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OPTIMUM CONTRACTS FOR RESEARCH PERSONNEL, RESEARCH EMPLOYMENT, AND THE ESTABLISHMENT OF "RIVAL" ENTERPRISES

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ABSTRACT

This paper considers the problem of hiring scientists for research and development projects when one takes explicit account of the fact that the scientist may be able to use the information acquired during the project in a rival enterprise. Management's problem is to determine an optimum labor policy for its project. The policy consists of an employment decision and a labor contract. Given optimum behavior, it is straightforward to analyse the effect of the potential for mobility of scientific personnel on project profitability and on research employment. We also formalize conditions under which one would expect to observe a scientist leaving his employer to set up (or join) a rival.

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OPTIMUM CONTRACTS FOR RESEARCH PERSONNEL, RESEARCH EMPLOYMENT, AND THE ESTABLISHMENT OF 'RIVAL' ENTERPRISES*

> However, no amount of legal protection can make a thoroughly appropriable commodity of something so intangible as information. The very use of information in any productive way is bound to reveal it, at least in part. Mobility of personnel among firms provides a way of spreading information.
>
> Arrow (1962, p. 615)

At least since the work of Schumpeter (1942) economists have stressed the fact that the private rate of return to research resources (and hence research employment) is determined, in part, by the degree to which a firm can maintain proprietary rights (monopoly power) over the information produced in its research laboratories. Given the rapid increase in industrial research expenditures since World War II and the increasingly convincing empirical evidence on their impact, it is a bit disconcerting that so little work has been done on how firms facing this appropriability

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problem ought to behave. That is, how should a firm act in order to protect its innovations? and how does the action it takes affect research demand and the structure of science-based industry?

One frequently cited mechanism for the spread of the information produced in industrial research laboratories is the mobility of scientific personnel. It is not a difficult mechanism to explain. Research projects often require a good idea and substantial investments before they produce an output which can be embodied in a marketable good or service. The output of the project is a new piece of information which has no (or a very low) cost of reproduction; and any scientist working on the project is likely to be at least as aware of this information as the management. The scientist can therefore wait until the information has been developed and then decide to leave and use it in a rival enterprise. Indeed (as will be discussed below) there are many well-documented cases of scientists leaving their employers to set up or join a rival.

This paper develops optimum labor policies for research personnel when management takes explicit account of the fact that a scientist has the option of leaving the firm to join a rival. We then consider the implications of these policies on project profitability, research employment, and the establishment of rival firms. The labor policy consists of an employment decision and a labor contract. The problem of determining an optimum labor contract for research personnel is a particular example of the principal's problem in the theory of agency (for a general description of the principal's problem, see Ross, 1973). It is closely related to Becker and Stigler's (1974) discussion of appropriate compensation schemes for law enforcers when malfeasance is possible (see also Harris and Raviv, 1978, and Lazear, 1979; articles by Nickell, 1976, Salop and Salop, 1976, and Mortensen, 1978, consider the relationship between alternative causes of employer-employee separation and labor contracts). The implications of the labor contract which are particularly interesting in this context are those related to project profitability and research employment. The determination of the level of research employment in market economies is an issue which has been extensively discussed in the literature. The discussion has centered on the question of whether the public-good characteristics of the output of research activity leads to under (or over) investment in research resources (see Arrow, 1962, Barzel, 1968, and Dasgupta and Stiglitz, 1980). Although we focus on only one of several mechanisms which can potentially spread the information produced in research laboratories--the mobility of scientific personnel--we analyse it in some detail. In particular, we shall consider how other aspects of appropriability are likely to affect our results, and we can formalize the conditions under which the potential mobility of scientists should lead to the establishment of a rival.

Section I describes the entrepreneur's basic problem. In Section II we provide an optimum labor policy, discuss how it can be implemented, and analyse some of its implications. Since the conclusions of Section II are somewhat surprising, Sections III and IV consider how they are modified by changes in the assumptions underlying the model; in Section III we consider cases where institutional constraints render the optimum labor contract unfeasible; Section IV considers changes in the model of the research and marketing process which have a substantive effect on our results. The paper concludes with a brief summary.

I. THE BASIC FRAMEWORK

Consider an entrepreneur with an idea which could lead to a successful innovation. To develop it into a marketable product, resources must be committed to a research project. The outcome of the project will be known after a single period. The period after the project is completed (the second period) will be used to market its output. Initially, assume that the only costly resource employed in the project is a scientist. At the end of the project he will possess information which enables him, if he so desires, to market the new information himself. As a result, the entrepreneur realizes that no matter what the project's technical outcome, at least two different market situations could arise. If the scientist does not leave the firm to set up (or join) a rival enterprise, the entrepreneur's firm may monopolize the information that resulted from the project. Alternatively, if the scientist sets up a rival, there will be at least two firms with the information. In this section we assume that these are the only two market situations that can arise. That is, either a single firm or two rivals will market the output from the project.

The entrepreneur's objective is to maximize the expected profits from the project. He can choose the skill level, say s, of the scientist he will employ. Given s, a series of exogenous events (associated with the realization of a particular state of nature) will determine the project's outcome. Let $\varepsilon \in R$ (R is the set of real numbers) be a random variable indicating the possible states of nature, and denote by $G(\varepsilon)$ the distribution function which embodies the entrepreneur's prior beliefs about the likelihood of the alternative states of nature. For any $\varepsilon \in R$ let $f(\varepsilon, s)$ be the net revenues to be generated by the project, when the scientist chosen has skill level s and if he does not set up a rival after the project is completed. We assume that $f(\varepsilon, s)$ is finite and non-negative for all ε and s.[1] A scientist who does not set up a rival has two alternatives. He can either stay with the firm or return to the labor market to engage in some other activity. To simplify the analysis we assume that if he should decide to stay with the firm during the second period the entrepreneur can always employ him in some other activity in which his marginal productivity equals his alternative wage.[2] If, on the other hand, the scientist does set up (or join) a rival, let the entrepreneur's net revenues be $f(\varepsilon, s) - \ell(\varepsilon, s)$, where $\ell(\varepsilon, s)$, the loss due to the establishment of the rival, is assumed to be non-negative and finite for all ε and s.

In order to hire a scientist, management specifies a labor contract, which is assumed to consist of a flat wage, $w_0(s)$, to be paid before the realization of ε, and a bonus payment, $w_1(\varepsilon, s)$, which is paid in the second period and need therefore only be paid if the scientist decides to stay with the firm. Thus, for any s, a labor contract is a couple consisting of a number, $w_0(s)$, and a random function, $w_1(\varepsilon, s)$. The choice of the triple $\{s, w_0(s), w_1(\varepsilon, s)\}$ is referred to as a labor policy.

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[1] That is, if the net revenues to be generated from marketing the output were expected to be negative, the firm would simply not market that output. Note that 'net revenues' is used to denote the sales *minus* the costs incurred during the marketing period. 'Profits' refers to these net revenues *minus* the costs of the research project.

[2] A similar assumption (constant marginal productivity over time) is used in most of the literature on labor turnover and quits; see the discussion in Nickell (1976) or in Salop and Salop (1976). It simplifies the analysis considerably by allowing one to abstract from the effect of possible changes in the future demand for employees on current employment decisions.

Consider now the behavior of scientists of different skill levels. The wages they can receive in alternative places of employment are set by the labor market and are an increasing function of their skill. We normalize s so that it equals these alternative wages and assume $s \in [0, \bar{s}] = U$. It is assumed that scientists choose their place of employment by maximizing a utility function which is linear in the money income they receive, that is, scientists are expected-payment maximizers.[3] A scientist who becomes interested in the project is on inquiry informed of the terms of the contract. These terms include the probability distribution of the bonus [i.e., of $w_1(\varepsilon, s)$ or, as would seem more likely, that of $f(\varepsilon, s)$ and its relationship to $w_1(\varepsilon, s)$; see the next section];[4] they also include the stipulation that the bonus will be

[3] Allowing for risk aversion complicates the problem significantly without changing the basic thrust of the argument presented here. The source of the complication is that if the scientist is risk averse there will, in general, be a contract which is slightly more complicated than the contracts in the set $\{w_0(s), w_1(\varepsilon, s)\}$ which is superior to all contracts in that set. Broadening the set of possible contracts complicates the technical formulation of the problem. See also note 7 below.

