolution and the current information revolution. In some cases obsolescence may be an economy-wide, or worldwide, characteristic. Alternatively, obsolescence may be limited to a single industry which exhibits product innovations that make previous products obsolete. The degree of obsolescence is the inability to improve current products or processes after the entry of new products of other firms cause the product to fail. However, this concept is not a common one in economic literature. It is probably most closely related to Schumpeter's "creative destruction". However, in Kirchhoff (1989), creative destruction is measured by small firm entry. Clearly, entry is one source of obsolescence, but only if the entry makes successful product improvement, or leap-frogging, unlikely. Also, new firm entry is not necessary for new product entry which causes the failure of a current product. Expenditure on process innovation or product improvement would indicate the level of effort towards restoring the profits of current products. What is needed is an indication of the effectiveness of these efforts.

A related concept is the appropriability of profits. If failure of a current product is due to another firm's innovated product which cannot be imitated and adapted to the failed current product, then the degree of obsolescence is high. Therefore, the degree of obsolescence depends positively on the appropriability of the returns to the entrant's innovation; that is, the ability of the competitor to capture the value of its R&D output. This is increased by the protection offered by patents and also the degree of brand loyalty.[10] The adoption of new technologies would indicate the extent to which current products can incorporate new technologies and remain viable.[11]

Since the concept of obsolescence has not been explicitly modeled before, empirical studies containing measures of it are not available. However, the issue of the degree of obsolescence has been addressed in other contexts. One source of obsolescence is from competition from within an industry which exhibits product innovations that make previous models of the product obsolete. A possible measure of inter industry differences in the degree of obsolescence is offered by the taxonomy of Abernathy and Clark (1985). They distinguish among innovations along two scales. The first scale, a measure of "market transilience", indicates the degree to which an innovation affects current markets. The second scale, the "technology transilience" indicates the degree to which the innovation makes current products obsolete, what Abernathy and Clark call Schumpeterian creative destruction. In the model above, a market susceptible to obsolescence must face entering innovations, and so must exhibit market transilience. The degree of obsolescence would be reflected in the technology transilience, and thus the inability of the firm to adopt the new technology. New products which result in the obsolescence of current products are what Abernathy and Clark call revolutionary innovations. These are innovations which are introduced into established markets. Regular innovation involves applying established technologies to existing markets and is represented by process and product improvements. Examples from the auto industry are described to illustrate these concepts.

Another indication of the degree of obsolescence is provided by the literature on Schumpeterian business cycle theory. One concern of this literature is whether innovations appear in bunches during depressions, which then bring an end to the depression. For example, Kleinknecht (1987) points out that during depressions, the values of current products decline and firms are motivated to taking on more risky R&D, even though funds are drastically reduced. This is evident in the foundation of new research labs from 1929–1936. In this case, firms shift their concern from process innovation to product innovation. As Kleinknecht points out: "Why should an enterprise deal with the uncertainties and costs of introducing radically new products on the market as long as its established products can easily be sold? Is it not more attractive to restrict R & D activity to the gradual improvement of existing products?" (p. 63). The model above implies that innovations should appear in bunches during depressions because the degree of obsolescence is sufficiently high. Firms cease improving current products (process innovation) and concentrate on innovating new products.

Another source of obsolescence is the user-specific nature of the products of the firm. For example, Pavitt (1984) provides a taxonomy which compares the relative importance of product versus process innovation as a proportion of all innovations produced by firms in different sectors. He finds that product innovation is high in small mechanical and instrument engineering firms while process innovations are more important in large, more scale-intensive enterprises. This suggests an interpretation of the degree of obsolescence as the degree of idiosyncratic trade. These two sectors might be described in terms of the above model as follows. The specialized suppliers produce custom instruments for specific tasks for their customers which are not mass produced and so are discarded and new projects (new customers) are frequently evaluated. Because of a high degree of obsolescence (idiosyncratic trade), in that instruments developed for one use are not suitable for another, the firm uses an innovate-and-discard rule and the bound on firm size is small. Scale intensive firms face a low degree of obsolescence resulting in the firm using the age-inspection rule with a large bound on firm size. The firm eventually grows large and concentrates on process improvement.

These various sources of measures of obsolescence are offered in the hope that useful data may be available in some of these areas. Since the model is not specific about the source of the obsolescence, it provides no guidance for specific measurements of obsolescence. This is also true for the nature of the "projects", which here are interpreted as product lines but may also be interpreted as other activities.[12] The lack of characterization of these projects, the innovation process and the source of obsolescence is by design and makes the model broadly applicable.

