

THEORY OF COMPETITION, INCENTIVES, AND RISK*

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I. INTRODUCTION

It is now widely recognized that the nature of competition in market economies is far more complex (and more interesting) than the simple representation of price competition embodied in, say, the Arrow-Debreu model. Not only are there alternative objects of competition: firms compete not only about price but also about products and R&D; but also the structure of competition, the "rules" which relate the payoffs to each of the participants to the actions they undertake, may differ markedly from that envisioned in the standard model.¹

Not only is the central result of standard competitive theory, the fundamental theorem of welfare economics, not valid for these more general forms of competition, but this paradigm fails to provide insights into the kinds of circumstances in which the market will, in some sense, work well and those in which it won't; and as a consequence it fails to provide much guidance for policy decisions which relate to R&D and industrial structure. I should emphasize that it is not simply the case that the standard development of the theory has failed to integrate R&D into the analysis. Rather, it is that the natural assumptions concerning the structure of R&D (and more generally, information) are inconsistent with the basic structure of the Arrow-Debreu model.

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1. Most of us are familiar with sports competitions. There are a variety of rules of the game under which these competitions are conducted. Only a single prize may be awarded, or alternatively, the difference between the winning prize and the losing prizes (besides the "recognition" of being first) may be relatively small. There may be handicaps, and almost any contest imposes a variety of restrictions on the set of "feasible" actions which the participants can undertake; for instance, in sailing, the size of the mainsail is regulated; in boxing, the characteristics of the glove are regulated.

In earlier studies, I have investigated alternative objects of competition, both product competition (Dixit-Stiglitz (1977) and R&D competition (Dasgupta-Stiglitz (1980a, 1980b), Gilbert-Stiglitz (1979), Dasgupta-Gilbert-Stiglitz (1982 and forthcoming), Fudenberg-Gilbert-Stiglitz-Tirole (1983), and alternative structures (Stiglitz (1980), Nalebuff-Stiglitz (1983a, 1983b)). In this paper, I wish to bring these two strands together. Competition for R&D is often (but not always) much like a contest with a large first prize, and small (zero) prizes to the other participants. In my previous studies, I considered the design of the contract. Associated with each contract there is a particular payoff structure. Different contracts are thus characterized by different levels of risk which the participants have to bear; different incentives which they face; and different degrees of flexibility, the responsiveness of the (implied) payoff matrix to changes in the environment.¹

One of the central results of our analysis was that it was, in general, desirable to employ reward functions which related compensation to relative performance rather than simply to the individual's own performance. Indeed, even when one restricted oneself to simple reward structures—contests with compensation depending simply on rank—competitive reward structures could be preferable to individualistic reward structures,² and this would always be the case if there was sufficient uncertainty about the nature of the environment. This provides us with a new insight into the function of

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1. That is, we assumed that the contract had to be signed before all relevant properties of the environment were known; what would be a good contract for one environment might be a bad contract for another. The ability to adapt automatically to changes in the environment is what we refer to (somewhat roughly) as flexibility.
 2. Individualistic reward structures have the property that an individual's compensation depends only on his own performance (actions, announcements), not on that of others.

competition: when only one firm is engaged in a particular activity, it may be very difficult for an outsider to ascertain whether the firm is doing a good or a bad job. Since the firm has more information about the difficulty of the task than does the outsider, the outsider is somewhat at a disadvantage in designing effective reward structures. When there are several firms, we can get some information from the performance of the different firms. We can, implicitly, use this information to adjust the reward structure, so that individuals have incentives to adjust their behavior in response to changes in environmental conditions.¹

As I have said, competitive markets provide reward structures which, under certain conditions, look very much like the prizes of a contest. But while in our previous studies we were concerned with optimizing, choosing the best reward structure (contest prize structure) from among a set of feasible prize structures, here we are concerned with describing: ascertaining the nature of the prizes which are implicit in various market structures, and the consequences of these prize structures for the risks which the firms must bear, for the incentives of firms not only to engage in R&D but to choose among alternative research projects, and for the responsiveness of the incentives to changes in the environment.

Our concern, however, is more than just descriptive: changes in policy have effects on the implicit prize structure, and these consequences need to be taken into account in evaluating the desirability of any such policy change.

1. We are not, of course, claiming that they adjust their behavior to what they would have done had the information about the state of the environment been available prior to the signing of the contract.

The central question, then, which we address in our analysis is whether "competition" or "monopoly" provides a greater spur to innovation, and, more generally, whether there are particular biases in the direction of innovation undertaken under these alternative market structures.

I should emphasize my view that market structure itself should be taken as endogenous, a view which, in a more restricted context, Dasgupta and I developed earlier (Dasgupta-Stiglitz (1980a, 1980b)). The implications of the analysis of this paper for the evolution of market structures is a question which we hope to pursue on another occasion.

Competition and Innovation

In spite of the long-standing concern about the relation between competition and innovation, there is no consensus. One view holds that monopolies have insufficient incentives to engage in R&D; without the spur of competition, monopolies will simply enjoy their monopoly rents. The other view holds that without some degree of monopoly power, firms will be unable either to support R&D programs or to appropriate the returns from research. As is so often the case, there is undoubtedly a grain of truth in both views: our objective is to ascertain under what conditions, under what circumstances, each view is appropriate.

It is not, however, easy to translate these commonly expressed views into well formulated hypotheses, let alone testable models. The view that monopolies have insufficient incentives can be put in at least two different ways. The first, and more traditional way, is to show that the increment in profits from R&D is less than the social returns, and, indeed, less than the increment in profits in a competitive market. We argue that the sign of

the differences is somewhat problematical; for instance, there may be more or less technical progress in a "competitive" economy than in one in which each industry is dominated by a single monopolist. Indeed, under some circumstances, the monopolists may do an "efficient" level of R&D (in a sense to be defined more precisely below).

This traditional formulation does not, however, capture well the distinction between monopoly and competitive markets. There is something to the notion of "the spur of competition" in contrast to the slack (or X-inefficiency) associated with monopolies. To some extent, the notion that competition provides a spur to innovation can be translated into an analysis of how competition alters the payoff matrix to undertaking research. But a detailed analysis of the effect of competition on the payoff matrix suggests that the effects of competition are ambiguous.

To understand the role of competition in R&D markets, then, requires the abandonment of the simple model of the unitary firm maximizing its (expected utility of) profits. Since the returns to managers (or workers) seldom coincide with the returns to the firm, it is seldom rational (i.e., in their own self-interest) for individuals to take the actions which maximize the (expected) profits of the firm. The original shareholder of the firm can attempt to design incentive structures which lead managers to take actions which are more in accord with the interests of the firm (profit maximizing). The set of feasible incentive structures is limited, however, by what information is available, and it is this which is affected in a marked way by the presence of competition.

Moreover, there is little reason to believe that firms employ incentive structures which lead to efficiency in general or to profit maximizing levels

of R&D in particular. Whether an incentive structure is "good" or is not is often revealed only by the consequences; the consequences of "bad" incentive structures become apparent more readily in competitive environments than in monopolistic markets. Even if the owners-managers of firms fail to respond of their own accord to evidence concerning their inefficiency, the market may force them: these firms will fail and control of the assets will pass to others. It should be emphasized, however, that there is no welfare theorem concerning the optimality of these evolutionary processes. Indeed, we conjecture that there may be systematic biases towards excessively myopic policies, at least in the presence of the kinds of capital market imperfections (which themselves may be endogenous, and related to costly information) commonly observed.¹

There is a final, quite distinct role that competition plays: while in traditional economic models (as well as those presented in this paper), individuals' actions (and welfare) are determined completely by the outcomes, the (expected) utility which they receive, in fact, individuals are affected, in an important way, by processes; the competitive process itself may indeed provide a spur for action, a spur which cannot adequately be explained by the magnitude of the difference between the winner's and loser's prizes.²

The explanation of why individuals respond in particular ways to competition (other than in terms of the direct consequences); e.g., whether it provides an outlet for aggressive instincts, which themselves might be explained in terms of vestigial traces from an earlier era in which such

1. See Stiglitz (1975).

2. In some contexts, e.g., in small group interactions, competition may, in the same sense, be unproductive. See Nalebuff-Stiglitz (1982).

behavior had survival value, is of no direct concern for our argument. So long as individuals do respond to the competitive process, it will be in the interests of firms (entrepreneurs) to take account of this behavior in the design of the compensation schemes which they employ to pay their managers.

Thus, I am contending that to make sense of the commonly expressed views concerning the virtues of competition in spurring R&D and innovation--views which I find persuasive--one needs to do more than simply incorporate R&D into the traditional theory of the profit maximizing firm; one needs to do more than understand the (fairly complex) ways that competition affects the payoff matrix to undertaking R&D. One needs to understand the behavior of the managers and workers in these organizations, the rules by which they behave and the incentives which they face, and the circumstances under which the rules, the incentive structures, and ultimately, the managers, get changed.

It is the aim of this paper to go a little way towards this goal. In Section II we present the standard comparison of the incentives for R&D of a monopolist, of a competitive firm, and of a social planner. Section III discusses in an intuitive way what is wrong with the standard argument that monopolists engage in too little research, while Section IV presents a simple general equilibrium model within which one can compare the level of R&D expenditures under different market structures. Sections V-VII analyze the incentives for risk taking; Section V demonstrates that a variant of the traditional model can be used to show that monopolists undertake too much risk (do not spend enough resources to reduce risk), while Section VI

uses the same framework to compare the incentives for undertaking more than one independent research project. In both sections, however, we assume only a single research project. Section VII considers the far more important case of competition among researchers. Finally, in Section VIII, we analyze innovation in the new theory of the firm.

II. A SIMPLE MODEL

The object of this and the following two sections is to show that there is no presumption that an economy which is characterized by monopolies in its different sectors will do too little research, that technical progress will be less rapid than in a competitive environment.

We begin by reviewing the traditional analysis which argues that the monopolist will engage in too little research, less than is socially optimal and less than that which would occur in a competitive industry.

Consider an industry with a demand curve

$$(1) \quad p = p(Q) \quad p' < 0 .$$

Monopoly

If there is a single (monopoly) firm in the industry, it would have set marginal revenue equal to marginal cost, c_0 , which, for simplicity, we assume are constant. Defining

$$(2) \quad R(Q) = p(Q)Q$$

we obtain

$$(3) \quad R'(Q) = c_0 ,$$

generating firm profits of

$$(4) \quad P(c_0) \equiv \max_Q \{R(Q) - c_0 Q\}$$

$$= R(R'^{-1}(c_0)) - c_0 R'^{-1}(c_0) .$$

Assume an R&D project lowers the costs to c_1 . Then the value of the innovation is given by^{1,2}

$$(5) \quad v^m = (P(c_1) - P(c_0))/r$$

where r is the rate of interest. The change in the flow of monopoly profits is represented diagrammatically in Figure 1 by the area AEDF.

(AHDF is the increment in profits at the old output, simply the savings in costs; DHE is the increment in profits from increasing output (from Q_0^m to Q_1^m).

R&D will be undertaken if

$$\pi v^m \geq x$$

where π is the probability of success of the R&D project and x is its cost.

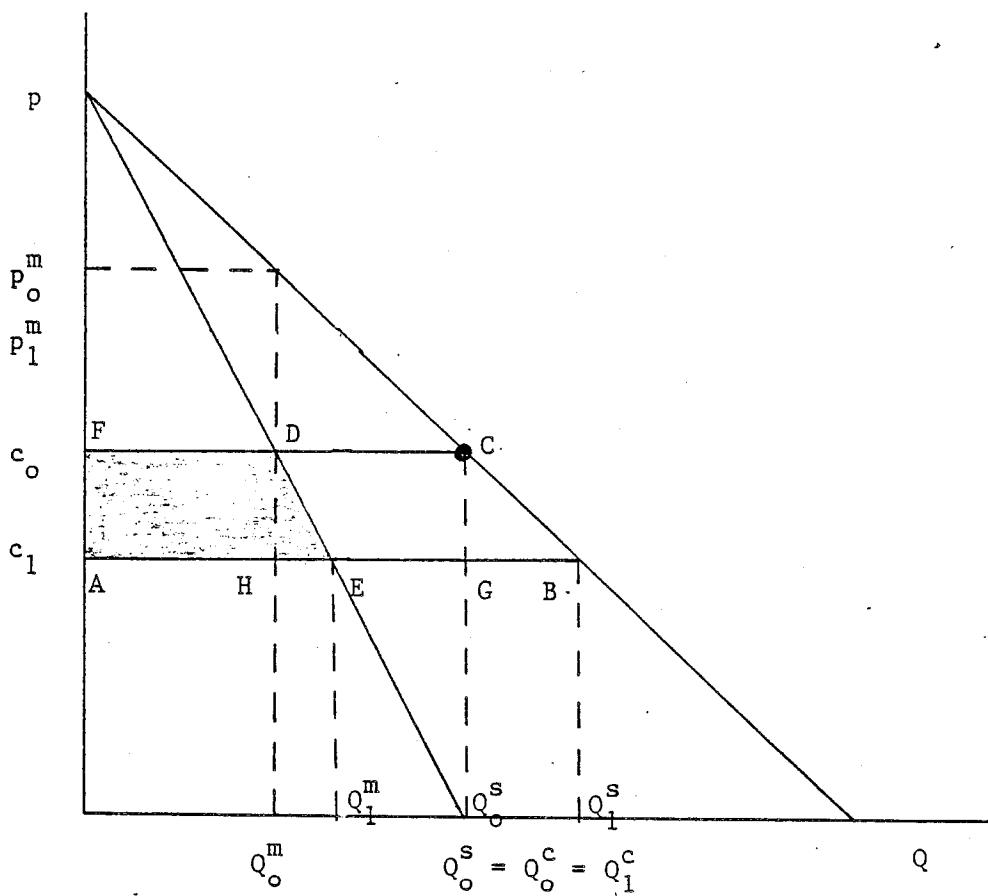
Social Payoff to Innovation

We now analyze the conditions under which it is socially desirable to undertake the R&D project, and to compare it with the monopoly equilibrium, which we have just described.