[4] Thus if the distribution of $w_1(\varepsilon, s)$ is approximately normal the scientist is told so and provided with its mean and variance. In a broader framework one would also ask whether the entrepreneur could, by providing the scientist with the wrong distribution function, increase expected profits. It can be shown that provided the scientist does not have sufficient information on the distribution of $f(\varepsilon, s)$ from other sources (say, from the stock market or from a community of people involved in science-based industry who have considered similar projects in the past), and provided nothing else in the problem changes as a result of the entrepreneur's actions, the entrepreneur could increase his expected profits by persuading the scientist of an overly optimistic distribution function (see Section IV). In this case, however, other aspects of the problem are likely to change. In particular, the entrepreneur is likely

paid only if the scientist decides to stay with the firm during the second period. The scientist is aware of the fact that by joining the project he will acquire information of potential value, and he realizes that it may not be in his interest to stay for both periods. If he does in fact join, he will face three alternatives at the end of the first period. He can stay and obtain the bonus, $w_1(\varepsilon, s)$. Alternatively, he can try to capitalize on the information he has acquired by setting up or joining a rival. To evaluate this possibility the scientist uses his knowledge of science-based industry and the information he has been given on the project to compute the possible pay-offs from using the information he has acquired on the project in a rival enterprise, say $p(\varepsilon, s)$. Assume that if the scientist does join (or set up) a rival he receives $p(\varepsilon, s)$ plus the market value of his labor during the second period s [all that is, in fact, required is for the amount the scientist earns in a rival to be less than or equal to $p(\varepsilon, s) + s$]. Finally, deciding that neither of these alternatives is particularly attractive, the scientist may return to the labor market to engage in another activity and earn the going rate on his skill level, s. Being an expected-payment maximizer, he will accept the bonus and stay with the firm if $\varepsilon \in A = \{\varepsilon | w_1(\varepsilon, s) \geq \max[p(\varepsilon, s) + s, s]\}$. He will quit to set up a rival if $\varepsilon \in Q =$

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to want to hire additional scientists later and they are not likely to believe in an entrepreneur who has cheated before. Moreover, the scientist may realize that he has been cheated early on in the project and leave before its completion. Similar issues arise in much of the literature on labor contracts (see, for example, Lazear, 1979) and we assume, as is customary, that the considerations outlined above induce the entrepreneur to reveal the correct information. A deeper analysis of this issue may, however, be warranted.

$\{\varepsilon | p(\varepsilon, s) + s > \max[w_1(\varepsilon, s), s]\}$; and if $\varepsilon \in R - A - Q$ he will return to the labor market.[5] Clearly, then, a scientist of skill level s will only accept the offer to join the project if $w_0(s) + {}_A\int w_1(\varepsilon, s)dG + {}_Q\int[p(\varepsilon, s) + s]dG + s \int_{R-A-Q} dG \geq 2s$, that is, if the expected payments from joining the project are at least equal to the payments he would receive over the two periods in alternative employment (for simplicity we shall ignore discount factors).

The economic structure of the problem set out in this section suggests one more constraint (Section IV differs in this respect). If the scientist's evaluation of $p(\varepsilon, s)$ and the entrepreneur's beliefs on $\ell(\varepsilon, s)$ are at all close to the gains the scientist would actually make from setting up a rival and the entrepreneur's consequent losses, respectively, we would expect $p(\varepsilon, s) - \ell(\varepsilon, s) \leq 0$. The difference between $p(\varepsilon, s)$ and $\ell(\varepsilon, s)$ is likely to be a result of two factors: the additional costs incurred if a rival is set up, and the fact that post-project competitive behavior is likely to divert to consumers some of the gains that would otherwise accrue to the monopolist. Thus, the sum of the gains that would accrue to the two agents in a situation involving rivalry could never exceed those that would accrue in the monopolistic situation. This would be true even if neither of them incurs any additional costs as a result of the rival appearing. The rival, however, is likely to incur some start-up costs, and he must also be able to circumvent any legal and institutional mechanisms which give the entrepreneur some degree of protection on the innovations emanating from his own research laboratories.

[5] Let B and C be two sets. To simplify the notation we denote the union of B and C when B and C are disjoint by $B + C$; and the set of all elements in B which are not contained in C, by $B - C$.

These may include the costs of 'patenting around' entrepreneur's patents, or simply the costs of advertising and product differentiation [in this context the appearance of a rival may also induce the entrepreneur to increase his expenditures and this would also tend to reduce $p(\varepsilon, s) - \ell(\varepsilon, s)$]. Although, as we show in the next section, the condition that $p(\varepsilon, s) - \ell(\varepsilon, s) \leq 0$ is sufficient for our purposes, we begin by restricting the problem further and assuming that $\ell(\varepsilon, s) = \alpha f(\varepsilon, s)$ for $0 \leq \alpha \leq 1$, and $p(\varepsilon, s) = \alpha f(\varepsilon, s) - c(s)$. Here, if the scientist sets up a rival, the entrepreneur loses a fraction α of the net revenues that he would otherwise have obtained. The scientist, on setting up or joining a rival, gains all these net revenues but must incur set-up costs, $c(s) \geq 0$.

We can now formalize the entrepreneur's expected-profit maximization problem.

Problem A

$$\max_{\{s \in U, w_0(s), w_1(\varepsilon, s)\}} \Pi = \int_R f(\varepsilon, s)dG - w_0(s) - \int_A [w_1(\varepsilon, s) - s]dG - \int_Q \alpha f(\varepsilon, s)dG ,$$

where $A = \{\varepsilon | w_1(\varepsilon, s) \geq \max[\alpha f(\varepsilon, s) - c(s) + s, s]\}$ and $Q = \{\varepsilon | \alpha f(\varepsilon, s) - c(s) + s > \max[w_1(\varepsilon, s), s]\}$, subject to

$$\text{(A.1)} \qquad 2s \leq w_0(s) + \int_A w_1(\varepsilon, s)dG + \int_Q [\alpha f(\varepsilon, s) - c(s) + s)]dG + s \int_{R-A-Q} dG .$$

We shall impose the usual regularity conditions on $f(\varepsilon, s)$. That is for each ε, $f(\varepsilon, s)$ will be assumed to be increasing and concave in s [$f_s'(\varepsilon, s) > 0$, $f_{ss}''(\varepsilon, s) < 0$], while $f_{ss}''(\varepsilon, s)$ is assumed to be bounded.

(The regularity conditions are required for the existence of a unique optimum s, but not for our derivation of the optimum contract.)

II. OPTIMUM LABOR POLICIES

> Semiconductor firms attract and reward valuable employees not so much by offering high salaries as by giving stock options.
>
> Braun and MacDonald (1978, p. 132)

Proposition 1 provides the solution to Problem A.

Proposition 1: An optimum labor policy for Problem A consists of the labor contract

$$w_1^*(\varepsilon, s) = \max\{\alpha f(\varepsilon, s) - c(s) + s, s\} \qquad \text{for all } \varepsilon \in R ,$$

$$w_0^*(s) = s - \int_{A_*} [w^+(\varepsilon, s) - s]dG = s - \int_{A^*} [\alpha f(\varepsilon, s) - c(s)]dG$$

[where $A_* = R$ and $A^* = \{\varepsilon | \alpha f(\varepsilon, s) - c(s) \geq 0\}$], and the unique skill level, s^*, which satisfies $\int_R f_s'(\varepsilon, s^*)dG = 1$ (if no such $s^* \in U$ exists, the optimum s is at one of the boundaries, 0 or $\bar{s}$).

Proof: It is helpful to construct the proof of this proposition in two parts; first showing that $\{w_0^*(s), w_1^*(\varepsilon, s)\}$ provides an optimum labor contract no matter what s is chosen, and then showing that s^* is indeed optimal.

We assume, to the contrary, that there exists an s, say $\tilde{s}$, and a feasible labor contract $\{\tilde{w}_0(\tilde{s}), \tilde{w}_1(\varepsilon, \tilde{s})\}$ such that $\Pi\{\tilde{s}, \tilde{w}_0(\tilde{s}), \tilde{w}_1(\varepsilon, \tilde{s})\} > \Pi\{\tilde{s}, w_0^*(\tilde{s}), w_1^*(\varepsilon, \tilde{s})\}$, and then show that this involves a contradiction. Since $\{\tilde{w}_0(\tilde{s}), \tilde{w}_1(\varepsilon, \tilde{s})\}$ must satisfy (A.1);

$\tilde{w}_0(\tilde{s}) \geq 2\tilde{s} - {}_{\tilde{A}}\int \tilde{w}_1(\varepsilon, \tilde{s})dG - {}_{\tilde{Q}}\int[\alpha f(\varepsilon, \tilde{s}) - c(\tilde{s}) + \tilde{s}]dG - \tilde{s} \int_{R-\tilde{A}-\tilde{Q}} dG$, with $\tilde{A}$ and $\tilde{Q}$ defined as in Problem A. Substituting this expression into the profit function and comparing it with the profits that would be earned as a result of $\{w_0^*(\tilde{s}), w_1^*(\varepsilon, \tilde{s})\}$, we have $\Pi\{\tilde{s}, \tilde{w}_0(\tilde{s}), \tilde{w}_1(\varepsilon, \tilde{s})\}$ - $\Pi\{\tilde{s}, w_0^*(\tilde{s}), w_1^*(\varepsilon, \tilde{s})] = -{}_{\tilde{Q}}\int c(\tilde{s})dG \leq 0$, a contradiction.

