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RISK AVERSION, MARKET STRUCTURE, AND INDUSTRIAL RESEARCH AND DEVELOPMENT

Marion B. Stewart
Rutgers College
New Brunswick, N.J. 08903

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Although industrial research and development programs may take as many forms as there are industries—or even firms—in which significant research expenditures are made, all R&D programs appear to share two important characteristics:

1. There is a considerable lag between the time the bulk of the research funds are expended and the time the firm reaps the benefits—the expected higher profits—of that research.

2. There is considerable uncertainty, at the time the research expenditures are made, about the magnitude of the eventual profit increase.

Of course research programs share these characteristics with other of the firm's investments, such as expenditures on plant and equipment; but the problem of uncertainty is perhaps more important in industrial research than in most other investments.

Because the return on the firm's research investment is subject to considerable uncertainty, we should not in general expect a firm's manager to choose a research strategy which maximizes expected profits in any period. Aversion to risk is apparently widespread among entrepreneurs and salaried managers, as well as among consumers, in which case rational behavior would lead to the maximization of some non-linear function of profits.

In this short essay, we shall attempt a preliminary examination of some of the effects which risk aversion is likely to have on industrial research effort. Our first step is to determine the general characteristics of a firm's optimal (utility-maximizing) research program. We then examine the effect of firm size (in particular, sales volume) on a firm's optimal research budget, an investigation which leads to a rather surprising conclusion and a potentially very important re-interpretation of recent empirical studies of the relationship between firm size and industrial research effort. We consider the effect that a reduction in uncertainty would have on industrial research effort, and find that the answer is disconcertingly ambiguous and reminiscent of recent work on the theory of optimal saving under uncertainty. We examine the effect of potential competitive entry on existing firms' optimal research budgets, in so doing reinforcing our earlier conjecture that many firms are quite risk-averse. And finally, we offer some tentative findings on the probable effect of changes in market structure on the research output of an innovative industry, as well as the effect on individual firms in that industry.

I. A Model of Industrial Research Effort

We suppose that firms invest in research and development because they believe that doing so will increase their future profits, perhaps by reducing manufacturing cost below that of existing or potential competitors, perhaps by increasing product quality (real or perceived) and permitting a higher selling price. We assume that there is a lag between the time the research expenditure is made and the time the higher profits are received; and we further assume that the magnitude of the future profit increase is not known with certainty at the time of the research expenditure.

The uncertainty about the payoff to industrial research may in principle be due either to imperfect knowledge about the research technology itself, or to uncertainty about the economic worth of a (known) innovation. Industrial research programs are no doubt characterized by uncertainty of both types, but it is perhaps the economic payoff which is subject to most of the risk. Firms do not engage in very much "basic" research; with only a few exceptions industrial "research and development" is nearly all development—the exploitation of well-known scientific principles for economic gain. The economic worth of that development is nonetheless subject to considerable uncertainty; a chemical manufacturer may know with virtual certainty that a research budget of X dollars will lead to Y new variants of a chemical compound, but the worth —if any—of those "discoveries" is still subject to considerable uncertainty. A new chemical compound will increase profits only if it smells better, tastes better, spreads easier, or kills insects faster than existing compounds, or compounds simultaneously developed by the firm's competitors.

We shall try to capture this important characteristic of industrial research with the following formulation. Let B be the firm's research expenditure in some time period, and let A—a function of B—be some well-defined measure of research output in the *next* period, a "period" thus being defined as the time lag between research expenditure and research output. Let V be the average *value* of each unit of research output—the increased profit margin resulting from the research program—so that the increased profit margin due to the research budget B is VA, where $A \equiv A(B)$ is a single-valued function of B, but V is not known with certainty at the time the research expenditure is made.

We suppose that the firm's manager maximizes the expected utility from profits; and, because of the presumed lag between research effort and research output, we shall assume that utility is derived both from current profits and next-period profits. In particular, we shall assume that the objective is to maximize the expected sum of the utility generated by current profits and (possibly discounted) next-period profits; that is, that the manager's objective is

$$\text{Maximize } EW \equiv U(P_1) + rEU(P_2) \tag{1}$$

where P_1 and P_2 are current profits and next-period profits, respectively, E is the expected value operator, and r is the manager's discount factor.