V. Empirical results

Perhaps, the greatest challenge facing researchers who undertake to measure innovation and its determinants has been the lack of data. The data base used in this study was constructed by combining two sources of data: the U.S. Small Business Administration Data Base, and the Business Week Survey of company-financed R&D expenditures. While the first data source provides one of the most important and unique direct measures of innovative activity (Acs and Audretsch, 1988, 1993) the second source provides company data on R&D expenditures, sales, and profits. The Business Week data, which incorporates 95 percent of the total company-financed R&D expenditures in the U.S., have been used in previous studies (Soete, 1979; Acs and Audretsch, 1991). In particular we were able to match these data for 634 firms.

The measure of a firm's innovative activity is the number of innovations recorded by the U.S. Small Business Administration in 1982 which were attributed to that firm. This prevents the problems associated with using R&D expenditures or patents as the measure of innovation. The data base was created by recording product innovations and product improvements in new product sections of technology, engineering and trade journals in 1982. Although these data are described in detail in the Acs and Audretsch (1990b) study, several points should be emphasized. First, the data base consists of 8,074 innovations and includes service firms as well as manufacturing firms. Second, based on a sub-sample of innovations from the entire data base, it was determined that the innovations recorded in 1982 were the results of inventions made, on average, 4.2 years earlier. Third, each innovation was classified by Edwards and Gordon (1984) according to the following levels of significance: (1) the innovation established an entirely new category of product, (2) the innovation is the first of its type on the market in a product category already in existence, (3) the innovation represents a significant improvement in existing technology, and (4) the innovation is a modest improvement designed to update an existing product.

While none of the innovations in the sample were in the first level of significance, 80 were in the second level and 576 in the third level, and 4,282 were classified in the fourth level. To provide a test for any biases that might arise in the assignment of the innovation significance classification, The Futures Group undertook telephone interviews based on a subset of 600 innovating companies that were randomly selected. The respondents of the interviews tended to rate their innovation as being more important than the rating assigned by The Futures Group. Then the innovation data were classified into two groups. Significance level two and three were combined as new product innovations, and significance group four was identified as product improvements.

Since the firm conducts product improvement only if the degree of obsolescence is low, we test the implications of the degree of obsolescence for the *Schumpeterian Hypotheses* by testing the effect of product improvement on the dependence of new product innovation on firm size and monopoly profits. The effect of product improvement on new product innovation can be expressed by the following function and the signs of its second derivatives:

$$y = f(i, s, m, t) \quad \text{where } f_{si} < 0, \quad f_{mi} > 0 \qquad (1)$$

The left hand side variable, y, is the rate of new product innovation, i is the rate of product improvement, s is firm size, m is monopoly profit, and t is technological opportunity. The signs of the cross partial derivatives, f_{si} and f_{mi}, reflect the hypothesis that for firms facing a sufficiently low degree of obsolescence to warrant conducting product improvement, new product innovation is decreasing in firm size and increasing in monopoly profits. As described above, the 1982 innovations are the result of inventions made, on average, in 1977. Following the example of Scherer (1965), we assume a seven-year lag exists between the implementation of a firm's strategy, such as expenditures on R&D, and the subsequent innovation. Thus, the 1982 innovations correspond roughly to 1975 firm profits, R&D and technological opportunity.

To test the hypotheses, we estimate the following reduced form model:

$$\begin{aligned} NP_i = B_0 &+ B_1PI_i + B_2FS_i + B_3MP_i \\ &+ B_4TO_i + B_5FS \times PI_i \\ &+ B_6MP \times PI_i + B_7TO \times PI_i + u_i. \end{aligned} \qquad (2)$$

The dependent variable NP is the new product innovation rate in 1982, defined as new product innovations of firm i divided by total firm innovations (new product innovations and new product improvements for firm i). Since NP is a limited dependent variable that takes values between zero and one, the model will be estimated using a Tobit model. PI is the number of new product improvements in 1982. FS is firm size, employment, defined as firm size for firm i in industry j divided by the employment of the largest firm in industry j in 1975.[13] MP is defined as monopoly profit and is measured as net income in 1975 divided by total company sales in 1975. TO is technological opportunity measured as company research and development expenditures in 1975 divided by total company sales in 1975.

Three interactive terms are also included in the model to capture the effect of obsolescence on new product innovation indirectly through the effect of product improvement. $FS \times PI$ measures the interaction of new product improvement and firm size on innovation and is expected to be negatively related to innovation. This captures the effect of an increasing number of activities competing for the entrepreneur's attention as firm size approaches the maximum if the firm conducts product improvement as well as new product innovation. Product improvement should further reduce the negative effect of firm size on new product innovation.