Output both prior to and after the innovation will, of course, be larger than with monopoly. Social optimality requires that

$$p_0^s = c_0$$

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1. For simplicity, we shall assume that there will be no subsequent innovations, which will decrease the value of the patent. Also, patents are assumed to be infinitely lived.
 2. Throughout, the superscript m will denote the value of a variable in the monopoly equilibrium.



$$V^s \equiv \frac{ABCF}{r} > V^c = \frac{AGCF}{r} > V^m = \frac{AEDF}{r}$$

Figure 1

Partial Equilibrium Analysis

Monopolies engage in less research than occurs in a competitive market, which, in turn, is less than the socially optimal level of R&D.

while

$$p_1^s = c_1$$

where p_0^s (p_1^s) is the price before (after) the innovation (in the socially optimal allocation).¹ Denote by S the consumer surplus associated with cost c (when price is chosen to equal the cost c). (S can easily be calculated in the standard way.) Then the value of the innovation is simply the increase in consumer surplus

$$v^s = \frac{S(p_1) - S(p_0)}{r}$$

where we assume the interest rate is equal to the social rate of discount.

In Figure 1, $S(p_1) - S(p_0)$ is the area ABCF. Hence

$$rv^s > rv^m$$

Since $v^s > v^m$, the monopolist does not undertake all socially desirable innovations.

Competitive Markets

Finally, we consider the incentives for R&D in a competitive market. Initially, the price is c_0 . An inventor will either charge the price c_0 minus ϵ , thus getting the entire market for himself, and profits $(c_0 - c_1)Q_0$, or he will charge the price where marginal revenue equals the new, lower marginal cost (c_1). Figure 1 depicts the case where the price will be just below c_0 , and the return to the innovator is the area

1. The superscript s will be used to denote variables in the socially optimal allocation.

AGFC. It is immediate that the present discounted value of the profits accruing to the inventor in this regime,¹ v^c , lie between v^s and v^m .

This analysis suggests that monopolies do engage in too little research, and in less research than that of a competitive market.²

1. The superscript c will be used to denote the competitive market equilibrium. We use the term "competitive" to cover a much broader range of economic environments than just that which has come to be associated with the Arrow-Debreu model.

2. The above analysis is due to Arrow (1962). This exposition is developed further in Dasgupta and Stiglitz (1980b).

III. DEFICIENCIES IN THE TRADITIONAL ANALYSIS OF THE EFFECT OF MARKET STRUCTURE ON R&D.

The analysis of the preceding section, providing a comparison of the level of R&D under alternative market structures, has a number of important limitations. When appropriate account of these is taken, the conclusions, that monopolies engage in too little research and that economies that are dominated by monopolies will have a lower rate of technical progress than more competitive economies, become problematical; in any case, the differences in the levels of R&D may be much less than the previous analysis suggested. In this section we present some of the more important deficiencies and explain, in a fairly intuitive way, how the conclusions are altered when the analysis is changed to take into account these criticisms.

1. The earlier analysis assumes that research projects come in discrete sizes; if firms can reduce their costs by spending more on R&D, the above analysis does not tell us anything about the marginal incentives for cost reduction.

2. It is a very partial equilibrium analysis. It does not provide an answer to the question: "Will there be more innovation in an economy in which all industries are competitive than in one in which each industry is monopolized?"

When we modify the simple analysis to take account of these two effects, we get drastically different conclusions; in one central case, monopoly and competition are identical.

Consider an economy in which all sectors have the same constant elasticity demand curves, and each is monopolized by a single firm. There is

a single factor of production, labor, which is inelastically supplied. Labor is also the single input into R&D. We postulate that all individuals (inventors and workers) have the same, homothetic indifference maps, so that an increase in national income of $z\%$ shifts the demand curve out by $z\%$.

To analyze the equilibrium level of R&D, we need first to analyze the general equilibrium of the economy, both before and after the innovation.

Consider first the competitive market. For simplicity, assume initially there are no profits; assume in each industry there is an invention which lowers the input required per unit of output by $z\%$. Thus, the new demand curve will be shifted out by $z\%$, leading to an increase in demand for output (and hence of labor) by $z\%$ in each industry; this exactly counter-
vails the decrease in the demand for labor in each industry resulting from the innovation. Thus, if the wage of production workers remains unchanged, but the inventor charges $(c_0 - c_1)w_0$ for the use of his patent (per unit output), the demand for production workers will remain equal to the supply.¹ If the demand for research workers remains unchanged, then if the labor market was in equilibrium prior to the innovation, it will still be in equilibrium (see Figure 2).

In contrast, real wages will rise in the monopoly equilibrium by the percentage reduction in labor input required to produce each unit of output; the marginal costs of production in the post-invention era are thus identical to the marginal costs of production in the initial period. To see this, note that in this case, real income of workers will have risen by $z\%$.

1. Which, by hypothesis, is assumed to be unchanged.

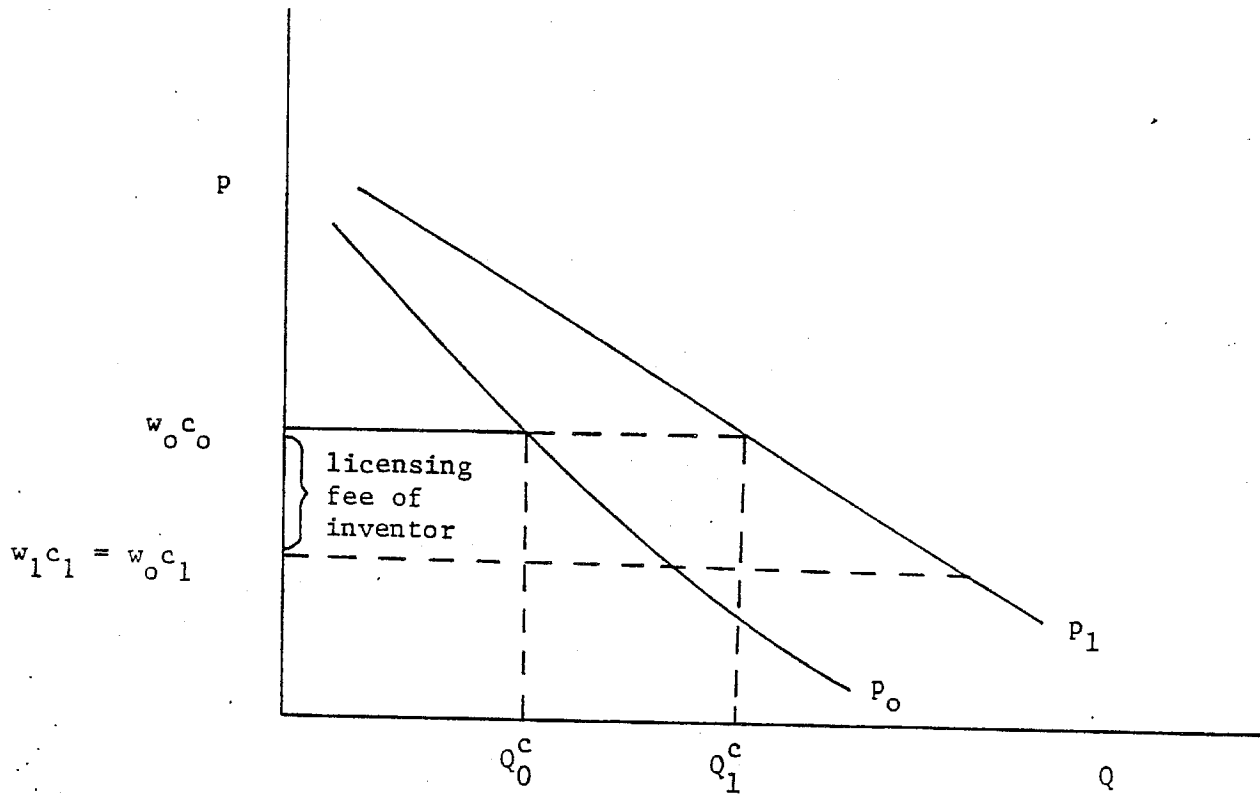


Figure 2

In a competitive economy, with a patent holder in each sector, with all sectors of the economy experiencing an increase in productivity of $z\%$, the demand curve shifts out by $z\%$, prices and wages remain unchanged, and output increases by $z\%$ in each sector.

Assume that the demand curve shifted out by $z\%$. Then monopoly output will have increased by $z\%$, with ⁴prices and marginal costs unchanged. Hence, profits will have increased by $z\%$. Hence, national income will have increased by $z\%$, confirming the postulated proportional shift in the demand curve. Since the output of each commodity has increased by $z\%$, while the labor requirement per unit of output had decreased by $z\%$, the demand for production labor remains unchanged (see Figure 3).

Thus, while workers and firms both benefit from innovations under monopoly (in the same proportion as their original share in national income), under competition, all of the gains are reaped by the inventor.

So far, we have contrasted the equilibrium before and after the innovations under the two market structures. We also need to compare the monopoly and competitive equilibria with each other. If the supply of production (non-research) workers is the same, then output in each industry must be the same under the two regimes; for the profit maximizing output of a monopolist to be the same as the competitive level, the wage under monopoly must be lower, by a factor of $1 - 1/\eta$ (the degree of monopoly), where η equals the elasticity of demand; thus, if w_0 is the wage in the pre-invention period,

$$w_0^m = \left(1 - \frac{1}{\eta}\right)w_0^c .$$

If we postulate further that the demand for research workers in the post-invention period is the same as in the pre-invention period, our earlier analysis established that

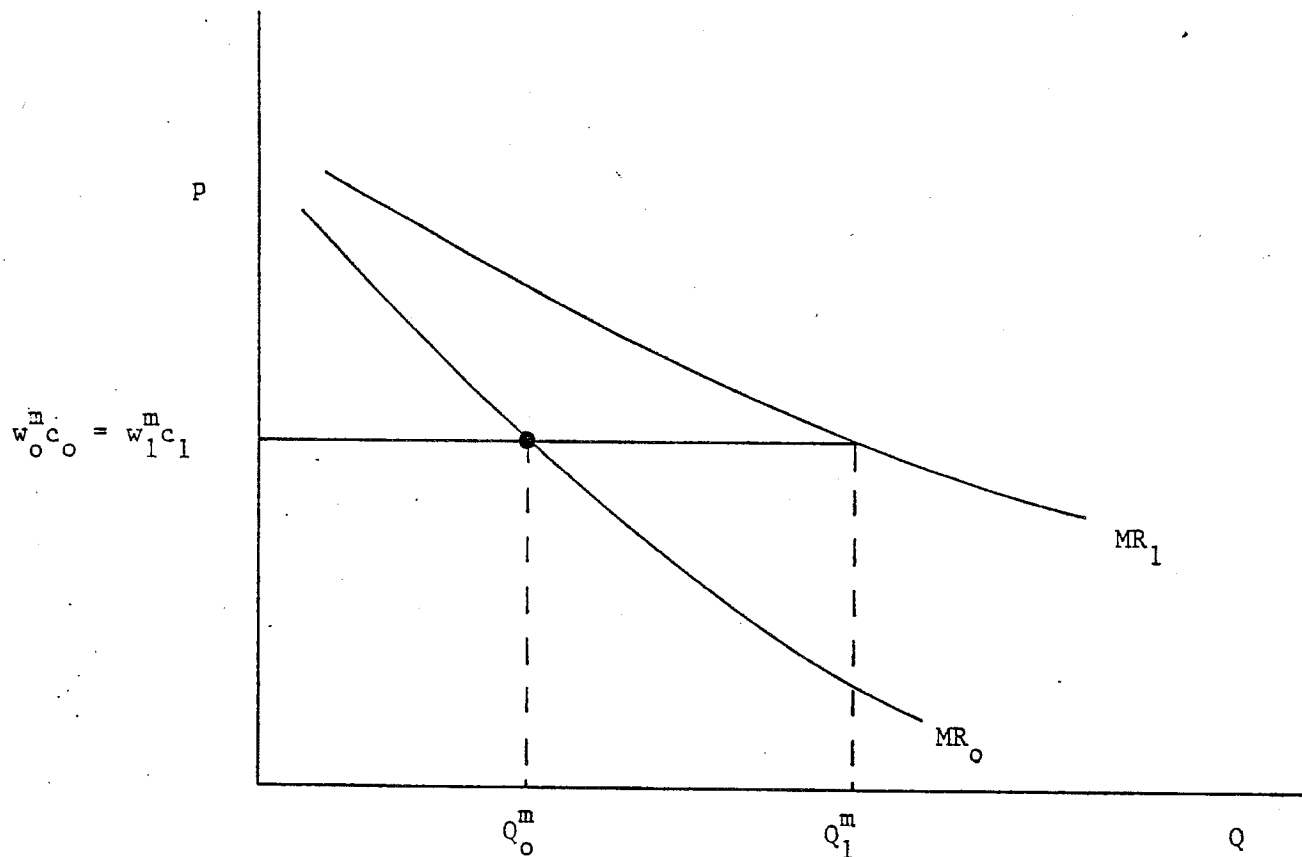


Figure 3

With a monopoly, the wage rises by the same percentage that productivity increases, so that the marginal cost of production remains unchanged; the demand and marginal revenue curves shift out proportionately, and hence the equilibrium level of output increases proportionately.

$$w_1^m = (1+z)w_0^m$$

$$w_1^c = w_0^c$$

(see Figure 4).