Let Q be the firm's sales volume in period 1, and let cQ be the projected sales volume in period 2. Let π_1 be the profit margin in period 1, and let π_2 be the profit margin in period 2, so that $P_1 = \pi_1 Q - B$, and $P_2 = \pi_2 cQ$; and recall that π_2 is taken to be a function of the period 1 research expenditure B. We may then write the objective function (1) as

$$\text{Max } E W \equiv U(\pi_1 Q - B) + r E U(\pi_2 c Q) \tag{1a}$$

The necessary condition for an optimal research budget is clearly

$$-U'(\pi_1 Q - B) + r E\left[U'(\pi_2 c Q) c Q \; d\pi_2/dB\right] = 0 \tag{2}$$

or $$U'(\pi_1 Q - B) = rE\left[U'(\pi_2 c Q) c Q \; d\pi_2/dB\right] \tag{2a}$$

A small increase in the research budget B reduces period 1 net profits by a like amount, while increasing expected next-period profits. Equation (2a) simply equates the marginal costs and benefits of research, a necessary condition for optimality.

To gain further insight into industrial research programs, we shall have to make some additional simplifying assumptions. We have defined the increased profit margin due to period 1 research effort as $\Delta\pi_2 = VA$, where $A \equiv A(B)$ is the (known) research output, and V is the (uncertain) economic value of that research. Let us go farther and assume that any additional profits will be competed away, so that $\pi_2 = \Delta\pi_2 = VA$: the total economic profit in period 2 is the rent earned on the firm's "trade secrets," the fruits of its period 1 research effort.[1]

Finally, we shall assume that the output elasticity of research,

$$\omega \equiv \frac{dA}{dB}\frac{B}{A} ,$$

is a constant number, at least for small changes in B; and, what is perhaps a stronger assumption, we shall assume that the elasticity of the marginal utility function,

$$\alpha \equiv -U''(P)P/U'(P) ,$$

is a constant number.[2] Since, by assumption,

$$\pi_2 = V\ A(B)\ ,$$

then
$$d\pi_2/dB = V\ A'(B) = V\omega A\, B^{-1} = \pi_2 \omega B^{-1} \tag{3}$$

and the first-order condition (2) may be written as

$$K \equiv -U'(\pi_1 Q - B) + r\omega B^{-1} E\left[U'(\pi_2 c\, Q)\pi_2\, c\, Q\right] = 0 \tag{4}$$

II. The Effect of Increased Sales Volume

Now suppose that the firm's sales volume Q increases by a small amount. To determine the effect of increased sales volume on optimal research effort, differentiate (4) totally with respect to B and Q (see the Appendix) and collect terms to obtain

$$\mathcal{E} \equiv \frac{dB}{dQ}\,\frac{Q}{B} = \frac{-1+\alpha-\alpha\pi_1 Q/(\pi_1 Q - B)}{-1+\omega-\alpha\omega-\alpha B/(\pi_1 Q - B)} \tag{5}$$

Equation (5), the elasticity of optimal research effort with respect to sales volume, appears at first glance to be rather complicated—it would be much more so but for our rather strong assumptions that α and ω are constants—but it readily yields some interesting conclusions. First, note that second-order conditions insure that the denominator of (5) is negative,[3] and notice that the numerator is likewise negative, so that, as expected, an increase in sales volume increases optimal research effort. Increased sales volume increases the expected worth of any innovation and hence leads to an increase in the firm's research budget.

The elasticity $\mathcal{E}$ is less than unity if

$$\omega(1-\alpha) < \alpha - \alpha(\pi_1 Q - B)/(\pi_1 Q - B) = 0$$

which simply requires $\alpha > 1$.

PROPOSITION: The elasticity of optimal research expenditure with respect to sales volume is less (greater) than unity if the elasticity of the firm's marginal utility function is greater (less) than unity.