Given that $\{w_0^*(s), w_1^*(\varepsilon, s)\}$ is optimal, $Q^* = \emptyset$ (the null set) and $w_0^*(s) = s - \int_{A^*}[w_1^*(\varepsilon, s) - s]dG$. Substituting these expressions into the profit function we find that the firm's problem is reduced to choosing an $s \in U$ which maximizes ${}_R\int f(\varepsilon, s)dG - s$. Clearly, the necessary and sufficient conditions for a maximum for this problem are obtained at s^* as defined above. []

It is worth noting that though there is a unique s^* there are many labor contracts which will maximize profits. In fact, all we require for a contract to be optimal is that the bonus payment be such that it never induces a scientist of skill level s^* to set up a rival, and that the flat rate be the minimum acceptable rate (satisfying A.1) given the structure of the bonus. More formally, we have

Corollary 1.1: Any labor policy consisting of s^* and a labor contract satisfying $w_1(\varepsilon, s^*) \geq \alpha f(\varepsilon, s^*) - c(s^*) + s^*$ (for all $\varepsilon \in A^*$) and $w_0(s^*) + {}_A\int[w_1(\varepsilon, s^*) - s^*]dG = s^*$ will be optimal for Problem A.

The project will always generate more net revenues if there is one firm monopolizing its output than if there are two rivals. The entrepreneur can ensure both that the rival never appears and that the expected costs of hiring the scientist do not exceed his alternative wage, by setting a high enough $w_1(\varepsilon, s^*)$ and lowering $w_0(s^*)$ appropriately.

By proceeding in this manner the entrepreneur gains the maximum expected rents that could accrue to the scarce factor, that is, to the entrepreneur's idea.

Of the contracts satisfying Corollary 1.1, we emphasize $\{w_0^*(s), w_1^*(\varepsilon, s)\}$ for two reasons; first, it is exceedingly easy to implement. The hiring agreement need only specify that during the second period the scientist will be offered, in addition to his alternative wage, a stock option. The stock option specifies that if the scientist decides to stay with the firm in the second period he will be allowed to purchase, at a cost of $c(s)$, a fraction α of the firm's equity.[6] Of course the offer of a profit-sharing scheme of the form $w_1(\varepsilon, s) = \beta f(\varepsilon, s) + s$, with $\beta \geq \max_{\varepsilon \in R}[\alpha f(\varepsilon, s) - c(s)]/f(\varepsilon, s)$ and with $w_0(s)$ as defined in the corollary, will do equally well. In fact, a stock-option (or profit-sharing) scheme of this form will be optimal for arbitrary gain $[p(\varepsilon, s)]$ and loss $[\ell(\varepsilon, s)]$ functions provided that $\beta \geq \max_{\varepsilon \in R} p(\varepsilon, s)/f(\varepsilon, s)$ [there may be some advantage in setting $\beta \geq \max_{\varepsilon \in R} \ell(\varepsilon, s)/p(\varepsilon, s)$, for then the scientist has no bargaining counter after the realization of ε]. The second, and perhaps more important, reason for emphasizing stock-option agreements is that they tie the second-period payment to the scientist directly to the fortunes of the firm--that is, the realization of ε--and to those aspects of the structure of the industry that determine the gains and losses that would result from setting up a rival [here, α and $c(s)$]. As we shall see, once one complicates Problem A

[6] This of course assumes that the project is financed by the issue of equity and that the stock market provides a reasonable approximation of the value of the project. Note that if $\alpha f(\varepsilon, s) - c(s) < 0$ it does not matter whether the scientist stays with the firm or engages in some other activity.

either by adding additional constraints or by changing the economics of the research and marketing processes in a substantive way, the set of optimum contracts narrows but they must always have these characteristics. In fact they are the characteristics that distinguish contracts for research personnel from contracts designed to deal with other problems of employer-employee relationships that may arise (which explains the quotation at the beginning of this section).[7]

Proposition 1 implies that the entrepreneur can maximize expected profits by following a simple two-stage decision procedure. First choose s to maximize expected profits, ignoring the fact that the scientist may be able to use the information he acquires on the project to set up a rival; then choose a labor contract that ensures both that a rival never appears and that the expected costs of employing the scientist just equal his alternative wage. There will always exist a particularly simple labor contract consisting of a flat rate and a profit-sharing scheme which satisfies these conditions. Note that this implies that, provided all agents behave optimally, input decisions (s), and the expected profitability of research projects are independent of the institutional, market, and technological conditions which determine the gains and the

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[7] An interesting literature is developing on the characteristics of employer-employee contracts that deals with an assortment of agency problems including monitoring of on-the-job effort, the allocation of uncertainty, and the unravelling of unobserved characteristics (see, among others, Stiglitz, 1975, Akerloff, 1976, Salop and Salop, 1976, Nickell, 1976, Mortensen, 1978, Lazear, 1979, and Lazear and Rosen, 1981). Each of these problems is of course likely to have some effect on contracts for research staff. However, so far as we can tell, none of them in themselves induce payment schemes with the characteristics discussed above.

losses agents would incur if a rival were set up. That is, the potential mobility of scientific personnel affects neither the profitability of research projects nor employment in them. As noted, these conclusions are not altered if we replace the particular gain and loss functions used here with arbitrary ones satisfying the basic condition that $p(\varepsilon, s) \leq \ell(\varepsilon, s)$ for all $\varepsilon \in R$. Nor will they change if one allows for the fact that many different factors of production are typically used in research projects (i.e., in this case all input quantities should be chosen to maximize expected profits ignoring the possibility that a rival will appear).[8]

[8] In particular, the entrepreneur will never be induced to substitute any other factor for skill beyond the point where the ratio of the expected marginal products of all factors equals the ratio of their costs; regardless, of course, of whether an increase in skill decreases the cost of setting up a rival. The problem does get more complicated in situations where it may be profitable to hire more than one scientist who will (at the end of the first period) possess information which enables them to set up a rival. The reason is that the gains any one of the scientists would make from setting up a rival may, in this case, depend on the behavior of the others. Provided the total gains from setting up a rival are always less than the entrepreneur's losses and that constraints analogous to (A.1) continue to hold, the solution does not, however, differ substantively. The entrepreneur ought still to ensure that a rival never appears by paying each scientist a high enough bonus (say higher than the maximum gain he could make as a result of a rival appearing), to lower the initial wage as much as possible, and thus to ensure that he (the entrepreneur) garners all the expected net revenues from the project other than the scientists' alternative cost. Of course, for many (usually all but one or two) of the individuals working on a research project these considerations are irrelevant. Most personnel do not work on tasks enabling them to gather information of much value to a rival.

There are two implications of this section which may be somewhat surprising. First, entrepreneurs need not be averse to the mobility of scientific personnel; second, provided all agents act optimally, we should not observe a scientist breaking away from an established firm to join or set up a rival. The next two sections investigate the robustness of these findings to certain changes in the assumptions underlying the model. Section III considers situations in which labor contracts of the form given in Corollary 1.1 are not feasible; while Section IV considers situations in which a different description of the research and marketing process is relevant.

III. NON-NEGATIVE LABOR CONTRACTS

The conclusions of the last section rest on the assumption that one can always implement a labor contract which satisfies the conditions that $w_1(\varepsilon, s) \geq \alpha f(\varepsilon, s) - c(s) + s$ for all $\varepsilon \in A^*$ and $w_0(s) = s - {}_A\int [w_1(\varepsilon, s) - s]dG$ where $A^* = \{\varepsilon | \alpha f(\varepsilon, s) - c(s) \geq 0\}$. Clearly, if the project has some probability of generating large net revenues, or if α is large while $c(s)$ is small, these conditions may require $w_0(s)$ to be very small or negative. Since either convention or legal restrictions (minimum-wage laws) may constrain $w_0(s)$ to be above some minimum value (which we take for simplicity to be zero), the question which arises is how the conclusions of the last section are changed if, in addition to the feasibility constraint (A.1), a labor policy must also satisfy the non-negativity constraint

(A.2) $$w_0(s) \geq 0 .$$

For any particular s it may now be impossible for the entrepreneur to ensure both that a rival does not appear and that the expected payments to the scientist just equals his alternative wage. In this case then the profitability of the project and the choice of research inputs may depend on the factors that determine the gains and losses that would occur if the scientist did set up a rival. On the other hand, provided all agents act optimally, the scientist will still never be induced to set up the rival. These assertions follow from Proposition 2 and its corollaries.