Assume now that increasing the input of labor into R&D in the i^{th} sector, ℓ_i^R , reduces the labor required to produce each unit by $C_i'(\ell_i^R)$; ¹ the savings in costs on output of Q_1 is $Q_1 C_1' w_1$ in the post-innovation period. Equilibrium labor input into research thus satisfies the equation ²

$$(6) \quad \frac{Q_1^j C_1^j w_1^j}{1+r} = w_0^j \quad j = m, c$$

i.e., for the monopoly equilibrium

$$(1+z)Q_1^m C_1^m = 1+r$$

while for the competitive equilibrium

$$Q_1^c C_1^c = 1+r$$

What is crucial about (6) is that it is not the level of wages which determines the equilibrium expenditure on R&D, but changes in the wages. The fact that with monopoly real wages are lower makes no difference. ³

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1. $c_i(x_i)$ gives the marginal cost as a function of the expenditures on R&D; $C_i(\ell_i^R)$ gives the marginal input requirements (in physical units) as a function of inputs (in labor units) into R&D. The functions $c_i(x_i)$ can easily be derived from the functions $C_i(\ell_i^R)$ once factor prices are known.
 2. Here, as elsewhere, we will drop the subscripts on i when no confusion results.
 3. This obviously is no longer true if both labor and goods enter the R&D process.

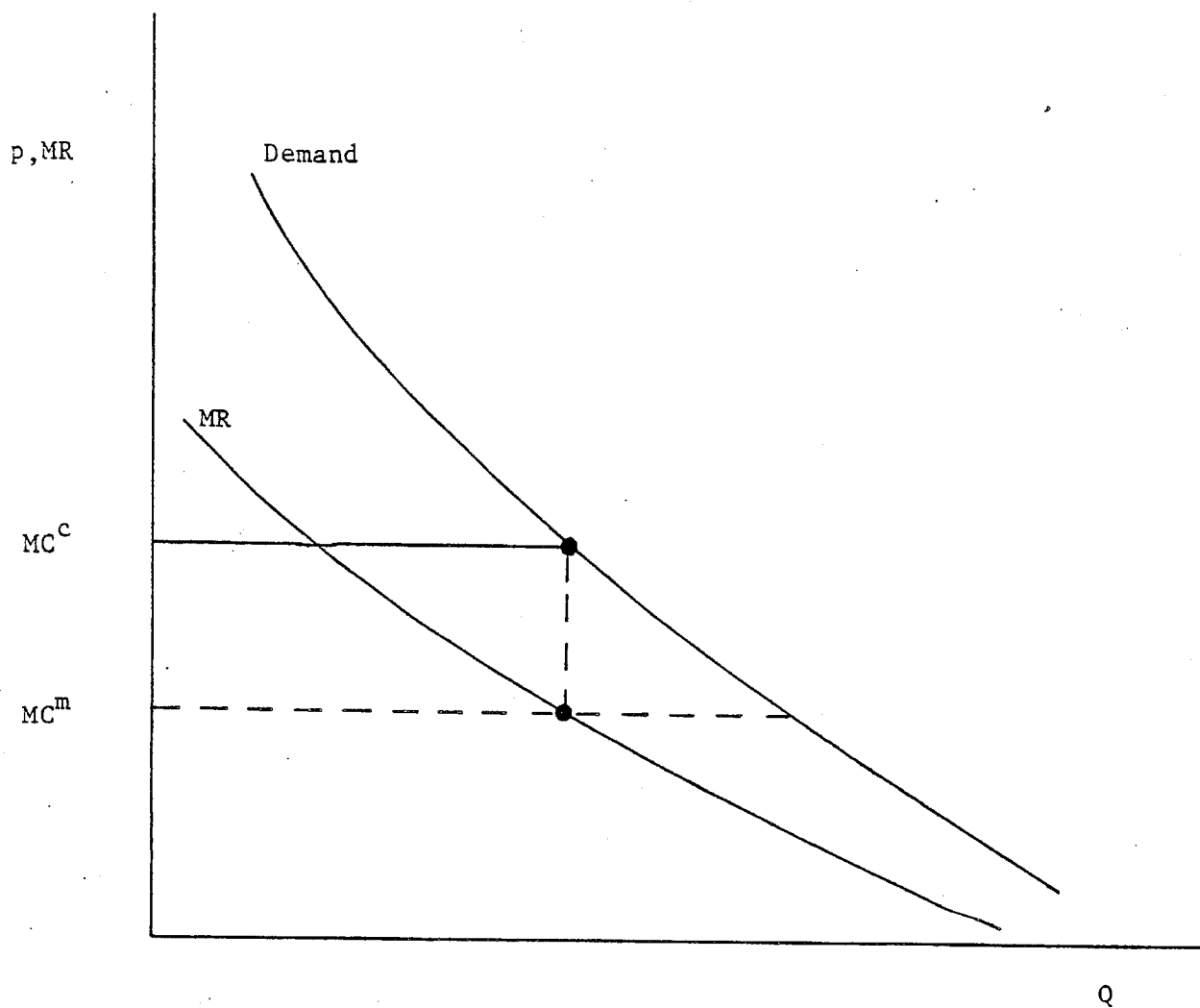


Figure 4

If there is an equal degree of monopoly in all sectors of the economy, and labor is inelastically supplied, the effect of monopoly is to lower the real wage, leaving output and R&D in all sectors unchanged.

The degree of monopoly thus has no effect on the equilibrium. Similarly, the differences in output between the monopoly and competitive equilibrium, on which the earlier partial equilibrium analysis focused, disappears in this general equilibrium formulation; with a constant degree of monopoly in all sectors, and an inelastic labor supply, output in each sector must be the same.¹ (If the labor supply curve is backward bending, as some have maintained, then

$$Q_o^m > Q_o^c ,$$

the lower real wage will elicit a higher labor supply, and hence in equilibrium, a higher level of output in each sector.) The fact that in a monopoly equilibrium real wages will be rising as a result of innovation provides an incentive for monopolies to engage in more research.

This result should not be taken too seriously: it is an anomaly of the two-period model we have formulated. In a more dynamic model, it is reasonable to postulate that eventually the increase in productivity will be reflected in the wages. Assume labor requirements at time t are given by $C_t = C_{t-1}/(1+z(\alpha_{t-1}^r))$. Then, expenditures on research at time t improve labor productivity at all subsequent dates, and a monopolist would take this into account. In a competitive market, the inventor would only take into account the cost reductions during the period in which his patent remained effective.² Thus, if the level of research in the two economies

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1. If the elasticity of demand differs among sectors, in the monopoly regime there will be relatively less output in the sectors with relatively low demand elasticities, and hence relatively less research in those sectors. Conversely for the sectors with high demand elasticities.
 2. At the expiration of the patent, prices would fall (real wages would rise). In steady state, wages would thus rise at the rate of technical progress.

were the same, then the steady state rate of wage increase would be the same. The differences between the two equilibria would then reside in the fact that while the monopolist appropriates all of the marginal returns, in the competitive regime the inventor only appropriates the return during the effective life of the patent.¹

We thus again obtain the result that the incentives for R&D are less in the competitive market than with monopoly, but our explanation focuses on the traditional problems of partial appropriability² associated with finite patent lives.

3. The traditional analysis does not ask the correct welfare questions.

Given that there is a distortion in the economy (e.g., a monopolized sector), then there is no reason to believe that the level of R&D in the monopolized sector "should" be the same as it would be if that sector were not monopolized. Since the benefits which accrue from research are related to the scale of output, if the scale of output is lower, the benefits will be lower, and there is therefore some presumption that R&D "should" be lower.

Moreover, the previous analysis assumed that the government could raise revenues to finance R&D costlessly, and could easily and costlessly identify the beneficiaries of the lower prices resulting from R&D. A

1. The effective life of the patent is often much shorter than the legal life; subsequent discovery may make the original patent obsolete; even though the subsequent discovery would not have been made had the original invention not occurred, the original invention will receive no compensation for this. If patents are long lived and $r \gg 0$, then the difference between the present discounted value of returns appropriated under the two regimes may be small.

Even with monopoly, there may be important spillovers across industries, the benefits of which are not appropriated by the monopolist.

2. We have not provided a complete analysis of the comparison of equilibria between the two regimes. Because the incentives for engaging in research will be greater with monopoly, this will increase the demand for research workers; this will bid up the wage, so that $w_o^m > (1 - 1/n)w_o^c$.

patent is like a benefit excise tax.¹ Those who pay for the R&D in a sector are those who consume the product. In fact, almost all taxes imposed by the government are distortionary, and there are other instances, e.g., highway programs, besides R&D where the government resorts to benefit excise taxes because they represent the only way of ensuring that the beneficiaries of a program pay for it.

The "correct" welfare question depends on what are perceived to be the relevant constraints. There are plausible constraints under which the market can be viewed as (constrained) Pareto efficient; and in other cases the distortions in the market allocation may be far smaller (and possible of different sign) than the Arrow analysis suggests.

The importance of this can be seen most clearly by considering the marginal incentives for R&D in the competitive regime, in contrast with social optimality. By spending more on research, the firm can lower its cost of production further; let $c_i(x_i)$ be the marginal cost of production to the i^{th} firm, if it spends x_i on R&D. Then, for small innovations,² the return from additional expenditures is just $-c'_i Q_0$.

Assume now that the government can subsidize or tax the R&D of this research firm, but cannot control its pricing and output decisions. It is easy to see that the government would not wish to intervene. Given that it cannot affect the output, the government knows that it will remain at

1. The relationship between patents and excise taxes is discussed in Stiglitz (1969).

2. That is, for those where after the invention, the price remains the same.

Q_0 (limiting our attention still to small innovations). And given that output remains at Q_0 , the returns to cost reductions are just $-c'Q_0$. The firm that has the monopoly on R&D does an efficient amount of research.

Assume the government is not in the position of breaking up a monopoly, forcing it to act competitively, or nationalizing it.¹ Then, the question the government needs to ask is: "Should it encourage or discourage research in that sector?" If the government could directly finance a monopolist's research, raising the required revenue by a lump sum tax, it would want to increase the level of R&D, but by an amount which is less than the earlier analysis suggested.

The marginal social return from the monopolist's doing additional research is the increase in consumer surplus plus the increase in producer surplus. Assume that the demand curves in each sector have constant elasticity (and are independent). Then an additional expenditure on R&D lowers the marginal cost by c' and hence price by c'/ρ (where $\rho \equiv 1 - 1/\eta$, the markup). If $v(p, I)$ is the representative consumer's indirect utility function, a function of all prices and income, I , then the lowering of price increases consumer welfare by $-v_p = v_I Q^m$ (where Q^m is the equilibrium output). The monopolist ignores this gain to consumers, and thus will do too little research. The "error" is not related to the difference in output in the competitive and monopolistic regimes, but simply to the change in prices at the monopoly output.²

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1. Or there may be large costs associated with each of these actions.
 2. If demand curves are linear, then (assuming we are considering an isolated monopoly, so wages in the two regimes are the same), $Q^m = \frac{1}{2}Q^s$ and $dp/dc = \frac{1}{2}$. Hence, assuming the marginal (social) utility of income to consumers and to capitalists is the same, constrained optimality entails setting $-3/2c'Q^m = 1$, while the monopolist sets $-c'Q^m = 1$, and unconstrained social optimality entails $-Q^s c' = -2Q^m c' = 1$.

But if we assume that the government must raise the revenue to finance the research by a tax on the sector, at the rate t per unit output, then monopolies have appropriate incentives for engaging in R&D, under our constant elasticity assumption. To see this, recall that now price p is given by

$$(7) \quad p = \frac{c+t}{\rho}$$

where research expenditures are given by

$$(8) \quad x = tQ(p) = tQ\left(\frac{c+t}{\rho}\right)$$

where Q is the demand curve. Profits, P , are given by

$$(9) \quad P = (p-c-t)Q = (c+t)\frac{(1-\rho)}{\rho}Q .$$

We can decompose the effects of a change in t into two parts:

(a) A price effect. Profits change by Qdp , while consumer welfare changes by $v_p dp = -v_I Qdp$. Assuming that the marginal (social) utility of a dollar is the same to consumers and capitalists, these effects just cancel.