Although this result depends upon the assumption that α and ω

are constants, it does <u>not</u> depend upon the magnitude of ω; and $\mathcal{E}$ is completely unaffected by the rate at which future profits are discounted and the rate at which sales volume is expect to grow.

A number of cross-section studies[4] have found that in most industries the elasticity of research effort with respect to firm size (either sales volume or a closely-correlated variable such as assets) is less than unity, at least for "large" firms; and this finding is sometimes interpreted (perhaps somewhat loosely) as supporting an anti-Schumpeterian hypothesis that increased firm size reduces the efficiency of industrial research programs. But equation (5) suggests that such an inference is possible only if firms' managers are known to be risk-neutral, so that $\alpha = 0$. In that case, we have

$$\mathcal{E} = \frac{1}{1 - \omega}\,, \tag{5a}$$

which is greater than unity since optimal research programs exist for risk-neutral firms only if $\omega < 1$.

If one is willing to assume that firms' managers are risk-neutral, then a finding that $\mathcal{E} < 1$ does indeed support a hypothesis that research efficiency is a decreasing function of firm size;[5] but given the widespread belief that many managers are risk-averse, that assumption may be too strong. It is apparent from (5) that if $\alpha > 1$, then $\mathcal{E}$ will be less than unity even though we have <u>assumed</u> that ω is constant and independent of Q. Unless one is sure that firms' managers are risk-neutral, an empirical finding that $\mathcal{E}$ is less than unity is seen to contribute little to the Schumpeterian debate about research efficiency and firm size.

If in fact ω is independent of Q, then (5) also suggests that a logarithmic utility function may not be a very good representation of firms' attitudes toward risk. With logarithmic utility we have $\alpha = 1$, in which case $\varepsilon = 1$; but the empirical evidence seems to be quite consistent in suggesting that $\varepsilon < 1$, except for some small firms. In their study of households' demand for risky assets, cited in footnote 2, above, Friend and Blume concluded that most households have a constant-elasticity marginal utility function, with elasticity greater than unity, and that firms' portfolio managers appear to be even more risk-averse than households. Our discussion above suggests that an empirical finding that $\varepsilon < 1$ is at least consistent with Friend and Blume's conjecture that $\alpha > 1$ for some firms' managers.

III. Increasing Risk and Optimal Research Effort

Some research programs are presumably more risky than others—in the sense that the economic payoff from research is subject to more variation—and if managers are risk-averse, then the optimal research budget in any period will be affected by the degree of uncertainty associated with that research program. A convenient method for examining the effect of increased uncertainty, first suggested by Agnar Sandmo, is to define a new variable

$$v \equiv \gamma V + \theta,$$

where V is the (uncertain) value of a unit of research output, and γ and θ are "shift parameters" initially equal to one and zero, respectively. A small increase in γ amplifies the variation in V and hence increases the uncertainty about v—in effect "spreading" the probability distribution of v. We may effect a "mean-preserving spread" in the probability distribution of v by choosing θ such that $d\theta/d\gamma = -EV$, since in that case

$$d(Ev)/d\gamma = E(V + d\theta/d\gamma) = E(V - EV) = 0$$

Replacing V with v, in equation (3), and then differentiating the first-order condition (4) with respect to γ (see the Appendix), we obtain

$$dK/d\gamma = (1-\alpha)\omega\, r\, c\, Q\, A\, B^{-1}\, E\left[U'(P_2)(V - EV)\right] \tag{6}$$

If U is concave, then $U'(P_2)$ is a decreasing function of V (since $P_2 = \pi_2 c Q = V A c Q$); and it is then easily shown that $E\left[U'(P_2)(V - EV)\right]$ is negative. Hence $dK/d\gamma < 0$ for $\alpha < 1$, and $dK/d\gamma > 0$ for $\alpha > 1$. Since second-order conditions insure that (4) is a decreasing function of B, we can immediately assert the following:

PROPOSITION: An increase in the riskiness of research will decrease optimal research expenditure if α, the elasticity of the marginal utility function, is less than unity, and increase optimal research expenditure if α is greater than unity.