Proposition 2: If constraint (A.2) is added to Problem A, then, no matter what the choice of s, the contract $\{w_0^+(s), w_1^+(\varepsilon, s)\}$ will be optimal where

$$w_1^+(\varepsilon, s) = \max\{\alpha f(\varepsilon, s) - c(s) + s, s\} \qquad \text{for all } \varepsilon \in R$$

and

$$w_0^+(s) = \max\{0, \delta(s) = s - {}_R\int[w_1^+(\varepsilon, s) - s]dG\} \quad .$$

Since $w_1^+(\varepsilon, s) = w_1^*(\varepsilon, s)$ for all $\varepsilon \in R$ the stock-option agreement will still be optimal. However, if the expected gains from the stock option are now greater than the scientist's market wage $[\delta(s) < 0]$, the entrepreneur sets the flat rate at zero and pays the scientist more than $2s$. Note that the entrepreneur ought never to induce a scientist to set up a rival, that is $Q_+ = \emptyset$.

Proof: We first show that for any contract $\{\tilde{w}_0(s), \tilde{w}_1(\varepsilon, s)\}$ satisfying (A.1) and (A.2) to be optimal, $\tilde{Q}$ must equal the null set. We then show that of all contracts satisfying $\tilde{Q} = \emptyset$ and (A.1)-(A.2), $\{w_0^+(s), w_1^+(\varepsilon, s)\}$

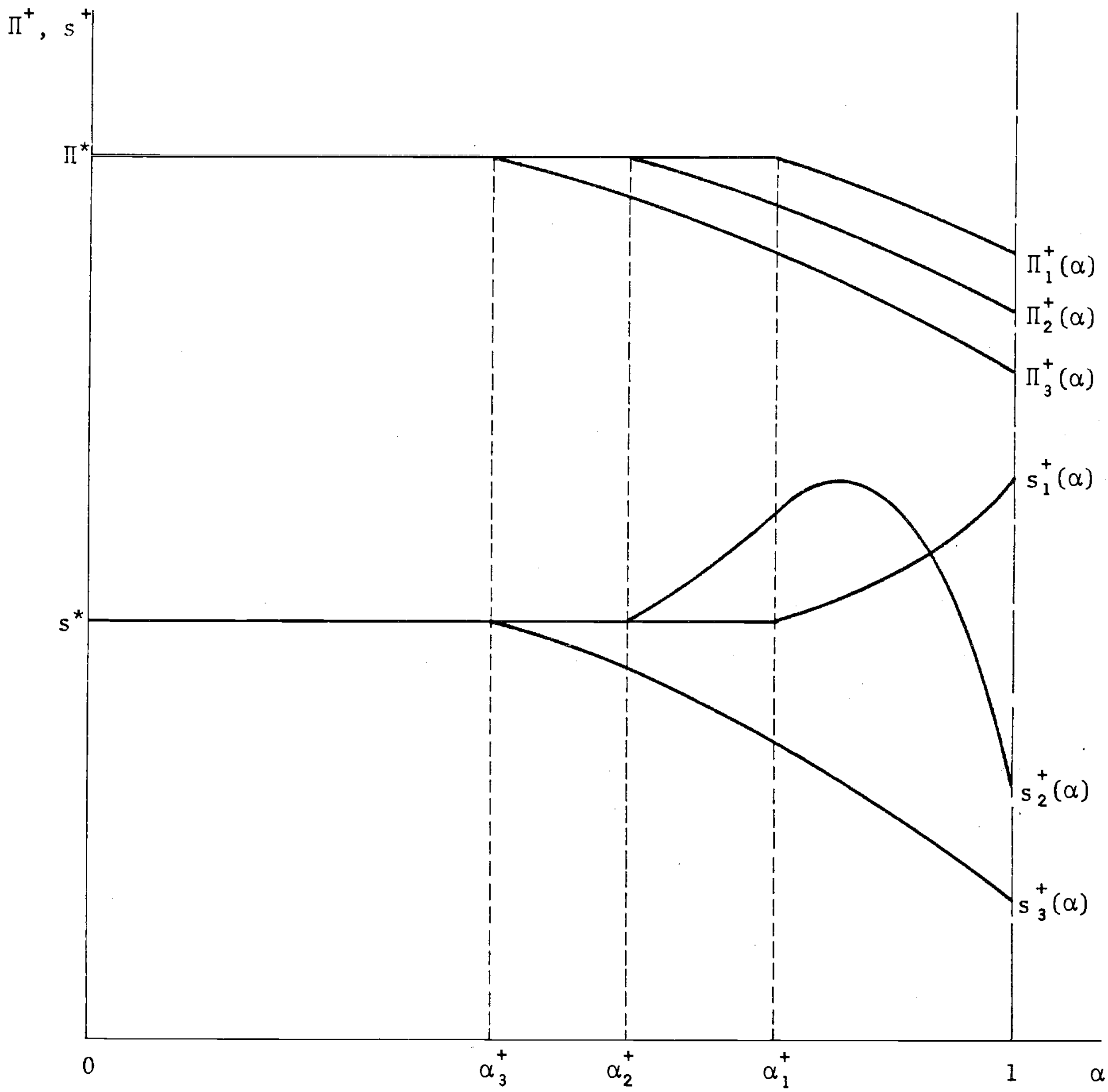
is the optimum. Thus consider comparing the expected profits from the contract $\{\tilde{w}_0(s), \tilde{w}_1(\varepsilon, s)\}$ to those from $\{\hat{w}_0(s), w_1^+(\varepsilon, s)\}$ where $\hat{w}_0(s) = \tilde{w}_0(s) + {}_{\tilde{A}}\int[\tilde{w}_1(\varepsilon, s) - w_1^+(\varepsilon, s)]dG$. Note that if $\{\tilde{w}_0(s), \tilde{w}_1(\varepsilon, s)\}$ satisfies (A.1)-(A.2) so does $\{\hat{w}_0(s), w_1^+(\varepsilon, s)\}$ [$\tilde{w}_1(\varepsilon, s) \geq$ the pay-offs to the scientist under the latter contract for $\varepsilon \in \tilde{A}$, while $w_1^+(\varepsilon, s) \geq$ the pay-offs to the scientist under the former for $\varepsilon \in R - \tilde{A}$]. On direct substitution into the profit function we have $\Pi\{s, \tilde{w}_0(s), \tilde{w}_1(\varepsilon, s)\} - \Pi\{s, \tilde{w}_0(s), w_1^+(\varepsilon, s)\} = -{}_{\tilde{A}}\int[w_1^+(\varepsilon, s) - s]dG - {}_{\tilde{Q}}\int \alpha f(\varepsilon, s)dG + {}_{A^*}\int[w_1^+(\varepsilon, s) - s]dG = -{}_{\tilde{Q}}\int c(s)dG \leq 0$, where the last equality follows from the fact that $A^* = \tilde{Q} + \tilde{A} - D$ $[D = \{\varepsilon | \varepsilon \in \tilde{A}$ and $\varepsilon \notin A^*\}]$, and $w_1^+(\varepsilon, s) = s$ for $\varepsilon \in D$. Thus we restrict our discussion to contracts which result in $\tilde{Q} = \emptyset$ which implies that $\tilde{w}_1(\varepsilon, s) - s \geq \alpha f(\varepsilon, s) - c(s)$ for all $\varepsilon \in A^*$. Among these contracts the feasibility condition implies that $\tilde{w}_0(s) \geq s - {}_{A^*}\int[\tilde{w}_1(\varepsilon, s) - s]dG$, from which it follows that for given s expected profits must be less than equal to the number $\Pi_1(s) = {}_R\int f(\varepsilon, s)dG - s$ [$\Pi_1(s)$ would be the optimum profit if there were no non-negativity constraint, see Proposition 1]. On the other hand, since $\tilde{w}_1(\varepsilon, s) - s \geq \alpha f(\varepsilon, s) - c(s)$ for all $\varepsilon \in A^*$, the non-negativity constraint implies that expected profits must be less than or equal to $\Pi_2(s) = {}_R\int f(\varepsilon, s)dG - {}_{A^*}\int[\alpha f(\varepsilon, s) - c(s)]dG$ [$\Pi_2(s)$ would be the optimum profit level if there were no feasibility constraint, i.e., if expected payments to the employee could be made as small as we like provided that $w_0(s) \geq 0$]. But $\Pi[s, w_0^+(s), w_1^+(\varepsilon, s)] = \min[\Pi_1(s), \Pi_2(s)]$. []

Note that though the non-negativity constraint should not produce a situation in which we actually observe a scientist setting up a rival, it may cause the expected profitability of the research project and research employment to differ from what they would be if the entrepreneur were to choose s by maximizing expected profits while ignoring the possibility of a rival appearing, that is, if he chose s^* of the preceding section. [Clearly, a necessary condition for this is that $\delta(s^*) < 0$; otherwise the policy $\{s^*, w_0^*(s^*), w_1^*(\varepsilon, s^*)\}$ will satisfy (A.2) as well as (A.1).]