$MP \times PI$ is the interaction of product improvement and monopoly profits and is expected to be positively related to innovation. The larger are monopoly profits, the less frequent are efforts to improve current products and the larger is the number of activities which the entrepreneur can undertake. If the firm conducts product improvement as well as new product innovation, product improvement should add a positive component to the effect of monopoly profits on new product innovation.

$TO \times PI$ is the interaction of new product improvement and technological opportunity. Greater technological opportunity increases the number of successful innovations, increases the number of product lines which can be maintained with product improvement and can eliminate product improvement altogether. The first effect implies that, given the amount of attention allocated to evaluating new projects, greater technological opportunity increases the number of successful innovations. The second effect implies that, for firms conducting product improvement, greater technological opportunity increases the amount of attention available for new product innovation. The third effect implies that all attention is allocated to new product innovation. All of these effects imply that the total effect of technological opportunity on new product innovation is positive.

However, for a firm which conducts product improvement less attention is allocated to new product innovation, and so the first effect on successful innovations has fewer attempted innovations to operate through. In addition, this firm does not benefit from the third effect, since it continues to improve products. Therefore, the theoretical prediction is for a negative sign for B_7.

Using the ratio of new product innovation to total firm innovation, including product improvement, in 1982 as the dependent variable, the Tobit regression model is estimated for 632 firms.[14] Our data includes the universe of all firms which do R&D, and therefore have the potential to innovate. Some firms innovate and others do not. Therefore, we assign a zero value to non-innovating firms and a positive value to innovating firms. The large number of non-innovating firms calls for a Tobit analysis. For the Tobit model, the regression results are[15]

$$\begin{aligned} NP_i = {} & \underset{(-8.705)^{**}}{-88.433} + \underset{(5.618)^{**}}{8.543\, PI_i} + \underset{(1.860)^{*}}{28.259\, FS_i} \\ & \underset{(-2.388)^{**}}{-\,3.983\, MP_i} + \underset{(4.421)^{**}}{8.275\, TO_i} \underset{(-1.430)}{-\,2.504\, FS \times PI_i} \\ & + \underset{(2.108)^{**}}{1.292\, MP \times PI_i} \underset{(4.168)^{**}}{-\,0.839\, TO \times PI_i} \end{aligned} \tag{3}$$

The positive and statistically significant coefficient of PI suggests that product improvement is an important determinant of innovation even after controlling for other major influences. However, the total effect of PI is actually measured by

$$\partial NP/\partial PI = 8.543 - 2.504\, FS + 1.292\, MP - 0.839\, TO. \tag{4}$$

Note that firm size decreases the positive effect of product improvement on new product innovation and that monopoly profits increase the effect of product improvement on new product innovation. This is consistent with the theory above. However, the coefficient on FS not significant. Note that the right hand side of (4) cannot be negative since firm size and technological opportunity are both less than one.

The coefficient of FS is positive and statistically significant, indicating that larger firms are more innovative even after controlling for product improvements. However, the total effect of firm size on new product innovation is

$$\partial NP/\partial FS = 28.259 - 2.504\, PI. \tag{5}$$

Therefore, current product improvement reduces the positive effect of firm size on new product innovation, as the theory suggests, although not significantly. The effect of firm size on new product innovation would be negative for $PI > 11.28$. This is consistent with the theory above.

The negative and statistically significant coefficient of MP indicates that higher levels of monopoly profits are associated with less and not more innovation. This is consistent with Acs and Audretsch (1988) and Connally and Hirschey (1984). However, the total effect of monopoly profits on new product innovation is

$$\partial NP/\partial MP = -3.983 + 1.292\, PI, \tag{6}$$

which is positive for $PI > 3.08$. That is, current product improvement increases the effect of monopoly profits on new product innovation, making it positive for a relatively low value of PI. This is consistent with the theory which suggests that increased monopoly profits increase the upper bound on firm size only when the firm conducts product improvement, allowing the firm to innovate more new product lines.

The coefficient for technological opportunity is positive and statistically significant, indicating that even after controlling for firm size, higher levels of technological opportunity lead to greater innovative output. However, note that the total effect of technological opportunity on new product innovation is

$$\partial NP/\partial TO = 8.275 - 0.839\, PI. \tag{7}$$

The negative coefficient on $TO \times PI$ implies that the fact that the firm is conducting current product improvement reduces the positive effect of technological opportunity. This supports the argument that product improvement reduces the number of attempted new product innovations, and so reduces the effect of technological opportunity on the success of innovative effort. These results are robust for different specifications of the model.

The weakness of these results may be due to the fact that in the theory, new product innovation refers to products which are new to the firm in question, and so increase the demands on the entrepreneur's attention, while product improvement refers to products which the firm currently markets. However, in the data, it was not possible to determine whether an innovation in classification (3), which is a significant improvement on current technology, is new to the firm or is an improvement on one of the firm's current products. If it is the latter, this would tend to generate the positive effect of product improvement on new product innovation because these "new product innovations" are actually improvements of the firm's current products and so do not increase the number of activities of the firm.