This rather startling result is reminiscent of similar findings in the theory of optimal saving under uncertainty.[5a]

The economic interpretation of the sudden "watershed" at $\alpha = 1$ is far from clear. In one-period models, increased α may be interpreted as increased aversion to risk—α is frequently referred to as a "coefficient of relative risk aversion"—and a finding that large α leads a firm to do <u>more</u> research as it becomes more risky could perhaps be intuitively justified by arguing that a manager who is extremely risk-averse is dominated by the fear of earning very low profits and hence protects himself against the greater risk of low profits by doing more research. In multi-period models, however, the coefficient α is clearly not an unambiguous measure of a manager's aversion to risk—it apparently measures some combination of risk aversion and time preference[6]—and little more can be said here than to note the importance of the magnitude of α in the firm's optimal response to increased uncertainty about the economic return on its research.

The results of the previous section suggest that we should not rule out the possibility that $\alpha > 1$ for many firms' managers, in which case a reduction in the riskiness of industrial research would lead to a reduction in optimal research effort. Unfortunately, we do not know of any empirical evidence which indicates that industries in which research is more speculative engage in either more or less research than do industries in which research is relatively riskless. If, however, one were willing to accept Friend and Blume's conjecture that $\alpha > 1$, and if one believed that the expansion of industrial research was sound public policy (perhaps because industrial research generates external benefits), then one might wish to effect a "mean-preserving spread" in the distribution of firms' research-generated profits. This is in principle quite easily done, requiring simply a reduction in corporate income tax rates, combined with an increase in lump-sum taxes to leave the expected value of net profits unchanged.

IV. The Threat of Entry

It is widely believed that the threat of entry into an innovative industry has a role in determining the rate of technological progress in that industry; and there is some evidence that increased threat of entry encourages innovation. F.M. Scherer, for example, has argued[7] that "there is abundant evidence from case studies to support the view that actual and potential new entrants play a crucial role in stimulating technical progress, both as direct sources of innovation and as spurs to existing industry members;" and he lists a large number of innovations brought about by new entrants, as well as a somewhat smaller number of innovations brought about because "the threat of entry through innovation by a newcomer stimulated existing members [of an industry] to pursue well-known technical possibilities more aggressively." As an example of the effect of potential entry on innovation in the radio industry, Scherer notes S.G. Sturmey's conclusion that "where the entry of significant competitors appears to be impossible, innovation will be slow; when the entry of significant competitors is possible, innovation will be much faster."[8]

We shall not examine, in this essay, the proposition that new entrants in an industry are often "direct sources of innovation." Rather than focusing on any <u>direct</u> role which potential entrants play in the "innovative process," we wish to examine the assertion that increased threat of entry into an innovative industry stimulates existing members of the industry to increase their research effort. We do not deny that this is so; indeed we know of no evidence to the contrary. But we shall argue below that the hypothesis that an innovative firm increases its research effort in response to an increase in the threat of entry may not be consistent with a hypothesis of risk neutrality. We shall show, however, that increased research effort is the expected response to an increased threat of entry if firms' managers are sufficiently risk averse.

We have assumed throughout this essay that the eventual economic return on a firm's research expenditure is not known with certainty at the time the expenditure is made. Among the reasons for this uncertainty is surely the possibility that a "potential competitor" will effect a similar, or superior, innovation and enter the industry, thus reducing existing firms' expected profit margins, sales volume, or both. We may re-define the expected next-period profit $E P_2$ in a way which separates the effect of new entry from the other sources of uncertainty. Define

$$E P_2 \equiv (1 - \phi + \phi X) E P_2' , \tag{7}$$

where $E P_2' = E(\pi_2 c Q) = E(V A c Q)$ is the expected profit in period 2 if entry does <u>not</u> occur

ϕ is (the firm's subjective estimate of) the probability that new entry will occur

X (< 1) is the fraction of profits which will be retained if entry occurs

Using the above notation, we may write the first-order condition (4) as

$$K = -U'(\pi_1 Q - B) + r\omega B^{-1} E\left[U'(P_2) P_2\right] \tag{4'}$$

$$\begin{aligned} &= -U'(\pi_1 Q - B) + (1-\phi) r\omega B^{-1} E\left[U'(P_2') P_2'\right] \\ &\quad + \phi r\omega B^{-1} E\left[U'(XP_2') X P_2'\right] = 0 \end{aligned} \tag{8}$$