Figure 1 illustrates this point by providing the optimum profit and research employment (Π^+ and s^+) for this problem when $c(s) = c_0 + c_1 s$ [$c(s) \geq 0$ for all $s \in U$]. In the figure α^+ is that level of α which solves $\delta(s^*) = 0$. Three cases are distinguished. In case 1, $c_1 \geq 0$ or $|c_1|$ is small; in case 3, $c_1 < 0$ and $|c_1|$ is large; and in case 2, $c_1 < 0$ and $|c_1|$ is in some intermediate range. Clearly increases in α to the left of α^+ will not affect either s^+ or Π^+, and, as one might expect from Schumpeterian arguments, increases in α to the right of α^+ can only decrease Π^+ (a similar argument, also following directly from Proposition 2, can be made regarding decreases in c_1). More surprising is that though profits decrease as a result of increases in α (decreases in c_1) the skill level need not. For example, provided $c_1 \geq 0$ or $|c_1|$ is small (case 1) s^+ will always be greater than s^* and s^+ will increase with α. More formally, we have the following corollary.

Corollary 2.1: Assume $c_1 \geq 0$ and define $N^+ = \{s | s \geq s^*$ and $\delta(s) \geq 0\} \cup \bar{s}$. Then $s^+ = \min s$ subject to $s \in N^+$. That is, if $\delta(s^*) \geq 0$, constraint (A.2) is superfluous and $s^+ = s^*$. If there is no $s^* \leq s \leq \bar{s}$ that satisfies $\delta(s) \geq 0$, then $s^+ = \bar{s}$ (the maximum value of s). If $\delta(s^*) < 0$ and $\delta(\bar{s}) \geq 0$, then s^+ is the unique s contained in N^+ that satisfies $\delta(s^+) = 0$, since $\delta(s)$ is a monotonic increasing function of s for $s \geq s^*$. Clearly, $s^+ \geq s^*$ and nondecreasing

Figure 1. Π^+, s^+, α *and* c_1



in α, i.e., $\partial s^+/\partial\alpha \geq 0$ (see Figure 1).

Proof: From Proposition 2, s^+ is that value of s which satisfies $\max_{s \in U}[\min\{\Pi_1(s), \Pi_2(s)\}]$. Note that $\delta(s) = \Pi_2(s) - \Pi_1(s)$, and that $\Pi_2'(s) \geq 0$ for all $s \in U$ while $\Pi_1(s)$ is concave and has a maximum at s^*. Thus if $\delta(s^*) \geq 0$, $\Pi_1(s^*)$ is attainable $[\leq \Pi_2(s^*)]$ and since $\Pi_1(s^*) \geq \Pi_1(s)$ for all $s \in U$, $s^+ = s^*$. If $\delta(s^*) < 0$ while $\delta(\bar{s}) > 0$, then, since $\delta'(s) > 0$ for all $s \in (s^*, \bar{s})$, there exists a unique s, say $\hat{s} \in (s^*, \bar{s})$, with $\delta(\hat{s}) = 0$. For $s \geq \hat{s}$, $\Pi_1(s) \leq \Pi_1(\hat{s})$, while for $s \leq \hat{s}$, $\Pi_2(s) \leq \Pi_2(\hat{s})$, which proves that in this case $s^+ = \hat{s}$. Finally, if $\delta(\bar{s}) \leq 0$, then $\Pi_2(\bar{s})$ is attainable $[\leq \Pi_1(\bar{s})]$ and since $\Pi_2(\bar{s}) \geq \Pi_2(s)$ for all $s \in U$, $s^+ = \bar{s}$. []

It may be helpful to consider the intuition behind this result. Say $\delta(s^*) < 0$. Then at s^* the marginal increase in costs from increasing skill equals the increase in the expected bonus, which is just a fraction α of the increase in benefits. This will be true for any $s^* \leq s < s^+$. At s^+ the feasibility constraint becomes binding and the increase in costs that results from a further increase in skill jumps discretely to unity. Since $s^+ > s^*$, and $f(\cdot, \cdot)$ is concave in s, the marginal increase in benefits at s^+, i.e., $_R\int f_s'(\varepsilon, s^+)dG$, is less than unity. Hence increases in s beyond s^+ increase costs more than expected benefits. (The proofs for the second and third cases in the diagram are slightly more complicated. They follow from the fact that $c_1 < 0$ implies that $\Pi_2(s)$ is concave in s.)

There is here a point worth emphasizing. Although the institutional and technological factors which determine the gains and the losses that would result if the scientist sets up a rival may affect the allocation of resources to research if certain reasonable (non-negativity) constraints are placed on labor contracts, a more protective environment does not necessarily induce more research expenditures. If, for example, the proportion of revenues the scientist would derive by setting up a rival were independent of his skill level, any increase in this proportion should induce more expenditures on skill.[9,10]

The other implication of this section which should be stressed is that non-negativity constraints on labor contracts ought not, in themselves, lead to scientists actually breaking away from their employers to set up rivals. Thus, if we are looking for the conditions that may induce them to do so, we should probably examine the economics of the research and marketing processes themselves more closely. This is the topic of the next section.

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[9] Barzel (1968) and Dasgupta and Stiglitz (1980) have shown that research expenditures will tend to be higher in a world where many individuals possess the idea underlying the research project than in a world where one individual monopolizes the idea. In this section we have assumed that initially only one individual has the idea and have considered changes in the environment which allow more or less protection to the resulting innovations. See also the discussion of the next section.

[10] Note also that if constraint (A.2) is binding at s^+, the optimum contract is unique (this contrasts with the situation when there is no non-negativity contraint; see the discussion of the preceding section). In this case the optimum labor policy will be more closely related to the precise assumptions underlying the model. For example, with the assumptions used here, $\Pi(s^+) \geq 0$ if $\Pi_1(s^*) \geq 0$. If we had allowed for a fixed start-up cost of engaging in the project (say the cost of a laboratory), then $\Pi(s^+)$ could be negative, in which case the solutions provided in the diagram would only be appropriate if $\Pi(s^+) \geq 0$. If $\Pi(s^+)$ is negative the project will not be undertaken.

IV. *QUITS AND THE ESTALISHMENT OF 'RIVALS'*

> Mobility within the semiconductor industry has been aided by the very tolerant attitude of most firms towards movement of personnel.
>
> Braun and MacDonald (1978, p. 135)

Though it may well be true that in most science-based industries one seldom observes a scientist breaking away from his employer to set up a rival, there is at least one industry, the semiconductor industry, where this has happened quite often.[11] Indeed many studies of the structure of the semiconductor industry begin by constructing a 'family tree' of firms that were offshoots from each other (see, for example, Freeman, 1974, pp. 147-49). Clearly to accommodate this phenomenon in our framework, we will have to modify the assumptions underlying our model. In this context, the crucial assumption of the preceding sections is that $p(\varepsilon, s) \leq \ell(\varepsilon, s)$ for all $\varepsilon \in R$. That is, optimum behavior by all agents will not induce the scientist to set up a rival if he believes that he will thereby gain less than what the entrepreneur believes he (the entrepreneur) has to lose. On the other hand, one can show (see below, p. 30) that if there are possible outcomes in which $p(\varepsilon, s) > \ell(\varepsilon, s)$, optimum behavior may induce the establishment of a rival. There are, therefore, at least two questions of interest. First, when would we expect such outcomes

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[11] One would need a very detailed history of an industry to determine that it does not exhibit this phenomenon. On the other hand, many science-based industries seem to operate with a fairly stable number of firms; see Temin (1979) on the drug industry since World War II, Phillips (1974) on the aircraft industry, and Freeman's (1974) description of the synthetic materials industry after World War I.

to occur? Second, how do they affect project profitability and research employment? This section discusses two sets of conditions which have the potential of actually inducing the scientist to set up a rival. In both, the actions of all agents are a result of optimum behavior based on correct information.[12] Moreover, these conditions are not unlike those which have developed in the semiconductor industry. Our discuccion will focus on their implications for project profitability and on optimum labor policies, leaving several interesting questions concerning the environments which generate these conditions for subsequent work. In particular it will be shown that, provided the entrepreneur uses an optimum labor contract, he need not be troubled by the possibility that scientific personnel may move. In fact, all else equal, the entrepreneur should prefer situations in which it is relatively easy for the scientist to do so.