(b) An output effect¹ on profits, given by

$$(10) \quad (c+t) \frac{(1-\rho)}{\rho} \frac{dQ}{dt} = (c+t) \frac{(1-\rho)}{\rho} \frac{dQ}{dp} \frac{dp}{dt}$$

$$= \frac{(c+t)}{\rho} \frac{(1-\rho)}{\rho} \frac{dQ}{dp} \frac{d(c+t)}{dt}$$

1. Making use of the fact that $1/\rho = 1 - 1/\eta$.

$$= - \frac{(1-\rho)}{\rho} Q_n \frac{d(c+t)}{dt}$$

Thus, social optimality requires setting

$$\frac{d(c+t)}{dt} = c' \frac{dx}{dt} + 1 = 0$$

But from (8),

$$\frac{dx}{dt} = \frac{Q + tQ'}{\rho} \cdot \frac{1}{1 - tQ'c'/\rho}$$

Substituting, we obtain after some manipulation,

$$c'Q + 1 = 0$$

precisely the monopolist's first order condition for R&D expenditure. (As we shall see in the next section, the monopoly equilibrium may still not be a constrained Pareto optimum; the level of expenditures on R&D depends on Q as well, and to determine this, we need to analyze the full equilibrium of the economy.)

This list of objections to the earlier analyses is not meant to be exhaustive. In earlier work (Dasgupta and Stiglitz (1980a, 1980b)), we dealt with two further objections.

4. The earlier analysis fails to distinguish between competition in the product market and competition in R&D. The argument that there is too little research in competition implicitly assumes that there is competition (originally) in the product market, but that there is not competition in R&D.

In our earlier work, we showed, for instance, that if there is competition in R&D, the level of R&D expenditures in the market equilibrium may exceed the socially optimal level.

5. It treats the market structure as exogenous, rather than endogenous.

In the next section we present a simple general equilibrium model illustrating some of the propositions we have put forward in a heuristic way in this section.

IV. A SIMPLE GENERAL EQUILIBRIUM MODEL

In this section, we construct a simple general equilibrium model illustrating the basic propositions established in the preceding section. The model is an adaptation of the Dixit-Stiglitz general equilibrium model (1977), in which there are n industries, each with a single firm, facing a downward sloping demand curve of constant elasticity, and one competitive market (labor). To make our welfare calculations simple, we assume everybody has the same utility (demand) functions. The demand curves are derived from utility functions of the form¹

$$(11) \quad U = U[Q_0, \{\sum_i Q_i^\rho\}^{1/\rho}]$$

where Q_0 is the numeraire, Q_i is the i^{th} commodity, and we assume U is homothetic.

The budget constraint is

$$(12) \quad Q_0 + \sum_{i=1}^n p_i Q_i = I$$

where p_i are the (consumer) prices and I is income (of the representative individual) in terms of the numeraire

$$(13) \quad I = 1 + \sum_{i=1}^n (W_i - x_i) - T$$

where we have set the value of the endowment of Q_0 , the numeraire, at unity, $\{W_i - x_i\}$ is the profits of the i^{th} firm distributed to consumers,

1. For concavity, we require that $\rho < 1$. To ensure that the elasticity of demand exceeds unity, we assume $\rho > 0$.

x_i is expenditure on research, and T is the lump sum taxes, imposed to cover the losses of the firms.

This gives rise to demand curves of the form

$$(14) \quad Q_i = y \left[\frac{v}{p_i} \right]^{1/1-\rho}, \quad Q_0 = I(1-s(v)),$$

where y and v are dual quantity and price indices,

$$(15) \quad y = \left\{ \sum_{i=1}^n Q_i^\rho \right\}^{1/\rho}, \quad v = \left\{ \sum_{i=1}^n p_i^{1/\beta} \right\}^{-\beta}$$

where $\beta = (1-\rho)/\rho$, and where $s(v)$, the share of full income spent on the non-numeraire commodities depends simply on the form of the utility functions.

Changing p_i affects the demand for Q_i directly, and indirectly through v . The indirect effect is of the order $1/n$ (provided only that the prices of the products in the group are not of different orders of magnitude). We assume n is reasonably large, and accordingly ignore this indirect effect. Thus, the elasticity of demand is (approximately)

$$(16) \quad - \frac{\partial \ln Q_i}{\partial \ln p_i} = \frac{1}{1-\rho} = \frac{(1+\beta)}{\beta}.$$

It is immediate that price will be a constant markup over marginal costs, c_i :

$$(17) \quad p_i = c_i(1+\beta) = c_i/\rho.$$

We assume that the marginal cost, c_i , is a convex decreasing function of the level of expenditure on R&D (but independent of the scale of production):

$$(18) \quad c'_i(x) < 0, \quad c''_i(x) > 0.$$

We focus our analysis on the symmetric equilibrium where

$$(19a) \quad P_i = p, \quad Q_i = Q, \quad P_i = P, \quad \text{all } i$$

$$(19b) \quad y = n^{1/\rho} Q, \quad v = n^{-\beta} p$$

$$(20) \quad P \equiv (p-c)Q - x = \frac{(p-c)}{p} pQ - x \\ = \frac{\beta}{1+\beta} \frac{s(v)}{n} (1+nW - nx - T) - x \\ = \frac{\{(1-\rho)s(v)(1-T)/n\} - x}{1 - (1-\rho)s(v)},$$

(where P is net profit, $W - x$), since

$$(21) \quad Q = \frac{sI}{np}.$$

Using (13), (17) and (21), we obtain

$$(22) \quad Q_i = \frac{\rho s}{c n} \left(1 - T + \frac{(1-\rho)s(v)(1-T) - nx}{1 - (1-\rho)s} \right) \\ = \frac{\rho s(n^{-\beta} c/\rho)}{c n} \left(\frac{1 - T - nx}{1 - (1-\rho)s(n^{-\beta} c/\rho)} \right).$$

Market equilibrium is described by (22) (with $T = 0$) and the first order condition for x

$$(23) \quad -c'_i(x)Q_i = 1.$$

$(-c'(x)Q_i)$ is the marginal savings in variable cost from increasing R&D).¹ This provides us with two equations in two unknowns. The graphical solution for the case where $s' = 0$ (constant shares) is given in Figure 5.

Constrained Pareto Optimality

Assume now the government cannot break up the monopoly, and finances the R&D out of profits taxes. (It gives a direct grant to each firm, and ensures that the funds are used to do R&D.) Would it support more research than the private sector does on its own?

The equations describing the equilibrium outputs and prices, for each level of expenditure, remain exactly as before. To ascertain the optimal levels of research, we employ the indirect utility function, giving the representative individual's level of utility as a function of the vector of prices, p , and income, I ,

$$v = v(p, I) .$$

Differentiating, and making use of (20), we obtain²

$$(24) \quad \frac{dv}{dx} = \sum \frac{v p_i}{p} c'_i + v_I \frac{dI}{dx}$$

$$= \frac{-v_I n}{p} \left(c'_i Q_i + \frac{1}{1 - (1-p)s} \left(1 + \frac{s' c'_i n^{-\beta-1} (1-p)(1-nx)}{s(1 - (1-p)s)} \right) \right) = 0.$$

Equilibrium is described by (24) and (22). In two limiting cases, this approximates the market equilibrium given by (22) and (23): if $s' = 0$ (so that the share of "full income" spent on the commodity group is in-

-
1. Our model should be contrasted with Dixit-Stiglitz, who took x as exogenous, but n as endogenous.
 2. We are calculating the effect of a simultaneous increase in the input of resources into R&D in all sectors.

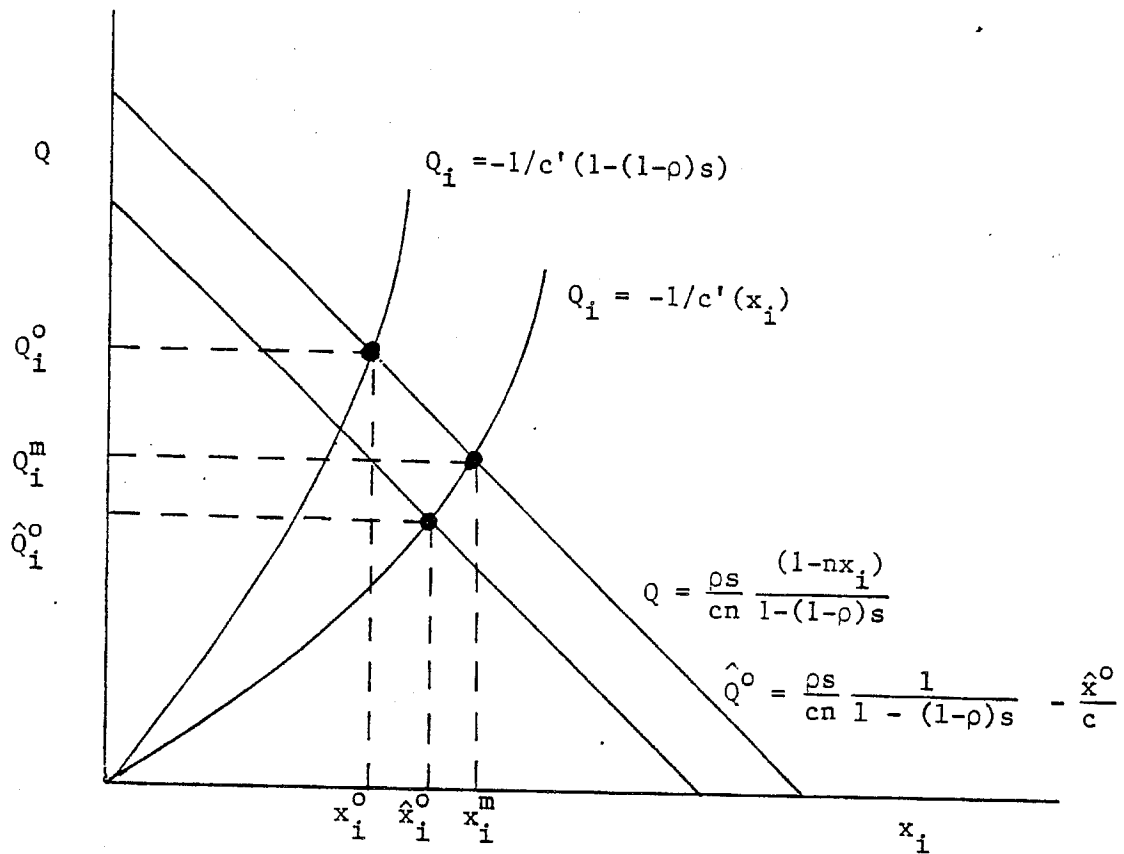


Figure 5

Comparison of Market Equilibrium with Constrained Optimality

$\{Q_i^o, x_i^o\}$ Constrained optimality: profits taxes

$\{\hat{Q}_i^o, \hat{x}_i^o\}$ Constrained optimality: excise taxes

variant to the price) and either (i) $s \approx 0$, the industrial sector is relatively small; or (ii) $\rho \approx 1$, i.e., demand curves are (almost) infinitely elastic. There are two reasons that the market equilibrium deviates from constrained Pareto optimality: first, the government takes into account the multiplier effects of the income effects associated with the increased expenditures on R&D; these are of the nature of the kind of externalities which we normally can ignore. But when there are distortions in the economy (here, we have distortions arising from the monopoly power, but similar results obtain with distortions generated by taxes, or by moral hazard (Arnott-Stiglitz (1983), Greenwald-Stiglitz (1983))), we cannot ignore these indirect effects. Second, the government takes into account the change in the level of expenditure on the industrial sector (s') which results when all firms together change their prices.

If $s' = 0$, we obtain

$$(25) \quad c'_i Q_i + \frac{1}{1 - (1-\rho)s} = 0,$$

so that, at each level of output, the optimal level of research is lower than in the market equilibrium. It immediately follows that the market equilibrium will entail a higher level of research and a lower level of output in each sector than the constrained Pareto optimum. This result is reinforced if $s' > 0$. If $s' < 0$, just the opposite may occur. We summarize this result in

Proposition 1: The market equilibrium with each sector controlled by a monopolist may entail either more or less R&D than the constrained Pareto optimum, where the government is not allowed to intervene directly in the production decisions of the monopolists, but can control the level of R&D,

and where it finances the R&D expenditure by a profits tax. The market equilibrium will entail too much R&D provided $s' \geq 0$.