Now differentiate (8) with respect to ϕ to obtain

$$dK/d\phi = r\omega B^{-1} E\left[U'(XP_2') X P_2' - U'(P_2') P_2'\right] \tag{9}$$

Since $X < 1$, the bracketed expression in (9) will be positive if $y U'(y)$ is a decreasing function of y, and negative if $y U'(y)$ is increasing in y.

Now $$d\left[y U'(y)\right]/dy = U'(y) + y U''(y) \tag{10}$$

and, using the definition of α, we may write (10) as

$$d\left[y U'(y)\right]/dy = (1 - \alpha)\, U'(y)$$

which is positive if $\alpha < 1$, and negative if $\alpha > 1$. It follows at once that (9) is positive when $\alpha > 1$, and negative when $\alpha < 1$. Second-order conditions insure that (4') is decreasing in B, so an increase in ϕ leads to an increase (decrease) in optimal B if α is greater (less) that unity. Hence we can assert the following:

PROPOSITION: An increase in the perceived probability of competitive entry will increase (decrease) optimal research effort if α, the elasticity of the marginal utility function, is greater (less) than unity.

Broadly similar results have been noted in the previously-cited optimal saving literature. By assumption, an increase in the probability of competitive entry reduces expected profits, either by reducing the existing firms' expected sales volume or profit margin, so that an increase in the perceived threat of entry is equivalent to a downward shift in the expected return to research, with no change in the variance of that return. In optimal saving models, it has frequently been noted that an increase in the rate of return on savings and an increase in the variance of that return have opposite effects on optimal capital accumulation; given the formal similarity between our model of industrial research and these models of optimal accumulation, it is not too surprising that some of our results are qualitatively similar.

V. Are Firms Very Risk-Averse?

We have offered some circumstantial evidence in support of the hypothesis that firms' managers are in fact quite risk-averse. In particular, if one assumes that managers derive utility from a firm's profits, and makes the rather strong, but not implausible, assumption that managers' marginal utility functions have a constant elasticity over the expected range of profits, then our analysis suggests that the elasticity of that marginal utility function is greater than unity. Assuming that elasticity to be greater than unity leads to two results which are consistent with empirical observation:

1. The elasticity of optimal research effort with respect to sales volume is less than unity, and
2. An increase in the threat of competitive entry increases optimal research effort.

Moreover, we noted earlier that from empirical analysis of households' investment in risky assets, Friend and Blume concluded that households appear to have constant-elasticity marginal utility functions, and that the elasticity is probably greater than unity; and they noted that firms' portfolio managers, at least, appear to have utility functions with even greater elasticity than do households.

These are only three fragments of evidence in support of a marginal-utility-elasticity-greater-than-unity hypothesis; but, as far as we know, that is three more than have been offered in support of, say, a risk-neutrality hypothesis.

VI. Antitrust Dissolution and Industrial Research Output

Suppose that n firms in some industry are engaged in research and development; and assume for simplicity that those n firms have identical profit margins, sales volumes, utility functions, and future expectations, so that each firm has the same optimal research budget B. The research output $A = A(B)$ will than be of the same magnitude for every firm—the same number of patents, or new chemical compounds, for example—but it is perhaps too strong to assume that the firms' research output will be identical in every respect. If every firm produced exactly the same research "bundle," then total industry research output would equal A, while total research expenditure would equal nB: all firms carry out the same experiments, so that (n-1) of the research programs are redundant. This seems unlikely—indeed it is far from clear that in this case any economic rent could be earned on a firm's research, since all competitors would make the seme product improvements simultaneously—so we shall assume that the n firms' research output is somewhat heterogeneous. In that case the total industry research output is greater than the output of a single firm, but less than the product nA unless the firms' research programs are perfectly complementary.