Third-party entrants

Sections I to III have assumed that the entrepreneur and the scientist whom he employs jointly retain perfect monopoly power over the information produced during the research project. There are, however, several ways in which third parties might gain access to this information. The output

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[12] Of course, the scientist may wrongly believe that $p(\varepsilon, s) > \ell(\varepsilon, s)$; or the entrepreneur may err in his evaluation of $\ell(\varepsilon, s)$. Provided one precisely specifies the entrepreneur's information on $p(\varepsilon, s)$ in the first period, this case can be analysed in a model similar to those developed below and it has the same qualitative implications on project profitability and research employment.

of the project may spread as a result of inspection of either the product in which it is embodied or the patents resulting from the project (indeed patents would not exist if there were no possibility of third party entrants), or a third party may complete a similar research project after the leading firm. If there is a possibility of third party entrants the entrepreneur's optimum stategy will take into account his beliefs on how third parties are likely to act (for a formal model of entrepreneurial behavior in a related context, see Gaskins, 1971). This optimum strategy will include a labor policy. Clearly, however, if there are potential third party entrants, the logic that led us to the optimum labor policies of the preceding sections is no longer appropriate. There the argument was that since the benefits that would accrue to the scientist from setting up a rival were smaller than the consequent losses of the firm, the entrepreneur would always devise a contract deterring the scientist from setting up the rival. If other agents have access to the information, however, then the scientist, by setting up a rival, may also be able to break into profits that would otherwise accrue to third parties. In this case, both the scientist and the entrepreneur may be able to gain, if the scientist can set up a rival.

To analyse this situation we must add some notation. Again $f(\varepsilon, s)$ represents the net revenues that would accrue to the entrepreneur if the scientist did not set up a rival (given the expected behavior of third parties). If the scientist does set up a rival, the pay-offs to entrepreneur, scientist, and third parties all change. For simplicity, we maintain the assumption that if the scientist does set up a rival, the entrepreneur loses a fraction α of the net revenues [to allow for the possibility that his revenues actually increase we permit $\alpha < 0$ in this section, though we continue to refer to $\alpha f(\varepsilon, s)$ as the entrepreneur's losses]; and that the costs of setting up a rival are $c(s)$. Depending on the realization of ε, on technological and market conditions, and on the oligopolistic strategies pursued by the agents, part of the losses incurred by the firm may now go to agents other than the entrepreneur and the scientist (to the third parties or to consumers); alternatively, by setting up a rival, the scientist may be able to break into the net revenues that would otherwise accrue to the third parties. Accordingly, in this section we assume that the gains that would accrue to the scientist if he set up a rival are $\alpha f(\varepsilon, s) - c(s) + s + r(\varepsilon, s)$, where the only restriction placed on $|r(\varepsilon, s)|$ is that it be finite for all $\varepsilon \in R$ [$r(\varepsilon, s)$ has a finite support].[13]

At the end of the first period the scientist will be induced to set up a rival if this is the best of the three alternatives available to him, that is, if $\alpha f(\varepsilon, s) - c(s) + s + r(\varepsilon, s) > w_1(\varepsilon, s)$ and $\alpha f(\varepsilon, s) - c(s) + s + r(\varepsilon, s) > s$. He will stay with the firm if the first inequality is reversed and $w_1(\varepsilon, s) \geq s$; while if neither of these two conditions is met he will return to the labor market and engage in some other activity.

Given the scientist's decision rules (and assuming contracts are unbounded), the entrepreneur's expected profit-maximization problem is given by Problem B.

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[13] Here $r(\varepsilon, s)$ can be interpreted as the revenues extracted from (or lost to) third parties (or possibly consumers). It is not difficult to work out examples where its value can be either positive or negative depending on the realization of ε and other parameters of the problem.

Problem B

$$\max_{\{s \in U,\, w_0(s),\, w_1(\varepsilon, s)\}} \Pi = \int_R f(\varepsilon, s)dG - w_0(s) - \int_{A_r}[w_1(\varepsilon, s) - s]dG - \int_{Q_r} \alpha f(\varepsilon, s)dG ,$$

where $A_r = \{\varepsilon | w_1(\varepsilon, s) \geq \max[\alpha f(\varepsilon, s) - c(s) + s + r(\varepsilon, s), s]$ and $Q_r = \{\varepsilon | \alpha f(\varepsilon, s) - c(s) + s + r(\varepsilon, s) > \max[w_1(\varepsilon, s), s]\}$, subject to

$$\text{(B.1)} \quad 2s \leq w_0(s) + \int_{A_r} w_1(\varepsilon, s)dG + \int_{Q_r}[\alpha f(\varepsilon, s) - c(s) + s + r(\varepsilon, s)]dG + s\int_{R-A_r-Q_r} dG .$$

Proposition 3 underlies most of the discussion in this section.

Proposition 3: Regardless of the choice of s, an optimum labor contract for Problem B is

$$w_1^r(\varepsilon, s) = \max\{\alpha f(\varepsilon, s) + s, s\} ,$$

$$w_0^r(s) = 2s - \int_{Q_r^*}[\alpha f(\varepsilon, s) - c(s) + s + r(\varepsilon, s)]dG - \int_{R-Q_r^*} w_1^r(\varepsilon, s)dG ,$$

where $Q_r^* = \{\varepsilon | r(\varepsilon, s) - c(s) > 0$ and $\alpha f(\varepsilon, s) - c(s) + r(\varepsilon, s) > 0\}$. Verbally, the bonus scheme is implemented by the entrepreneur offering the scientist a profit-sharing agreement plus his alternative wage. The share is the fraction of the firm's net revenues the scientist would take away if he were to set up a rival. The scientist only accepts the profit-sharing agreement if $\alpha f(\varepsilon, s) > 0$. The initial wage is the minimum flat wage acceptable, given that the scientist will receive $w_1^r(\varepsilon, s)$ if $\varepsilon \in A_r^*$, and $\alpha f(\varepsilon, s) - c(s) + s + r(\varepsilon, s)$ if $\varepsilon \in Q_r^*$.

Proof: To prove this proposition we assume, to the contrary, that there exists an s, say $\tilde{s}$, and a feasible contract $\{\tilde{w}_0(\tilde{s}), \tilde{w}_1(\varepsilon, \tilde{s})\}$ such that $\Pi\{\tilde{s}, \tilde{w}_0(\tilde{s}), \tilde{w}_1(\varepsilon, \tilde{s})\} > \Pi\{\tilde{s}, w_0^r(\tilde{s}), w_1^r(\varepsilon, \tilde{s})\}$ and then show that this involves a contradiction. Since $\{\tilde{w}_0(\tilde{s}), \tilde{w}_1(\varepsilon, \tilde{s})\}$ must satisfy (B.1), $\tilde{w}_0(\tilde{s}) \geq 2\tilde{s} - {}_{\tilde{A}_r}\int \tilde{w}_1(\varepsilon, \tilde{s})dG - {}_{\tilde{Q}_r}\int[\alpha f(\varepsilon, \tilde{s}) - c(\tilde{s}) + \tilde{s} + r(\varepsilon, \tilde{s})]dG - \tilde{s}\ {}_{R-\tilde{A}_r-\tilde{Q}_r}\int dG$ where $\tilde{Q}_r = \{\varepsilon | \alpha f(\varepsilon, \tilde{s}) - c(\tilde{s}) + \tilde{s} + r(\varepsilon, \tilde{s}) > \max[\tilde{w}_1(\varepsilon, \tilde{s}), \tilde{s}]\}$. Substituting this condition and the optimum labor contract into the definition of Π we have $\Pi\{\tilde{s}, \tilde{w}_0(\tilde{s}), \tilde{w}_1(\varepsilon, \tilde{s})\} - \Pi\{\tilde{s}, w_0^r(\tilde{s}), w_1^r(\varepsilon, \tilde{s})\} \leq {}_{\tilde{Q}_r}\int[r(\varepsilon, \tilde{s}) - c(\tilde{s})]dG - {}_{Q_r^*}\int[r(\varepsilon, \tilde{s}) - c(\tilde{s})]dG \leq 0$, a contradiction. To prove the last inequality let Ω be the set of all subsets of the set $M = \{\varepsilon | \alpha f(\varepsilon, \tilde{s}) - c(\tilde{s}) + r(\varepsilon, \tilde{s}) \geq 0\}$. Clearly, $Q_r^*, \tilde{Q}_r, \subset \Omega$ and Q_r^* maximizes ${}_Q\int[r(\varepsilon, \tilde{s}) - c(\tilde{s})]dG$ (over $Q \subset \Omega$). []

Since the scientist can always return to the labor market and earn his alternative wage, he will not set up a rival unless $\alpha f(\varepsilon, s) - c(s) + r(\varepsilon, s) > 0$. Now consider those realizations of ε where this condition is satisfied. If $\alpha f(\varepsilon, s) - c(s) + r(\varepsilon, s) > \alpha f(\varepsilon, s)$, the entrepreneur would have to pay the scientist more in order to induce him to stay than the entrepreneur would lose if the scientist set up a rival. For those realizations of ε, then, it will pay the entrepreneur to allow the employee to leave. The bonus scheme $w_1^r(\varepsilon, s)$ will induce precisely this behavior.