An Alternative Formulation of Constrained Pareto Optimality: Excise Taxes

Assume now that government must finance R&D in the i^{th} industry by imposing a specific tax, at rate t , on the i^{th} industry:

$$(26) \quad x_i = t_i Q_i .$$

Now

$$(27) \quad p_i = (c_i + t_i)/\rho$$

and (20) becomes (in the symmetric equilibrium)

$$(28) \quad nP = \frac{(1-\rho)s[n^{-\beta}(c+t)/\rho]}{1 - (1-\rho)s[n^{-\beta}(c+t)/\rho]}$$

and (22) becomes

$$(29) \quad Q_i = \frac{\rho s}{(c+t)n} \frac{1}{1 - (1-\rho)s} .$$

Using the indirect utility function, $v = v(p, I)$, we obtain

$$\begin{aligned} \frac{dv}{dt} &= \frac{nv}{\rho} \frac{d(c+t)}{dt} + v_I \frac{dI}{dt} \\ &= \frac{nv_I}{\rho} \left[Q_i + \frac{(1-\rho)s'n^{-\beta-1}}{(1 - (1-\rho)s)^2} \right] \frac{d(c+t)}{dt} \end{aligned}$$

This is maximized when $d(c+t)/dt = 0$, i.e.,

$$(31) \quad 1 + c'(Q_i + t \frac{dQ}{dt}) = 0 .$$

But at the point where $d(c+t)/dt = 0$

$$(32) \quad \frac{dQ_i}{dt} = 0$$

(since Q_i is simply a function of $c+t$). Hence, constrained Pareto optimality entails

$$(33) \quad -c'(x)Q_i = 1$$

which is identical to (23). The difference between the market equilibrium and constrained optimality lies in the determination of Q_i . Substituting (26) into (29), we obtain

$$(34) \quad \hat{Q}^0 = \frac{\rho s}{nc} \frac{1}{1 - (1-\rho)s} - \frac{\hat{x}^0}{c}$$

which should be contrasted with (22), which we rewrite as

$$(35) \quad Q^m = \frac{\rho s}{nc} \frac{1}{1 - (1-\rho)s} - \frac{x^m \rho s}{c(1 - (1-\rho)s)}$$

If s were fixed, at each value of nx

$$(36) \quad Q^m > \hat{Q}^0 \quad \text{since} \quad \frac{\rho s}{1 - (1-\rho)s} < 1$$

Hence, if s were fixed

$$(37) \quad x^m > \hat{x}^0$$

The level of research in the monopoly equilibrium exceeds the constrained Pareto optimal level. On the other hand, s itself may be variable. Since at any x ,

$$s^m \geq s^0 \quad \text{as} \quad s' \leq 0,$$

and since

$$\frac{d[s/1 - (1-\rho)s]}{dv} = \frac{s'}{[1 - (1-\rho)s]^2} \geq 0 \quad \text{as} \quad s' \geq 0,$$

$$(38a) \quad Q^m > \hat{Q}^0$$

and

$$(38b) \quad x^m > \hat{x}^0$$

provided $s' \geq 0$.

When the government finances R&D through an excise tax, the tax is shifted, raising the price of the goods in the sector. There is thus an additional distortion associated with each increase in R&D expenditures; this should be contrasted with the market solution, where R&D expenditures are taken as fixed costs, and increases in expenditures on R&D affect price only through their effect on direct production costs. It is not surprising, then, that, in general, this constrained Pareto optimum entails less expenditure than the market equilibrium.

Proposition 2: The monopoly equilibrium entails more research than the constrained Pareto optimum where the government is not allowed to intervene directly in the production decisions of the monopolist, but can control the level of R&D, but must finance the R&D by a specific excise tax, provided $s' \geq 0$.

Constrained Optimality: Free Distribution of Knowledge

The final constrained Pareto optimum which we consider here is that where the government imposes a specific tax, to finance R&D; the knowledge produced by this R&D is then distributed freely. Thus

$$(39) \quad p = c+t, \quad x = tQ$$

and $I = 1$ (since there are no profits or lump sum taxes). Hence,

$$(40) \quad Q = \frac{s(n^{-\beta}(c+t))}{n(c+t)}$$

$$(41) \quad \frac{dv}{dt} = \Sigma \left\{ \frac{dv}{dp} \frac{dp}{dt} \right\}$$

$$= -v_I nQ \frac{d(c+t)}{dt} = 0,$$

or

$$(42) \quad c' [Q + t \frac{dQ}{dt}] + 1 = 0.$$

But $dQ/dt = 0$ when $d(c+t)/dt = 0$.

Hence,

$$(43) \quad c'Q + 1 = 0.$$

Substituting (39) into (21) and rearranging, we obtain

$$\hat{Q}^0 = \frac{s}{nc} - \frac{x}{c}.$$

It immediately follows that (using the fact that $P \geq 0$, or $nx \leq (1-\rho)s$, for each level of x ,

$$(44) \quad \hat{Q}^o - Q^m = \frac{(1-s)[(1-\rho)s - nx]}{c(1-(1-\rho)s)n} = p_i \frac{(1-s)}{c}$$

The constrained Pareto optimum output exceeds the market equilibrium, and hence the level of research in the constrained Pareto optimum exceeds that in the market equilibrium. However, the magnitude of the difference will be small, provided the level of pure rents (profits, after paying for R&D) is small. In particular, this implies that

Proposition 3: In the monopolistically competitive equilibrium, where entry occurs until profits are (approximately) zero, not only will the number of commodities being produced be the same as at the constrained Pareto optimum, but the level of research in each sector will be the same.

The analyses of this and the preceding section have established that the widespread presumption that monopolies will be characterized by too little research is, at best, questionable. Depending on the set of instruments available to the government, the monopoly equilibrium may entail just the right amount of research, too little research, or too much research.

In the following section, we explore another potential source of inefficiencies in the market allocation: will there be too little risk taking in R&D?

V. RISK TAKING IN R&D

So far, we have assumed that all research endeavors are successful. In fact, one of the most important characteristics of R&D is that the outcome of any expenditure is uncertain. The results of any research program can be described by the probability distribution of production costs. We simplify the analysis by assuming that there are only two outcomes. Either the research project fails, and costs remain at their original level, or it succeeds, with costs lowered to c_1 . By spending more resources, the probability of success may be increased.

$$(45) \quad \pi = \pi(x, c) \quad \text{with} \quad \pi_x > 0, \quad \pi_c > 0.$$

Firms may be risk averse, and this may induce them to undertake less risky research projects than a risk neutral government might desire. But the inefficiencies with which we are concerned in this paper arise from other sources as well; to focus on these other sources of inefficiency, we assume in this section that firms are risk neutral. Thus, for any given c , x is chosen by a monopolist to maximize

$$\pi\{V^m(c_1) - V^m(c_0)\} - x$$

where V^m is the present discounted value of the monopolist's profits when (marginal) costs are c . Hence x is chosen so that

$$[V^m(c_1) - V^m(c_0)]\pi_x = 1.$$

In contrast, social optimality with lump sum taxation entails

$$[S^m(c_1) - S^m(c_0)]\pi_x = 1$$

while the single researcher in an otherwise competitive market sets

$$(c_1 - c_0)Q_0\pi_x = 1 .$$

The differences between the different market allocations correspond to those discussed in Section II:

$$\pi^m < \pi^c < \pi^o ,$$

i.e., of the three, the monopolist undertakes the most risk (has the smallest probability of success), while social optimality entails undertaking the least risk (the highest probability of success). But the qualifications we raised earlier apply here as well, with two major modifications.

First, we noted earlier that when we focused our attention on a marginal analysis, where the firm could lower its costs slightly more by spending slightly more on R&D, the value of an incremental cost savings was simply proportional to output; if output under alternative market structures were the same, then R&D would be the same. This is not true for our analysis of risk taking, even when we can change the probability of success slightly by spending slightly more on R&D. Even if output under two regimes were the same, the incentives for R&D would be different.

Second, in the earlier discussion in analyzing the symmetric equilibrium, we assumed that all firms had their costs reduced by an equal amount. Now, even when all firms expend the same amount of resources on R&D, some will be successful, and others not.

To see how this changes the analysis of Section III, consider the limiting case where π is very small. Then the demand curve facing the industry the next period will shift out¹ by a negligible amount, and the wage will change a negligible amount. This implies that

$$w_0^m = w_1^m \quad w_0^c = w_1^c .$$

Though at each value of π the incentives for spending more on R&D to reduce costs further are the same under monopoly as they are in the market equilibrium, since the incentives for increasing the probability of success are greater with the market equilibrium, i.e., since $\pi^m < \pi^o$, it follows that¹

$$(46) \quad c_1^m \geq c_1^o \quad \text{as} \quad \frac{\partial c}{\partial x} + \pi \frac{\partial(\partial c_1 / \partial x) | \bar{\pi}}{\partial \pi} \geq 0 .$$

It is only through this indirect route that the traditional presumption that monopolies spend too little on R&D may be restored. (Offsetting this effect are the concerns raised earlier, that while the monopolist appropriates all of the future returns to R&D, at least those which are internal to the industry, this is not true in the competitive market structure; overall, there may be more or less research under monopoly.)

1. That is, the first order condition for c now becomes, for the monopolist,

$$\pi^m \frac{\partial V^m}{\partial c_1} \frac{\partial c_1}{\partial x | \bar{\pi}} = 1$$

while social optimality entails

$$\pi^o \frac{\partial S^m}{\partial c_1} \frac{\partial c_1}{\partial x | \bar{\pi}} = 1 .$$

Inverting (45), to express R&D expenditures as a function of c and π ,

$$x = x(c, \pi) ,$$

(46) can be rewritten as

$$c_1^m \geq c_1^o \quad \text{as} \quad \frac{\pi x_c}{x_c} \geq 1 .$$

VI. THE NUMBER OF INDEPENDENT RESEARCH PROJECTS

A third important characteristic of the research program of a firm, or the economy, is the number of independent research programs undertaken. When the probability of success of a particular line of enquiry is less than one, there may be some gains from attempting simultaneously two (or more) alternative research strategies. Whether this is the case quite clearly depends on the correlation between the success of the two projects. With perfect correlation, it is obvious that if the first project fails, so too would the second project, and therefore, it would never be socially optimal to undertake two projects. If the two projects are not perfectly correlated, it may be desirable to undertake two (or more) projects.

The first project will be unsuccessful with probability $1 - \pi_1$, and it is only in that state that the second project has a social return. Thus, the expected social return from the second project is

$$\pi_{2f}(1 - \pi_1)V^S$$

where π_{2f} is the probability of success of the second project given that the first fails. An exactly parallel analysis applies to the monopolist's decision to undertake two (or more) projects. His marginal return to the second project is

$$\pi_{2f}(1 - \pi_1)V^m .$$

Thus, the distinction between the behavior of a monopolist and social optimality depends simply on the difference between V^S and V^m , a

difference which, in the general equilibrium, we suggested might not be very large.¹

This is not true, however, of the incentives for two or more independent researchers; that is, in situations where there is competition in the R&D market (as opposed to simply competition in the product market).

Before turning to this, in the next section, we comment briefly on a closely related question: Should one wait to find out whether the first project is a failure before beginning the second project; the cost is the possible waste from unnecessary duplication; the gain is that if the first project is unsuccessful, while the second is successful, the fruits of the research project will be enjoyed earlier than if the two projects are undertaken sequentially. Obviously, if the interest rate is zero, then there is no gain from discovering the invention earlier, and it is never optimal to pursue the two research projects simultaneously.

More generally, when the interest rate is positive, there is some gain from making the discovery earlier. But whether the interest rate is zero or positive, the private and social returns to undertaking a second project simultaneously differ markedly. When both projects are successful, the private return is half of the (patentable) value of the invention, even though the marginal social return is zero. There is a systematic bias towards "too fast" research.²

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1. Precisely analogous results hold for a single researcher undertaking a second research project in a market in which there is a competitive supply at the price c_0 .
 2. The problem is analogous to the dynamic inefficiencies which arise in common resource situations; each owner of an oil well may extract oil from the well too quickly, since he believes if he does not take the oil, the other owners of wells will.

VII. COMPETITION AND RISK

Though the prevalent view among economists is that competition is good, that it stimulates innovation and economic efficiency, businessmen are often less enthusiastic about the virtues of competition. One of the central concerns expressed by businessmen is that competition forces upon them a high level of risk; there is uncertainty both about whether their own research will be successful and about what research program their rivals are undertaking, exacerbated by each firm's attempt to keep its strategies secret. Economists tend to treat their concerns as self-serving attempts to acquire monopoly rents.

In this section, we shall see that competition actually reduces risk, if the research strategies of rivals are known, but may in fact force upon entrepreneurs a high degree of risk when they are not; as a result, if they are risk averse, there may be less innovation than there is with monopoly.

The simplest "competitive" environment is that of duopoly, and accordingly, that is what we focus on here. The consequences of engaging in R&D in a duopoly depends critically on the way the duopoly functions. Before considering, however, any particular set of assumptions, it is useful to provide the general structure.