Let the "effective" research output of an innovative industry be the product δA, where δ is defined by

$$\delta \equiv 1 + (n-1)\tau \quad ;$$

and let the parameter τ be a measure of the "research complementarity" in the industry.[9] If $\tau = 1$, then (by assumption) all research programs are perfect complements; no duplication of effort occurs, $\delta = n$, and the "effective" research output δA is equal to nA. If $\tau = 0$, then all research programs are perfect substitutes, $\delta = 1$, and the effective research output δA is simply equal to a single firm's research output. If, as seems likely, τ is non-zero but less than unity, then $1 < \delta < n$: the effective research output δA is greater than the output of a single firm, but—because of certain redundancies—less than the potential research output nA.

We have established that if α, the elasticity of a firm's marginal utility function, is greater than unity, then a reduction in sales volume Q will lead to a smaller-than-proportional reduction in optimal research effort. If there are non-increasing returns to research effort, that is, if $\omega \leq 1$, then the fall in the firm's research output A will likewise be proportionately less than the fall in Q. Now suppose an antitrust dissolution leads to an increase in the number of firms in an innovative industry, each of the resultant firms being smaller than the original firms. Is it possible, on a purely theoretical level, that industry research output δA will be increased?

In order to simplify our analysis, let us assume a continuum of firms, so that a small change in n is feasible. The change in total industry research output is

$$d(\delta A)/dn = \delta \; dA/dn + A \; d\delta/dn \tag{11}$$

Now $$d\delta/dn = \tau \tag{12}$$

and $$\frac{dA}{dn} = \frac{\partial A}{\partial B} \frac{\partial B}{\partial Q} \frac{\partial Q}{\partial n} \tag{13}$$

Since total industry sales volume nQ is taken to be constant, we have $\partial Q/\partial n = -Q/n$. From the definition of ω, we have $\partial A/\partial B = \omega A/B$. And by definition, $\partial B/\partial Q = \varepsilon B/Q$ (see equation (5)). Hence we may write (13) as

$$\frac{dA}{dn} = -\frac{\omega A}{B}\,\frac{\varepsilon B}{Q}\,\frac{Q}{n} = -\omega\varepsilon A/n \tag{13a}$$

Substituting (12) and (13a) into (11), we have

$$d(\delta A)/dn = A(\tau - \delta\omega\varepsilon/n) ,$$

which is positive if

$$\tau n/\delta > \omega\varepsilon \tag{14}$$

The left side of (14) is less than unity (see the definition of δ), so a necessary condition for an antitrust dissolution's leading to increased industry research output is that the product $\omega\varepsilon$ be less than unity. We have already noted the empirical evidence that $\varepsilon < 1$; there are also a small number of empirical studies suggesting that ω is no larger (and perhaps smaller) than unity in most industries.[10] Thus it is apparently possible that dissolution could increase a representative industry's research output.

To say that such an outcome is possible is not to say that it is likely. We do not know how much duplication of effort takes place in industrial research programs; but there may be considerable redundancy, in which case τ could be quite small. The product $\omega\varepsilon$ is apparently greater than 0.5 in most industries studied; therefore $\tau n/\delta > 0.5$ is apparently necessary if $d(\delta A)/dn$ is to be positive. It is easily shown that if $n = 4$, this requires $\tau > 0.2$; and for $n = 2$, $\tau > 1/3$ is necessary. These values do not seem to be outside the realm of possibility. With 4 firms, and $\tau = 0.2$, for example, industry research output δA is only 1.6 times the output of a single representative firm; thus even if considerable duplication of effort takes place, total industry research output could conceivably be increased by dissolution.

VII. Summary and Concluding Remarks

In this initial attempt to gain some understanding of the effects of risk and risk aversion on industrial research effort, we constructed a highly stylized two-period model in which firms can increase the expected magnitude of future profits by engaging in "research and development." A one-period lag between research effort and research "output"—with resultant higher profits—was assumed; and the magnitude of the eventual profit increase was assumed not to be known with certainty at the time the research expenditure was made. The firm's manager was taken to be a utility-maximizer and to derive utility from current and next-period profits; unless a manager is risk-indifferent, however, his utility function will be a non-linear function of profits. In the interests of tractability, we assumed that the manager's objective was to maximize the expected sum of first- and second-period utility, and that the marginal utility of profits in either period could be characterized as a constant-elasticity function of those profits.