To derive the optimum skill level for Problem B we require additional assumptions on $T(s) = {}_{Q_r^*}\int[r(\varepsilon, s) - c(s)]dG$, which is likely to increase in s, since one would expect $r_s'(\varepsilon, s) \geq 0$ and $c_s'(s) \leq 0$. If in addition we assume that $T(s)$ is concave for all s [or at least not sufficiently convex to offset the concavity of $_R\int f(\varepsilon, s)dG)]$ and that $T''_s(s)$ is bounded, we have the following corollary.

Corollary 3.1: If there exists an $s^r \in U$ which satisfies $_R\int f'_s(\varepsilon, s^r)dG + \int_{Q^*_r(s^r)} [r'_s(\varepsilon, s^r) - c'_s(s^r)]dG = 1$, then s^r is the optimum skill level for Problem B. Otherwise the optimum s is at one of the boundaries, 0 or $\bar{s}$.

Proof: Substituting $\{w^r_0(s), w^r_1(\varepsilon, s)\}$ into the equation for Π in Problem B we obtain $\Pi(s) = {_R\int} f(\varepsilon, s)dG - s + \int_{Q^*_r(s)} [r(\varepsilon, s) - c(s)]dG$. Taking the derivative of this expression with respect to s and setting it equal to zero we obtain s^r as defined above.[14] []

The sum of the entrepreneur's and scientist's gains from setting up a rival is $r(\varepsilon, s) - c(s)$, and $Q^*_r(s)$ is the set of all ε for which this sum is positive, and for which the scientist, if he quits, would actually set up the rival (rather than engage in some other activity). By using a labor contract which induces the scientist to set up a rival if $\varepsilon \in Q^*_r(s)$, and then setting the flat wage at the minimum acceptable given optimum behavior by the scientist, the entrepreneur ensures that

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[14] To see this partition $Q^*_r(s)$ into J subsets, i.e., $Q^*_r(s) = \sum_{j=1}^{J} q_j(s)$, where $q_j(s) = \{\varepsilon | \kappa_{0j}(s) < \varepsilon < \kappa_j(s)\}$. Then $\Pi(s) = {_R\int} f(\varepsilon, s)dG - s + \sum_{j=1}^{J} \int_{\kappa_{0j}(s)}^{\kappa_j(s)} [r(\varepsilon, s) - c(s)]dG$. Noting that the value of the integrand at both its upper and lower limits for each of the J groups is zero we obtain the derivative in the corollary (see Kolmogorov and Fomin, 1970, Section 31.3).

his expected gain includes the maximum expected gain that could possibly arise as a result of the mobility of scientific personnel $[T(s)]$. The entrepreneur will choose s to maximize thse gains plus $_R\int f(\varepsilon, s)dG - s$. All else equal, then, the entrepreneur ought clearly to prefer environments in which it is easier for the scientist to set up a rival and where the scientist can earn larger profits from the rival.

Finally, from the definition of $Q_r^*(s^r)$, we have Corollary 3.2.

Corollary 3.2: Given optimum behavior of all agents, the necessary and sufficient condition for quits and the establishment of rivals to be possible is that $r(\varepsilon, s^r) - c(s^r) > 0$ and $\alpha f(\varepsilon, s^r) + r(\varepsilon, s^r) - c(s^r) > 0$ for some ε with positive probability.

Thus, one should observe scientists setting up rivals when set-up costs are low and when other agents (third parties) are likely to enter similar activities. Indeed, one would expect these two conditions to be mutually supportive, i.e., low set-up costs may induce third-party entrants, while third-party entrants may attract venture capital to the particular field of activity (see the description of the evolution of Santa Clara or 'Silicon' Valley in Bylinsky, 1976, Chapter 4).

To summarize: it is clear that the inability of the firm to maintain perfect monopoly power over its discoveries may induce third party entrants, thereby creating conditions which result in the scientist breaking away from the entrepreneur to set up a new enterprise. Nonetheless, the mobility of scientific personnel is not, in itself, a source of concern to entrepreneurs. Indeed an optimum labor contract ensures that the scientist will only set up a new enterprise when it would help the entrepreneur to gain some of the revenues that would otherwise accrue to third parties.

Spin-offs

One way of stating the general result underlying the discussion of this section is that an optimum labor contract has the potential of inducing the scientist to set up a rival if there are possible states of nature in which the establishment of the rival increases the sum of the returns accruing to the two agents involved in the project.[15] The classic economic reason for total profits to increase when two firms (rather than one) engage in an activity is increasing costs (here interpreted to include the costs of gathering and processing information; see the review by Spence, 1975, and more recently, Keren and Levhari, 1981, and Rosen, 1981). There is one characteristic of research projects which deserves emphasis in this context. Research projects, especially those in relatively young science-based industries, often produce multiple outputs, that is, discoveries leading to several different innovations, some of which are only marginally related to the project's original goals.[16] In cases with multiple discoveries

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[15] What is required is that there exist possible states of nature in which $p(\varepsilon, s) - \ell(\varepsilon, s) > 0$ *and* $p(\varepsilon, s) > 0$. For the case of arbitrary gain and loss functions an optimum contract is: $w^g(\varepsilon, s) = \max\{\ell(\varepsilon, s) + s, s\}$, and $w_0^g(s) = 2s - \int_{R-Q^g} w_1^g(\varepsilon, s)dG - \int_{Q^g}[p(\varepsilon, s) + s]dG$, where $Q^g = \{\varepsilon | p(\varepsilon, s) - \ell(\varepsilon, s) > 0$ and $p(\varepsilon, s) \geq 0\}$. The set Q^g is the set of realizations of ε which induce the scientist to set up a rival and, provided that it is non-negligible [i.e., $\text{prob}(\varepsilon \in Q^g) \neq 0$], there is the possibility of a rival appearing. An entrepreneur who uses this contract will be led to choose s to $\max_{s \in U^R} \int f(\varepsilon, s)dG + \int_{Q^g(s)} [p(\varepsilon, s) - \ell(\varepsilon, s)]dG - s$.

[16] See, e.g., the discussion in Nelson (1959). Mueller's (1962) study of the origin of Du Pont's major innovations lists nine of them as

there will, in general, be costs and benefits associated with the coordination of subsequent financial, development, and marketing decisions. The particular aspects of the process worth coordinating may be best served by different organizational structures (the possibilities include, in addition to the formation of a separate enterprise, the establishment of a holding company, and the setting up of separate research and production departments within a given firm); which one is economic will depend on technological, market, and (particularly when antitrust laws are a factor) institutional considerations.

To incorporate these issues into our framework, consider a model in which the research project can result in two types of discoveries; those related to its original objectives the ('innovation'), and those that are not (the 'spin-off').[17] Assume, for simplicity, that only the scientist has direct access to the spin-off. Clearly, an entrepreneur working in such an environment will have an incentive to devise contracts which will induce the scientist to reveal the spin-off if it is in the entrepreneur's interest for him to do so. However, it might be more profitable to produce the spin-off in a rival firm; and in that event, the entrepreneur may have to pay more in order to induce the scientist to reveal the spin-off

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originating in Du Pont's own laboratory and of these, two (the discoveries of teflon and of ducose lacquers) resulted from research accidents. Of course, a new application of a given discovery would also result in a different innovation. See in particular the historical discussion in Rosenberg (1963 and 1969).

[17] In this subsection we make do with a verbal description of the model and the results. The technicalities are similar to those in the preceding subsection (see also note 15).

than it is worth if utilized in the original firm. It is in such a case that optimum behavior by all agents results in the scientist setting up a rival. To complete the model, assume, as in the preceding sections, that if the scientist does set up a rival he takes with him a share α of the net revenues from the innovation, and that the costs of setting up a rival are $c(s)$.[18] It can then be shown that entrepreneurs using an optimum contract will offer a second-period bonus consisting of two profit-sharing schemes: a share α of the net revenues from the innovation, and the entire net revenue generated by the spin-off. With this bonus offer the scientist will only set up a rival if he expects the difference between the net revenue generated by the spin-off when utilized in a separate firm and that generated when it is utilized in the original firm to be greater than the cost of setting up the separate firm. Further, an optimizing entrepreneur will choose s to maximize all the expected net revenues from the project (those from the innovation as well as from the spin-off) and will, all else equal, prefer situations in which it is less costly and more profitable for scientists to set up their own enterprise. These latter points follow because scientists who work in industries where spin-offs do occur realize that by joining a project they will gather information which may allow them to profit in their own enterprise in the future, and are therefore willing to lower their initial wage accordingly.

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[18] A particularly relevant case is $\alpha = 0$. In this case, if the rival is set up, one firm produces the original innovation and the other produces the spin-off. There is a set of interesting questions regarding the determination of the gains and losses that result from a rival being set up. Here we do no more than take as given whatever functions are determined and consider their implications for optimum labor policies.