The decision tree facing the firm can be represented as in Figure 6. There are six distinct outcomes. (Contrary to the old adage, it is not, in general, better to have tried and failed than never to have tried at all: one loses the amount x .) We use the following notation:

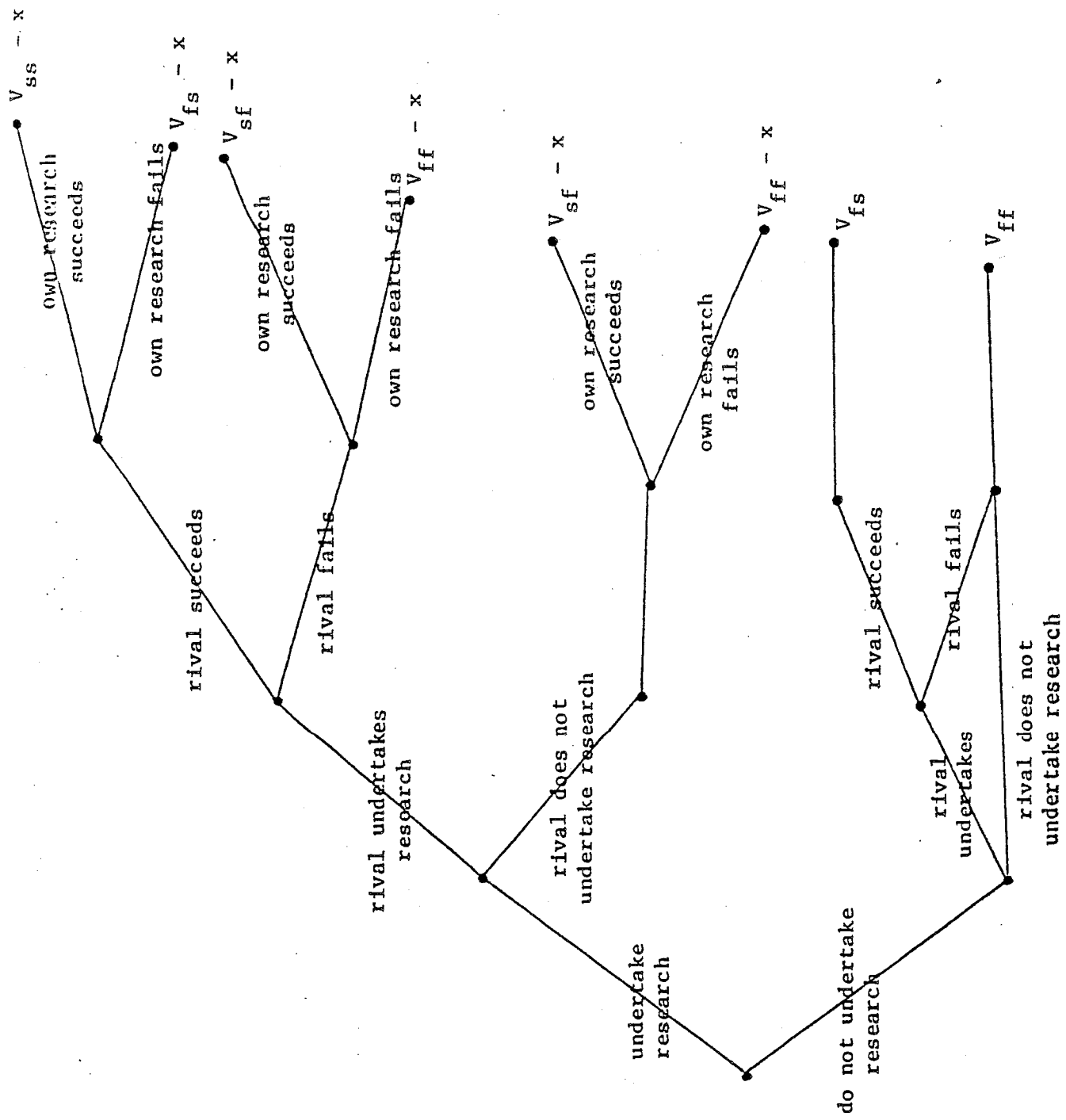


Figure 6

V_{ss} = the present discounted value of profits when both firms are successful;

V_{fs} = the present discounted value of profits when the rival succeeds in developing the new technology, but you fail;

V_{sf} = the present discounted value of profits when you succeed in developing the new technology, but your rival fails;
and

V_{ff} = the present discounted value of profits when neither succeeds in developing new technology.

Clearly

$$V_{sf} > V_{ff}$$

while

$$V_{sf} > V_{ss}$$

and

$$V_{ss} > V_{fs}$$

The firm is better off when it is successful and its rival is not than when it is not successful and its rival is not; the firm is better off when it is successful and its rival is not than when both are successful; and the firm is better off when it is successful and its rival is successful than when it is a failure and its rival is successful. Success pays. The question is, does it pay enough.

Without detailing the nature of the interactions between the two duopolists, we can still say something about the nature of the payoffs.

The increment in profits of a duopolist, if he alone is successful, can be divided into two parts:

(a) The increment in his profits, assuming his rival keeps his output constant. This, in turn, can be broken down into two parts:

- (i) The increment in profits, assuming he keeps his output constant; and
- (ii) The increment in profits from a change (increase) in his output.

(b) The change in his profits resulting from the response of his rival to his changed circumstances.

The return to the duopolist may be greater or less than that to the monopolist.

To see this, we focus on the case where one duopolist has already decided to undertake a given research project (the outcome of which is still uncertain), which will lower its costs from c_0 to c_1 with probability π_1 . The return to the second firm undertaking a research project which will lower its costs from c_0 to c_1 is

$$R^d \equiv \pi_{2s} V_{ss} \pi_1 + \pi_{2f} V_{sf} (1-\pi_1) + [(1-\pi_{2s}) V_{fs} \pi_1 + (1-\pi_{2f}) V_{ff} (1-\pi_1)] - (V_{fs} \pi_1 + V_{ff} (1-\pi_1))$$

where π_{2s} (π_{2f}) is the probability of success of the second research project given that the first project is a success (failure). To contrast this with the social return, we consider the limiting case of a Bertrand duopolist, for which

$$V_{ss} = V_{ff} = V_{fs} = 0 \quad \text{and} \quad V_{sf} = (c_0 - c_1) Q_0 /$$

Then
$$R^d = \frac{(c_0 - c_1)}{Q_0} \pi_{2f} (1 - \pi_1) = V^c \pi_{2f} (1 - \pi_1).$$

The only difference between social and private returns arises from the difference between V^c and V^s , a difference which we argued is likely to be small.

But this is the limiting case. With less fierce competition,

$$V_{sf} > V_{ss} > V_{ff} > 0 .$$

Profits are positive if the first duopolist is successful, but they are also positive if the first duopolist is not successful. As a result, it is possible for R^d to be either larger or smaller than with the Bertrand equilibrium.

We consider two limiting cases:

Perfect Correlation. Then $\pi_{2f} = 1 - \pi_{2s} = 0$ and $R^d = 0$ with the Bertrand solution. On the other hand, with the Cournot (quantity setting equilibrium),

$$V_{ss} > V_{ff}$$

and hence

$$\hat{R}^d = \pi_1 (V_{ss} - V_{fs})$$

Perfect Negative Correlation. Then $\pi_{2f} = 1, \pi_{2s} = 0$. Now for the Bertrand duopolists,

$$R^d = (V_{sf} - V_{ff})(1 - \pi_1) = V^c(1 - \pi_1)$$

while for the Cournot duopolists

$$\hat{R}^d = (1-\pi_1)(V_{sf} - V_{ff}),$$

which is positive for sufficiently small π_1 . Clearly,

$$V_{sf} - V_{ff} - V^c > 0$$

implies

$$\hat{R}^d > R^d.$$

But our concern is not just with the mean return, but with the riskiness of R&D. When the mean return to the monopolist and the duopolist from undertaking the second project is identical, the monopolist's return is unambiguously riskier (in the sense of Rothschild-Stiglitz (1971)). For the monopolist, there is only one state in which the second project has a payoff; that is, when the first project is a failure, and the second project is a success. But for the duopolist, there are four possible states, with the highest profits (when the rival's project is a failure and his a success) still being less than the monopolist's (so long as the first continues to produce).¹

It is thus apparent that if firms are sufficiently risk averse the second research project might not be undertaken by a monopoly, even though a duopolist would have undertaken it.

1. And so long as $V_{ss} - V_{fs} < V^m$. For a small innovation, this will, in general, be the case.

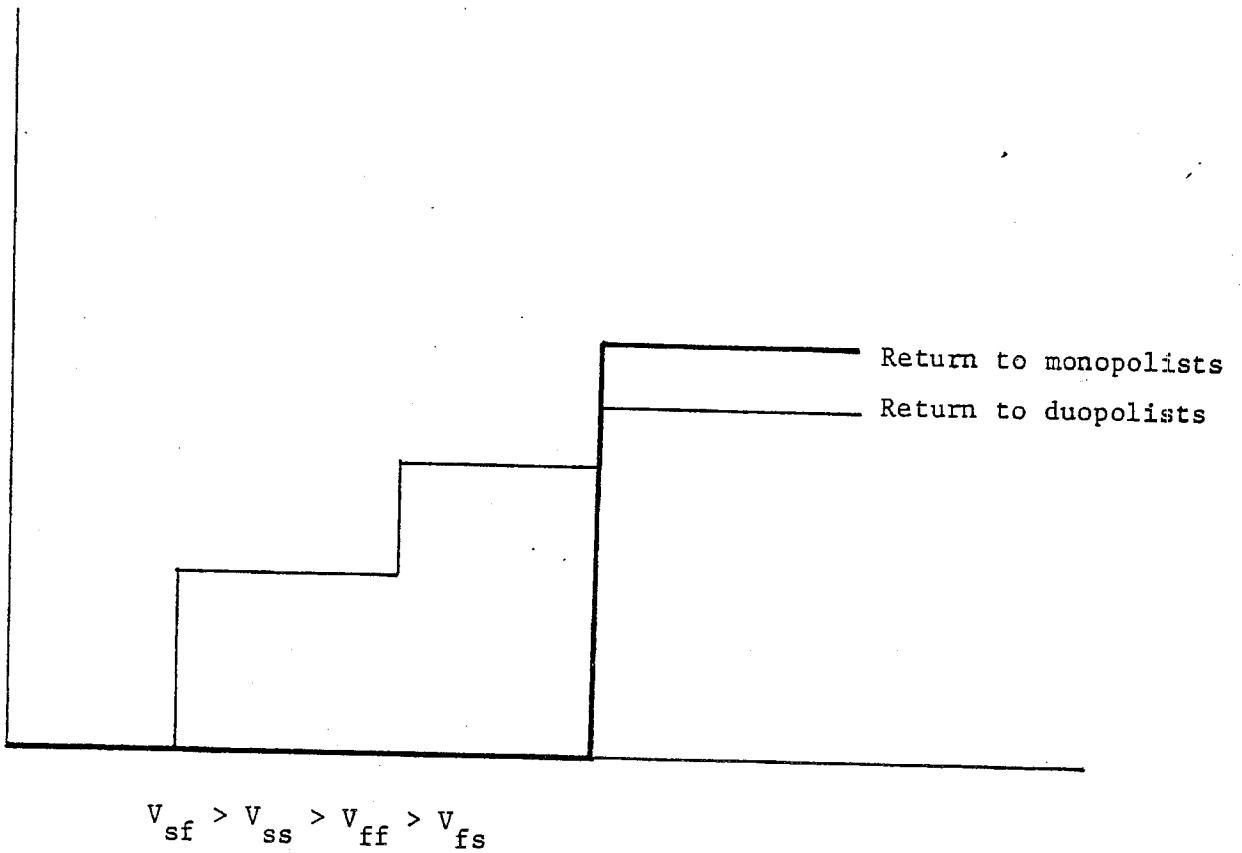


Figure 7

When there is no uncertainty about rival's research strategy, competition induces less risk.

Uncertainty About Rivals' Research Strategies

The analysis of the previous subsection assumed that the second firm knew that the first firm had undertaken a research project. We have thus eliminated one of the most important sources of uncertainty about which businessmen complain. In this section, in contrast, we assume that they do not know whether their rival has undertaken research. We shall show that, even when firms are risk neutral, equilibrium may be characterized by a slower pace of technical progress than with monopoly.

For simplicity, we limit ourselves to the case where the research projects yield perfectly correlated return, and where there is fierce competition (Bertrand price competition).

If the returns to research are perfectly correlated, there cannot exist an equilibrium in which they both always undertake research. For they will both either be successful (profits zero) or a failure (profits zero), and in either case the research has yielded no returns: competition (even in this limited form) seems inconsistent with innovation.

There exists an asymmetric non-competitive equilibrium, in which one firm always engages in research, making a profit of $\pi V_{sf} - x$, and the other firm never does (its profits are zero, but if it entered, they would be $-x$).

In this case, the only symmetric (competitive) equilibrium may be one in which both firms pursue a mixed strategy. If

$$\pi V_{sf} > x$$

there clearly is no equilibrium with no research, since if neither firm were undertaking research, it would pay a firm to enter. If each firm undertakes

the research with probability ϕ , expected profits are

$$(1-\phi)\pi Q_0 \Delta c - x,$$

where Δc is the reduction in production costs.