Given these, as well as some other, less important, assumptions, we were able to define a utility-maximizing research budget in a way which allowed some comparative static experiments to be carried out. We were able to show, for example, that an increase in sales volume increases optimal research expenditure, and—a less obvious result—that whether the elasticity of optimal research effort with respect to sales volume is greater or less than unity depends only upon the magnitude of α, the (constant) elasticity of the manager's marginal utility function. If $\alpha > 1$, then $\mathcal{E}$, the elasticity of optimal research effort with respect to sales volume, is less than unity; if $\alpha < 1$, then $\mathcal{E} > 1$.

We added the notion of "potential competition" to our model by assuming that an innovative firm continually faces some risk that new entrants will develop similar or superior products and reduce existing firms' profit margins, sales volume, or both. An increase in the perceived probability of competitive entry affects existing firms' optimal research budgets. Interestingly, whether an existing firm will increase or decrease research effort in the face of increased threat of entry was found to depend solely upon the elasticity of the firm's marginal utility function: if $\alpha > 1$, then increased threat of new entry leads to increased research effort; if $\alpha < 1$, the firm cuts back its research budget.

Since there is considerable empirical evidence that the elasticity of research effort with respect to firm size is less (or at least no greater) than unity in most industries; and since a number of case studies are said to indicate that innovative firms respond to an increased threat of competitive entry by <u>raising</u> research budgets, then our analysis suggests that many firms' managers are not risk-neutral, and that in fact their utility functions are very far from being linear functions of profit. If the assumption of constant-elasticity marginal utility functions is approximately true, then it appears that that elasticity is greater than unity for many managers (risk-neutrality requires an elasticity of zero).

Government taxation policy can increase or decrease the possible range of outcomes from a research program: the higher the corporate income tax rate, for example, the narrower is the difference between the highest and lowest returns to research. Our analysis suggests that if the elasticity α is in fact greater than unity, then a reduction in the uncertainty about the payoff from research will reduce optimal research effort, while an increase in uncertainty will increase research effort. The intriguing—though obviously highly speculative—implication of this finding is that a central government might be able to increase industrial research effort simply by reducing corporate income tax rates, replacing them with higher lump-sum taxes in order to leave expected after-tax profits (and tax revenues) unchanged.

If ε, the elasticity of research expenditure with respect to firm size, is less than unity, and if ω, the elasticity of research output (however defined) to research expenditure is likewise less than unity, then effective research output will grow less than proportionately with firm size. In section VI, we considered the following question: is it possible, at least in principle, that a reduction in average firm size—due, for example, to an antitrust dissolution—could increase the effective research output of the affected industry? Whether the answer is positive or negative depends upon the magnitude of ε and ω (the product $\varepsilon\omega$ must be less than unity), and upon the degree of "complementarity" among firms' research programs; but our analysis suggests that at least on a theoretical level, it is by no means impossible—and perhaps not even improbable—that dissolution could increase an industry's effective research output.

Appendix

1. Derivation of equation (5)

The first-order condition for utility maximization is given by equation (4):

$$-U'(\pi_1 Q - B) + r\omega B^{-1} E\left[U'(\pi_2 c Q)\pi_2 c Q\right] = 0 \tag{4}$$

or

$$U'(\pi_1 Q - B) = r\omega B^{-1} E\left[U'(\pi_2 c Q)\pi_2 c Q\right] \tag{4a}$$

Differentiating (4) totally with respect to B and Q, we have

$$\begin{aligned}&\left\{-U''(P_1)\pi_1 + r\omega B^{-1} E\left[U''(P_2)P_2\pi_2 c + U'(P_2)\pi_2 c\right]\right\} dQ \\ &\quad + \left\{U''(P_1) - r\omega B^{-2} E\left[U'(P_2)P_2\right] + r\omega^2 B^{-2} E\left[U''(P_2)P_2^{\,2} + U'(P_2)P_2\right]\right\} dB = 0\end{aligned} \tag{A1}$$

where $P_1 \equiv \pi_1 Q - B$; and $P_2 \equiv \pi_2 c Q$.