In addition, innovations in classification (4), modest improvements in design of a current product, which were used to measure product improvement, may actually be new products for the firm. If an innovation in classification (4) is actually new to the firm, then this would tend to bias the results towards a negative effect of product improvement on new product innovation. This is because these "product improvements" actually increase the number of activities of the firm.

VI. Conclusion

The most significant implication of the theoretical model of Section II is that firm size and monopoly profits matter for new product innovation only if the endurance of current products is sufficiently large relative to the level of technological opportunity so that the firm conducts current product improvement as well as new product innovation. In this case, as firm size increases, the entrepreneur is required to allocate more time to maintaining current operations through current product improvement and less time to new product innovation. However, higher monopoly profits imply a higher upper bound on the size of the firm, allowing the firm to innovate a greater number of new products. If the endurance of current products is sufficiently low relative to the level of technological opportunity, then the firm conducts no current product improvement and allocates all attention to innovating new products. Therefore, in this case, the rate of new product innovation is independent of firm size and monopoly profits.

The empirical results suggest an interaction between the degree of obsolescence and the validity of the *Schumpeterian Hypotheses* of the effect of firm size and monopoly profits on new product innovation. The positive effect of firm size on new product innovation is reduced by current product improvement implying that for firms which conduct product improvement, and thus face low obsolescence, innovation may be decreasing in firm size while for firms facing high obsolescence, innovation increases with firm size. The effect of monopoly profits may be reversed by current product improvement suggesting that, for firms which face low obsolescence, innovation may be increasing in monopoly profits, while for firms facing high obsolescence, innovation is decreasing in monopoly profits.

The allocation of entrepreneurial attention thus models a crucial aspect of the innovation production process: the effect of the limitations of attention on the ability of a firm to innovate. The optimal allocation of attention implies that the endogenous opportunity cost of product innovation embodied in the neglect of current operations affects the dependence of new product innovation on firm size and monopoly profits. In addition, it is not the absolute level of technological opportunity that determines innovation, but the level of technological opportunity relative to the level of endurance.

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Notes

[1] See Gifford (1993) and the references there for a more in depth discussion of the various roles of the entrepreneur.

[2] See Gifford (1992b) for a more extensive discussion of limited entrepreneurial ability. Although the current analysis addresses the problems of the "entrepreneurial" firm, Kaldor's remark suggests that the implications of limited attention apply to large bureaucratic firms as well.

[3] For an example, see Camacho (1991) where "coordination" within the firm is model explicitly but the costs of acquiring new activities or employees is ignored.

[4] A helpful analogy of the model is to imagine a juggler who spins plates on sticks on a table. Only a fraction of the plates are balanced. As more plates are set spinning, the first one starts to slow and requires respinning. The issue is whether to continue setting up new plates or go back and respin old plates. This decision depends on the probability that the old plate, which was originally balanced, falls and breaks and the probability that a new plate is balanced. The probability that a new plate is balanced can be interpreted as the level of technological opoortunity and the breakage rate can be interpreted as the degree of obsolescence.

[5] See Gifford and Wilson (1995).

[6] Shankerman and Pakes (1986) provide an alternative measure of R&D output and productivity using data on patent renewals and renewal fee schedules.

[7] If expansion implies the acquisition of more than one project at a time, then this changes the analysis significantly.

[8] More extensive reviews of this literature are contained in Schmookler (1966), Jewkes *et al.* (1969), Kamien and Schwartz (1982), Freeman (1982), Stoneman (1983), Scherer (1984) and Baldwin and Scott (1987).

[9] Also, one might consider the IBM-PCXT to be an improved version of a more generically defined product, the personal computer. Thus, the production status of the product may depend on how narrowly the product is defined.

[10] Cockburn and Griliches (1988) use survey data to create a measure of patent protection. Estimates of the rate of decay of returns to patents in Shankerman and Pakes (1986) indicate the degree to which these patents are either imitated or displaced by new innovations.

[11] The adoption and diffusion of new technologies for various industries have been investigated by Pavitt (1984).

[12] In Gifford (1994a,b,c) the projects are interpreted as ventures in a venture capital portfolio and contracts, either internal or market.

[13] This captures the fact that it is firm size as a fraction of the upper bound on firm size which affects new product innovation.

[14] The results for the OLS model were similar to the Tobit.

[15] (t-statistics in parentheses)

Maximum Likelihood Estimate –793.92.

* Significant at the 90% level, two-tail test.

** Significant at the 95% level, two-tail test.

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