Thus there is a mixed strategy equilibrium with

$$1-\phi = \frac{x}{\pi Q_0 \Delta c}$$

With only two firms, competition is so keen that expected profits from R&D are driven down to zero. All the (producer) surplus generated by innovation is dissipated in the form of duplicative research. Moreover, now there will be instances when the monopolist undertakes cost reducing innovation, but they will not be undertaken (with probability $(1-\phi)^2$) by either of the duopolists.¹

The results that we have just derived, that there may not be a Nash equilibrium in pure strategies in R&D markets (see Dasgupta and Stiglitz (1980a)), and that the level of technical progress (but not the level of R&D expenditures) may decline with an increase in competition, is more general than this simple example. Gilbert and Stiglitz (1979), for instance, consider a situation where, by spending more on research, the invention may be discovered at an earlier date. The first firm to make the discovery gets the patent, and reaps the entire returns. They show that if the R&D process is non-stochastic,² then there will not exist a pure strategy equilibrium;

1. For large innovations, where it pays a (non-discriminating) monopolist to lower his price, not all the expected social return to the innovation will be dissipated; some will accrue to consumers.

2. Or, more generally, if the uncertainty in the R&D process is sufficiently small.

that there does exist a mixed strategy equilibrium; competition again is sufficiently fierce that expected profits are zero; and that as the number of firms engaged in research increases, the expected date of discovery is increased (not decreased).

In this and the preceding sections of this paper, we cast considerable doubt on the widespread presumption that competition serves as a spur to innovation; or more accurately, we showed that the traditional argument was unpersuasive, when put into a general equilibrium context, and that there were other arguments, that competition increased riskiness and led to duplicative research, which suggested that competition may serve to discourage technical progress.

We believe, however, that there is considerable truth in the widespread presumption that competition is a spur to innovation. In the next section, we present an alternative view of the economy, in which the traditional presumptions concerning the desirability of competition can be shown to be valid.

VIII. INNOVATION IN THE NEW THEORY OF THE FIRM

In the analysis presented in the previous section, we assumed that firms maximized their profits; this assumption was maintained both in the competitive and non-competitive environments.

For decades, there have been competing theories of the firm, asserting that most large enterprises were controlled by their managers. Managers did not, in general, act in the interests of shareholders, and did not maximize firm profits. These theories, regardless of their empirical validity, were usually dismissed on a priori grounds: it was impossible for rational firms not to be profit maximizing. The shareholders would quickly dismiss any manager who refused to profit maximize; and if they failed to do so, some entrepreneur would undertake a take-over of the company, ensuring that all firms would in fact be profit maximizing (or, more accurately, value maximizing). Supporters of the managerial theory of the firm questioned the efficacy of these devices which were intended to ensure that all firms value maximized; more recently it has become clear that, in the presence of imperfect information, these mechanisms will not, in general, be effective: shareholders have only limited information concerning the performance of managers; it is costly for them to obtain additional information, and there is, effectively, a public good involved in the management of any enterprise. It is not in the interests of any small shareholder to ensure that the company is well managed.

The same problems imply that the take-over mechanism will be ineffective in maintaining discipline. Thus, the central problem facing the "founder" of a firm is devising incentive structures which ensure that his managers (workers) pursue policies which are in accord with those objectives of the entre-

preneur.¹ That is, the entrepreneur must find an appropriate compensation scheme.² This is precisely the problem we posed in our earlier study (Nalebuff-Stiglitz); while there the output (the number of widgets produced) was observable, the difficulty of the task was not. Similar considerations apply here. All that the firm's owner observes is whether the project was or was not successful. He generally does not have the information to judge whether the project should or should not have been undertaken. (Indeed, if he had had the information, he would not have needed to hire the manager to make the decision about undertaking the project; he could have simply directed the manager whether to undertake the project or not.)

The problem with which we are concerned in this section, inducing the manager to act in the interests of the owner, is the standard problem in the principal agent literature. Our analysis differs from the standard analysis of such problems in several respects: first, we allow the principal to make use of information provided by other firms (thus this problem is closely related to the principal multiple agent problem, studied, e.g., by Nalebuff and Stiglitz, Holmstrom, Green and Stokey, Farrell) but differs in that the information which is used as a basis of comparison is the result of agents working for other principals. Second, we are concerned with analyzing an (admittedly simple) market equilibrium, in which the payoffs depend on--and simultaneously determine--the actions taken by all of the "agents" in the

1. For a more extensive discussion of these issues, see, e.g., Grossman and Hart (1980) and Stiglitz (1982).

2. The general problem is somewhat broader: the corporate charter includes provisions which affect take-overs, managerial discretion in changing the incentive structure, etc., all of which would, in principle, affect the price at which the original entrepreneur can sell his shares.

market. Third, we have limited ourselves to analyzing a much more restricted class of actions, undertaking or not undertaking a research project, which will either be or not be successful.

As we noted in the introduction, the design of the optimal compensation scheme entails a balancing of risk, incentive and flexibility considerations. Because managers are risk averse, compensation schemes will entail the manager's compensation having less variability than output; because incentive problems are important, compensation schemes will, in general, have the manager's rewards increase to some extent with the profits of the firm.

The nature of the optimal compensation scheme depends critically on the economic environment of the firm, e.g., on the degree of competition, for two reasons:

(a) As we argued in Part II, the degree of competition will affect the riskiness of the returns to undertaking an R&D project. If the returns are less variable the optimal compensation scheme will, in general, entail the manager bearing a larger fraction of the risks; he will then have better incentives.

(b) The set of feasible compensation schemes depends critically on what information is available. When there is more than one firm in the industry, it is at least possible to glean some information from the performance of the given firm relative to that of other firms in the industry. When there is only a single firm, such information simply is not available.

In the limiting case where the returns to the two firms (for any given level of inputs, such as effort, by the manager) are perfectly correlated, then the presence of the second firm in the industry enables the design of an incentive structure which simultaneously provides perfect incentives and eliminates all risk.

That is, we simply make the pay of the manager of the i^{th} firm

$$(47) \quad Y^i = P^i(e, \theta) - P^j(e, \theta) + w$$

where θ is some random variable which affects both firms equally, and where P^i is the profits of the i^{th} firm, a function of θ and the level of effort, e_i , of its manager (an unobservable variable). (If it were observable, the manager could be directly compensated based on his level of effort.)

Thus, the manager who maximizes his utility simply maximizes

$$U(Y^i) - D(e_i)$$

where $D(e)$ is the disutility of supplying effort ($D' > 0$, $D'' > 0$) and $U(Y)$ is the utility of income, $U' > 0$, $U'' < 0$, reflecting the risk aversion of managers. When the two firms are symmetric

$$P^i(e, \theta) \equiv P^j(e, \theta)$$

and Y^i is not random: the manager faces no risk. However, the manager sets

$$(48) \quad U'(w) \frac{\partial \bar{P}^i}{\partial e_i} = D'(e_i) .$$

The manager behaves as he would if he obtained all the returns to the firm:¹ he has perfect incentives.

1. This is slightly imprecise: if the individual obtained all the returns, his income would be random, and he would act in a risk averse manner. (48) is equivalent to the individual's receiving the marginal increase in the average returns to the firm.

Thus, the extent to which the firm behaves as an owner-managed firm (the extent to which there is a divorce between ownership and control) should be viewed as an endogenous variable, to be explained, at least partly, by the nature of the risks faced by the firm and the availability of information on which we can base a compensation scheme which both reduces the risk of the manager and provides him with appropriate incentives.¹ (For a further development of this, see Nalebuff and Stiglitz (1983a).) Accordingly, monopolies will be characterized by their managers having incentive structures in which they appropriate only a small fraction of the increase in profitability of the firm. This is what gives rise to the widely observed phenomenon of managerial slack in monopolistic organization.

The fact that for managers in competitive environments in which the returns are perfectly correlated (for each level of output) there are compensation schemes which provide perfect incentives and eliminate all risk means that these industries will appear to be much more "efficient."

Matters are somewhat more complicated if the outcomes of the research projects undertaken by the two duopolists are not perfectly correlated. For then, the manager must still bear some risk, even in a symmetric equilibrium: there is some probability that his rival will be successful and he will not. This ameliorates the advantages of the use of comparative compensation schemes, but does not totally vitiate them.

1. It is important to realize that what we are concerned with here is not only "formal" compensation schemes, contracts which specify the pay of the manager for each level of performance of his firm, relative to the performance of his rivals, but also informal compensation schemes. A manager whose firm is losing market share, or whose profits are low relative to others in the industry will find himself under intense pressure, and if the company's relative performance remains poor, he will be fired or forced to resign.

Choice of Projects

The previous subsection showed how even with a limited degree of competition we could, under certain circumstances, design compensation schemes which ensured that the manager undertook the correct level of effort, while managers of monopolies put forth too little effort (even when we designed the "best" incentive schemes we could making use of the available data).

Managers often have a choice among a variety of projects; some, for instance, may be riskier than others. Ensuring that the manager undertakes the "correct" project (from the perspective of the owner of the firm) is a difficult question. In this section we compare the incentives, say, for risk taking in competitive and non-competitive environments.¹

We first consider the incentives of a manager of a monopoly whose compensation is a linear function of the profits of the firm, but depends on whether the manager undertakes a project:

$$(49) \quad Y = \begin{cases} \alpha P + w_1 & \text{if a research project is undertaken} \\ \alpha P + w_2 & \text{if no research project is undertaken} \end{cases}$$

$$w_1 \geq w_2$$

The firm must decide whether to undertake a research project, which is characterized by V , the value of the project if successful, x , the cost of the project, and π , the probability of success.² Assume that

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1. We focus here only on incentive issues, in the absence of "selection" or screening problems. One of the reasons that managers may work hard is so that they will be thought to be "good," i.e., their performance conveys information about their characteristics. See Stiglitz (1975).
 2. We are not addressing here the question of how α is chosen. Presumably, $\alpha > 0$ because the firm wishes the manager to exert effort. In that case, changes in the terms of the contract alter the characteristics of the project. We shall ignore these effects throughout this section.

the owner of the firm knows V and x , but does not know π ; only the manager knows π . Can the owner of the firm provide the manager with an incentive structure such that he will undertake the project if and only if it is in the interests of the owner for him to do so?

The manager will undertake the project if and only if¹

$$(50) \quad U(w_1 + \alpha(V-x))\pi + U(w_1 - \alpha x)(1-\pi) > U(w_2)$$

i.e.,

$$(51) \quad \pi \geq \pi^m \equiv \frac{U(w_2) - U(w_1 - \alpha x)}{U(w_1 + \alpha(V-x)) - U(w_1 - \alpha x)}$$

The risk neutral owner wishes the manager to undertake the project if

$$(52) \quad \pi > \pi^o \equiv \frac{x}{V} + \omega/(1-\alpha)V$$

where

$$\omega = w_1 - w_2, \text{ the reward for undertaking the risk.}$$

The two decisions coincide if and only if

$$\pi^m = \pi^o.$$

1. The actual expected return to the owner from undertaking the project is not πV but $(1-\alpha)V\pi - (w_1 - w_2)$, but he has to pay only $(1-\alpha)$ of the costs of research. So a risk neutral owner would wish the firm to undertake the research if and only if $(1-\alpha)V\pi > (1-\alpha)x + (w_1 - w_2)$. The compensation scheme we investigate here is special for at least two reasons.

First, it is linear: many firms employ highly non-linear compensation schemes. Second, it assumes the manager must bear the same fraction of the costs that he receives of the returns. The manager may bear a smaller or larger fraction of the costs than he receives of the output. There are both effort costs and financial costs. Typically the manager bears all of the former, but a relatively small fraction of the latter. See Braverman-Stiglitz for a discussion of alternative cost sharing rules, and the design of the optimal cost sharing rule.

We now show that for any $\alpha > 0$ there exists an $\omega > 0$ such that $\pi^m = \pi^o$, so that the two decisions coincide.

We first prove that if $\omega = 0$,

$$\pi^m > \pi^o .$$

This follows¹ from concavity of the utility function, which enables us to write

$$\pi^m = \left\{ \frac{U(w) - U(w - \alpha x)}{\alpha x} / \frac{U(w - \alpha x + \alpha V) - U(w - \alpha x)}{\alpha V} \right\} \frac{x}{V}$$

$$> \frac{x}{V} \equiv \pi^o .$$

Thus, a compensation scheme which only rewards individual managers on the basis of success or failure will always have a higher cut-off probability than the owner would. To correct this bias, the manager must be rewarded for undertaking the project, whether it succeeds or fails, i.e., $\omega > 0$.

Since an increase in ω increases π^o and decreases π^m , it is apparent that for a sufficiently large value of ω , the interests of the two can be made to coincide. Still, the manager does not do what the owner would have liked him to do, if he could have costlessly motivated him to undertake the right action, and the manager's decisions will not maximize expected (national) income.

1. I am indebted to Paul Klemperer for pointing out a mistake in an earlier draft of this paper.

Unfortunately, the critical value of π (and hence the compensation scheme, $[\omega, \alpha]$, which induces managers to make the correct decision), depends on the values of the parameters V and x . The assumption that we previously employed, that the owner knows V and x , but not π , and that he can adjust the compensation scheme as circumstances (i.e., as V and x) change, is obviously not completely plausible.