Using the definition $\alpha \equiv -U''(P)\,P/U'(P)$, we may write (A1) as

$$\begin{aligned}&\left\{\alpha U'(P_1)\pi_1 P_1^{-1} + (1-\alpha) r\omega B^{-1} E\left[U'(P_2)P_2 Q^{-1}\right]\right\} dQ \\ &\quad + \left\{-\alpha U'(P_1)P_1^{-1} - r\omega B^{-2}(1 - \omega + \alpha\omega) E\left[U'(P_2)P_2\right]\right\} dB = 0\end{aligned} \tag{A2}$$

Substituting from (4a), and dividing both sides of (A2) by $U'(P_1)$, we have

$$\left[\alpha\pi_1 Q/P_1 + 1 - \alpha\right] dQ/Q - \left[\alpha B/P_1 + 1 - \omega + \alpha\omega\right] dB/B = 0 \tag{A3}$$

from which equation (5) immediately follows.

2. Derivation of equation (6)

Replacing V with $v \equiv \gamma V + \theta$, we may write the first-order condition (4) as

$$K \equiv -U'(P_1) + r\omega B^{-1} E\left[U'(AcQ(\gamma V + \theta))AcQ(\gamma V + \theta)\right] = 0 \tag{A4}$$

Differentiating (A4) with respect to γ, and letting $d\theta/d\gamma = -EV$, we have

$$dK/d\gamma = r\omega B^{-1} E\left[U''(P_2)P_2 A\, c\, Q\, (V - EV)\right] \qquad \text{(A5)}$$

$$+ r\omega B^{-1} E\left[U'(P_2) A\, c\, Q (V - EV)\right]$$

$$= r\omega B^{-1} A\, c\, Q\, (1 - \alpha) E\left[U'(P_2)(V - EV)\right] \qquad (6)$$

Notes

1. This would be the case if, for example, the firm's trade secrets were lost to existing or potential competitors after generating profits for one period, so that the trade secrets which generated the first-period rents would contribute nothing to second-period profits. Given the speed with which trade secrets are stolen from innovative firms (see, for example, Telex v. IBM, 367 F.Supp. 258: DC Okla. 1973), this may be only a slight oversimplification.

2. Although this is a strong assumption, it is not completely without empirical support. In a recent study of households' demand for risky assets, Irwin Friend and Marshall E. Blume concluded that many households, at least, appear to have constant-elasticity marginal utility functions.

3. If the utility function is concave, then the second-order condition is satisfied if there are non-increasing returns to research, that is, if $\omega \leq 1$.

4. There have been at least a dozen studies of the relationship between firm size and research effort. See in particular F.M. Scherer (1965), H.G. Grabowski, W.S. Comanor, and, for a survey of other studies, Morton Kamien and Nancy Schwartz.

5. Suppose that $A \equiv A(B,Q)$, with $\partial A/\partial Q < 0$. Then rather than (5a), we have $\mathcal{E} = (1-e)/(1-\omega)$, where $e \equiv -(\partial A/\partial Q)\,Q/A > 0$; and $\mathcal{E} < 1$ if $e > \omega$. Given the presumption of profit maximization and risk neutrality, a finding that $\mathcal{E} < 1$ suggests that research efficiency is a decreasing function of firm size. The converse is of course not true; a finding that $\mathcal{E} > 1$ would <u>not</u> imply that research efficiency is an increasing function of firm size. On this point see also F.M. Fisher and Peter Temin.

5a. See Edmund Phelps, D. Levhari and T. Srinivasan, and Sandmo.

6. On this point see Larry Selden.

7. Scherer (1970), p. 377.

8. Sturmey, p. 277.

9. This notion of "research complementarity" is due to Larry Ruff.

10. See, for example, Edwin Mansfield, Comanor, Scherer (1965), and, for a survey of other studies, Kamien and Schwartz.

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