V. *SUMMARY*

The basic conclusion of this paper is that provided entrepreneurs act optimally and are not limited in their choice of labor contract, the potential mobility of scientific personnel will not have an adverse effect on the profitability of research projects. If, on the other hand, either convention or legal restrictions place a lower bound on the flat rate to be paid to scientists (if, for example, w_0 is constrained to be non-negative) and if the project has some probability of being highly productive, then our conclusion needs to be modified. However, though bounded contracts may induce a situation in which the potential mobility of scientific personnel has an adverse effect on project profitability, it does not necessarily induce lower research employment, nor can bounds on contracts in themselves generate situations in which we actually observe a scientist quitting in order to join (or set up) a rival.

The conclusion regarding the effects of the mobility of scientific personnel follows from the fact that an optimizing entrepreneur who is free to choose among alternative contracts will always choose one which only induces the scientist to leave and join a rival if the sum of the benefits to the two agents increases as a result of the scientist's leaving. Contracts which specify labor payments in the form of a combination of flat wage rate and stock option (or other profit-sharing agreement) ought to be able to induce a close approximation to this behavior. Given the expected value of the profit-sharing agreement, the entrepreneur should set the initial wage, w_0, to a level which is low enough to ensure that the total of the expected payments to the scientist is just equal to the scientist's alternative wage. The expected profits of an entrepreneur who follows this policy will include all the monetary gains expected to accrue to either of the two agents other than the scientist's alternative wage. That is, the entrepreneur extracts all possible rents accruing to the idea underlying the project.

Clearly, then, if the sum of the benefits to the two agents cannot be increased by the scientist's leaving, the entrepreneur should specify a contract which will never induce him to do so. In this case the best the entrepreneur can do is to choose all factors to maximize the expected profitability of the research project, ignoring the possibility of quits, and then to choose a labor contract which ensures that quits will never occur. It follows that project profitability and research employment will be independent of the technological, market, and institutional factors which determine the gains the scientist would make from setting up a rival. On the other hand, if there are possible outcomes from the research project in which the sum of the monetary benefits to the two agents can be increased by the scientist leaving, the entrepreneur ought to choose a contract which will induce the scientist to leave if such an outcome materializes. In this case, the entrepreneur's expected profits will never be adversely affected by conditions which enable the scientist to earn more by setting up a rival; and they will actually increase with the expected gains of the scientist from setting up a rival provided those gains are not simply a transfer of funds from the entrepreneur to the scientist.

We have focused on two characteristics of research projects which could lead to situations in which optimum behavior by all agents would result in the scientist breaking away from his employer to establish a rival. First, it may be possible for third parties to gain access to the information generated from the project, in which case the scientist's setting up a rival may enable the entrepreneur to recoup some of the profits that would otherwise accrue to third parties. Second, the research project may lead to several discoveries, in which case costs of coordination may result in its being economic to develop and market them in separate enterprises. In either of these cases an optimizing entrepreneur will be led to make research employment decisions to maximize all the profits to be generated by the project, whether the associated net revenues accrue to the rival or the original firm.

In short, though we are quite sure that there are mechanisms which, because of the fact that they can be used to spread the information produced in a firm's research laboratories, reduce the profitability of research projects and (perhaps) of employment in them, the potential mobility of scientific personnel need not be one of them. The reason is straightforward. Provided the firm is free to choose among alternative labor contracts it can provide an incentive structure which controls the mobility of the scientist--only inducing him to leave and set up a rival when it is in the firm's interest for him to do so.

References

Akerloff, George. "The Economics of Caste and of the Rat Race and Other Woeful Tales," *Quarterly Journal of Economics*, XC (November 1976), 599-617.

Arrow, Kenneth J. "Economic Welfare and the Allocation of Resources for Invention." In *The Rate and Direction of Inventive Activity: Economic and Social Factors*. Edited by R.R. Nelson. (National Bureau of Economic Research: Universities-National Bureau Conference Series No. 13.) Princeton: Princeton University Press, 1962. Pp. 609-25.

Barzel, Yoram. "Optimal Timing of Innovations," *Review of Economics and Statistics*, L (August 1968), 348-55.

Becker, Gary S., and George J. Stigler, "Law Enforcement, Malfeasance, and Compensation of Enforcers," *Journal of Legal Studies*, III (January 1974), 1-18.

Braun, Ernest, and Stuart MacDonald. *Revolution in Miniature: The History and Impact of Semiconductor Electronics*. Cambridge: Cambridge University Press, 1978.

Bylinsky, Gene. *The Innovation Millionaires: How They Succeed*. New York: Scribner's, 1976.

Dasgupta, Partha, and Joseph Stiglitz. "Uncertainty, Industrial Structure, and the Speed of R & D," *Bell Journal of Economics*, XI (Spring 1980), 1-28.

Freeman, Christopher. *The Economics of Industrial Innovation*. Harmondsworth: Penguin Books, 1974.

Gaskins, Darius W. Jr. "Dynamic Limit Pricing: Optimal Pricing under Threat of Entry," *Journal of Economic Theory*, III (September 1971), 306-22.

Harris, Milton, and Artur Raviv. "Some Results on Incentive Contracts with Applications to Education and Employment, Health Insurance, and Law Enforcement," *American Economic Review*, LXVIII (March 1978), 20-30.

Keren, Michael, and David Levhari. *The Internal Organization of the Firm and the Shape of Average Costs*. (Discussion Paper No. 819.) Jerusalem: Falk Institute, 1981.

Kolmogorov, A.N., and S.V. Fomin. *Introductory Real Analysis*. Rev. English edition, translated and edited by Richard A. Silverman. New York: Dover, 1975.

Lazear, Edward P. "Why is There Mandatory Retirement?" *Journal of Political Economy*, LXXXVII (December 1979), 1261-84.

———, and Sherwin Rosen. "Rank-Order Tournaments as Optimum Labor Contracts," *Journal of Political Economy*, LXXXIX (October 1981), 841-64.

Mortensen, Dale T. "Specific Capital and Labor Turnover," *Bell Journal of Economics*, IX (Autumn 1978), 572-86.

Mueller, Willard F. "The Origins of the Basic Inventions Underlying Du Pont's Major Product and Process Innovations, 1920 to 1950." In *The Rate and Direction of Inventive Activity: Economic and Social Factors*." Edited by R.R. Nelson. (National Bureau of Economic Research: Universities-National Bureau Conference Series No. 13.) Princeton: Princeton University Press, 1962. Pp. 323-53.

Nelson, Richard R. "The Simple Economics of Basic Scientific Research," *Journal of Political Economy*, LXVII (June 1959), 297-306.

——— (ed.). *The Rate and Direction of Inventive Activity: Economic and Social Factors*. (National Bureau of Economic Research: Universities-National Bureau Conference Series No. 13.) Princeton: Princeton University Press, 1962.

Nickell, Steve J. "Wage Structures and Quit Rates," *International Economic Review*, XVII (February 1976), 191-203.

Phillips, A. *Technology and Market Structure: A Study of the Aircraft Industry*. Lexington, Mass.: Heath Lexington, 1974.

Rosen, Sherwin. *Output, Income and Rank in Hierarchical Firms*. (Economics Research Center/NORC Discussion Paper No. 81-10.) Chicago: University of Chicago, 1981.

Rosenberg, Nathan. "Technological Change in the Machine Tool Industry, 1840-1910," *Journal of Economoc History*, XXIII (December 1963), 414-43.

———. "The Direction of Technological Change: Inducement Mechanisms and Focusing Devices," *Economic Development and Cultural Change*, XVIII (Part I, October 1969), 1-24.

Ross, Stephen, A. "The Economic Theory of Agency: The Principal's Problem," *American Economic Review Papers and Proceedings*, LXIII (May 1973), 134-39.

Salop, Joanne, and Steven Salop. "Self-Selection and Turnover in the Labor Market," *Quarterly Journal of Economics*, XC (November 1976), 619-27.

Schumpeter, Joseph A. *Capitalism, Socialism, and Democracy*. 3rd ed. New York: Harper, 1950.

Spence, A. Michael. "The Economics of Internal Organization: An Introduction," *Bell Journal of Economics*, VI (No. 1, Spring 1975), 163-72.

Stiglitz, Joseph E. "Incentives and Risk Sharing in Sharecropping," *Review of Economic Studies*, XLI (April 1974), 219-56.

———. "Incentives, Risk, and Information: Notes Towards a Theory of Hierarchy," *Bell Journal of Economics*, VI, (No. 2, Autumn 1975), 552-79.

Temin, Peter. "Technology, Regulation, and Market Structure in the Modern Pharmaceutical Industry," *Bell Journal of Economics*, X (Autumn 1979), 429-46.