Assume, by way of contrast, that the owner must specify a compensation scheme prior to knowing V (for simplicity, we assume throughout that x is fixed); the owner has a (subjective) probability distribution over the set of possible projects which the manager will have to consider next period. He chooses a compensation scheme which, on average, is correct. We now show that a risk averse manager will accept some small projects which the owner would like rejected and will reject some large projects which the owner would like accepted. There appears, in other words, to be a systematic bias in the manager's incentives towards accepting "conservative" projects.

To see this, we plot (the logarithm of) π^m and π^o as a function of (the logarithm of) V , in Figure 7. From (52) it is clear that

$$\frac{d \ln \pi^o}{d \ln V} = -1$$

as depicted. Straightforward differentiation of (51) with respect to V yields

$$\frac{d \ln \pi^m}{d \ln V} = -V \alpha U'(w_1 + \alpha[V-x]) / U(w_1 + \alpha[V-x]) - U(w_1 - \alpha x) .$$

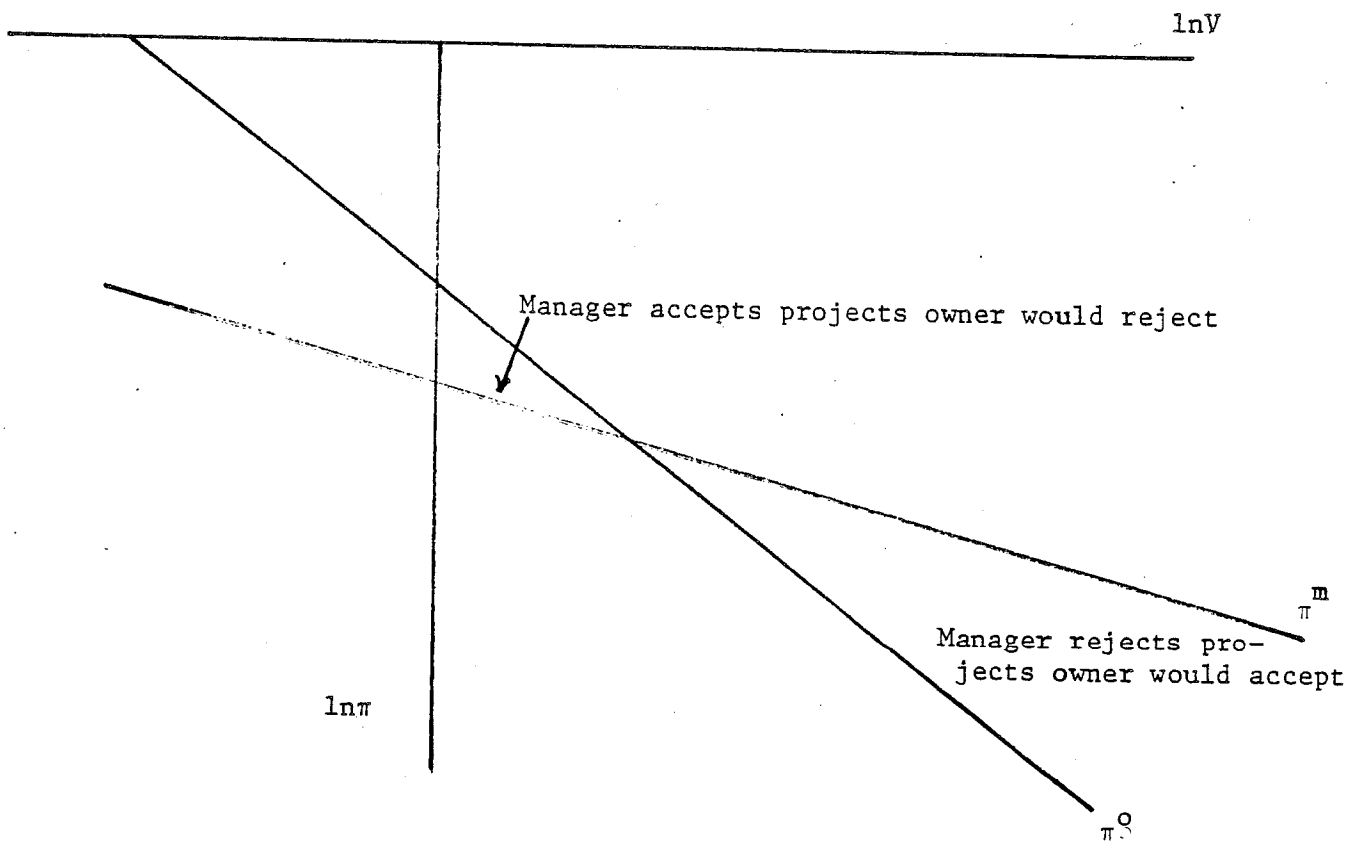


Figure 7

But the concavity of the utility function implies that

$$0 > \frac{d \ln \pi^m}{d \ln V} > -1$$

Duopoly

Consider, in contrast, the situation where there are two duopolists. Then a compensation scheme can be based on relative as well as absolute performance.

We consider the polar case of perfectly correlated outcomes. Assume the firm compensates its managers by paying him a fixed wage plus a multiple, k , of the difference between his profits and those of the rival. In that case, by choosing the multiple correctly, to offset the effects of risk aversion, the manager will always do precisely what the owners of the firm would like. At the same time, however, provided that there is a symmetric equilibrium, no risk is imposed upon the managers. This is the critical advantage of competition and compensation schemes based on relative performance.

As a result, it is possible to verify, for small variances, that if the incentives are correct on average they are correct on the margin; the critical value of π which induces a manager to undertake a project changes with a change in the value of π^0 .

Two Remarks About Welfare:

Duplication of Research Versus Incentives

We have so far said little of the welfare economics associated with the use of these schemes. In the case of perfectly correlated research projects, there is excessive duplication--an apparent waste of resources; but this duplication enables the design of an incentive scheme which reduces the risk borne by the managers, which induces risk decisions on the part of managers which are more in accord with the interests of the shareholders, which adjusts these decisions to a change in the environment, and which reduces the problems arising from managerial slack.

Correlation Among Research Projects

At the same time, we noted in previous sections that the payoff function for the firm need not coincide with the social payoff function. This may be particularly evident with compensation schemes based on relative performance, when there is a choice of research projects to be undertaken. Assume there are two projects, both of which pay off with probability 1/2, and one of which will pay off if the other does not. Assume the first firm undertakes project A. The manager of the second firm will undertake project A provided¹

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1. We assume here that the manager's pay depends not on his own performance, but only on relative performance:

$$Y = w + k (\Delta P)$$

where ΔP is the difference in profits. When both undertake the research, then in the Bertrand equilibrium, either both are successful or both are failures; in either case,

$$\Delta P = 0$$

and hence the manager receives just Y .

If the manager does not undertake the research project, then with probability .5, the other's research project is a failure, in which case

$$\Delta P = kx$$

(the other firm has spent x dollars on research, for which it has obtained no return); or the project is a success, in which case

$$\Delta P = V_{fs} - (V_{ss} - x)$$

$$U(w) > \frac{U(w + kx)}{2} + \frac{U(w - k[V_{fs} - V_{sf} + x])}{2}$$

where the manager receives a fixed wage w and a multiple k of the difference between his profits and those of his rival. Note that not undertaking the project is risky.

In contrast, the expected utility from undertaking project B is

$$\frac{U(Y + k[V_{sf} - V_{fs}])}{2} + \frac{U(Y - k[V_{sf} - V_{fs}])}{2}$$

Thus, undertaking project B, when his rival undertakes project A, imposes considerable risk, and since the expected return is zero, he will not do so. A compensation scheme which is designed to work well when managers do not have a choice over the correlation of their research projects, may not do so (at least from the social point of view) when managers have some choice over the correlation of their projects: there may be a bias to excessively high correlation. (It is also apparent that there may be multiple equilibria, one of which Pareto dominates the others.)¹

1. Similar observations have been made in the context of regulatory authorities' use of comparative performance as a basis of rate setting: see Stiglitz, et al. For a further discussion of this see Nalebuff and Stiglitz (1983a).

IX. CONCLUDING REMARKS

The traditional comparison between incentives for innovation under monopoly and competition (best represented, perhaps, by Arrow's (1962) study) entails a partial equilibrium comparison, with no uncertainty, and regardless of the nature of the competition in the product market, no competition for the development of the new product. The central issues revolve around (a) the ability of the firm to appropriate some of the returns to the innovation; e.g., if the innovation can be imitated, it is clear that the firm will not have incentives to innovate;¹ and (b) the relationship between the returns to the firm and the marginal social return to innovation; in the case of a non-discriminating monopolist, for instance, the social returns to lowering the price, as a result of a lower marginal cost, are not appropriated by the firm.²

This analysis gave rise to the view that (a) since both in competitive and non-competitive markets there were insufficient incentives for R&D, there should be government subsidies for research; and (b) since competition (provided the returns to invention could be appropriated) was more conducive to innovation than monopoly, it was important for the government to encourage competition (e.g., through anti-trust policy).

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1. The returns to R&D are often not patentable. Even an unsuccessful R&D program yields information; e.g., about the non-feasibility of a certain production process, and the returns to this kind of information can often not be appropriated.
 2. Similarly, some of the returns may represent the appropriation of rents on previously discovered knowledge which become embodied in the new innovation. See Barzel (1968) and Dasgupta and Stiglitz (1980).

Although the issues of appropriability and the relationship between marginal social returns and expected private returns from engaging in R&D are clearly the central issue, the traditional analysis has been shown to be faulty on several accounts, among the most important of which are the following:

(i) It is partial equilibrium rather than general equilibrium. The traditional analysis might be correct for an isolated sector; that is, it might provide the correct answer to the question, if all sectors of the economy but one were competitive, and that one is the only one in which R&D can occur, will there be too much or too little research? But this is hardly the question of interest: we are concerned with comparing two economies, one of which is characterized by "monopolistic" industries, the other by "competitive" industries. Which of these two economies would be characterized by more R&D is ambiguous. In one simple case, we showed that whether with monopoly more or less research is undertaken depends on whether the elasticity of labor supply is greater or less than zero.

(ii) It ignores the distortions required to raise the revenues to finance any government subsidies for R&D. Indeed, the patent system can be viewed as a special tax system designed to raise revenues for paying for R&D.

(iii) Competition affects, in an important way, the risks associated with undertaking R&D. In some cases it may be less risky to undertake research, given that one's rival does, than not to undertake it. These risk effects are important, not only in determining whether an R&D project will be undertaken, but also the nature of the R&D strategy. We suggested, for instance, that there might be a bias towards excessive correlation in research strategies.

As a consequence of the factors described above, we have concluded that there is no clear presumption that economies in which firms maximize profits (or expected utility of profits) which are dominated by monopolized industries have more or less R&D than more competitive economies.

The critical difference, we suggest, lies in the incentive structures for managers: in the presence of competition, compensation schemes based, at least in part, on relative performance can be employed, and these will in fact be more effective in inducing managers to undertake risky research projects; they have the further advantage of "flexibility" of inducing the manager to make "correct" decisions over a wider range of parameters than the incentive schemes which a monopolist might employ. Our model also provides some insights into the widely observed phenomenon of managerial slack in monopolistic sectors.

Though our analysis has focused on the comparison between the level of R&D under monopoly and with (at least some degree of) competition, our analysis provides some insights into the welfare economics of market allocations to R&D. Most importantly, we have emphasized that the appropriate comparison between the market and alternative solutions must take into account the costs of raising revenues, e.g., for R&D subsidies, and the difficulties of identifying the beneficiaries of any particular research project. We have identified circumstances in which the market, if not a constrained optimum, is probably not too far from it; R&D expenditures may be greater or less than in the constrained optimum; while the information required to design an optimal set of corrective taxes makes such schemes probably not feasible.

Two critical limitations in the analysis here--as in much of the earlier analysis--have been that we have not allowed for free entry, particularly into R&D, and we have treated the degree of monopoly in the product market (the number of firms) as exogenous, while in fact it should be viewed as endogenous (see Dasgupta and Stiglitz (1980)). This is important, because policies which might, in the short run, lead to more competitiveness (say, reducing the patent life) could, through the reduced incentives for entry into R&D, lead to less competitiveness in the long run. Moreover, while in some circumstances a monopolist's attempt to deter entry may induce it to engage in more R&D (thus potential competition may lead to faster technical progress, even if it does not lead to more competitive markets (see Dasgupta and Stiglitz (1980), Gilbert and Newbery (1979)), in other circumstances, it may have little effect on R&D (Gilbert, Stiglitz, Fudenberg and Tirole (1979)). With free entry into R&D, competition may not only result in excessive expenditures on R&D, relative to the social optimum (in contrast with the cases discussed here, where there is no significant difference), but welfare may be even lower than in the monopoly allocation (see Gilbert and Stiglitz (1979), Stiglitz (1981)).

It is clear that the threat of entry affects the riskiness of alternative research strategies for existing firms (whether presently monopolies or competitors) and risk considerations clearly affect the incentive for entry. The implications of this for the nature of the market equilibrium, the design of managerial incentive structures, and, more generally, for the level of R&D and the rate of technical progress are questions which we hope to pursue on another occasion.

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