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ABSTRACT

The reason for subsidizing graduate education is its presumed contribution to the advancement of knowledge. Other means of promoting the advancement of knowledge exist--subsidizing research directly. For the indirect graduate education subsidy approach to be as efficient as a direct approach two things must be true.

(1) An expansion in the number of doctorate scientists in teaching and research can be obtained more cheaply by subsidizing training than by paying higher wages.

(2) There are good reasons for subsidizing doctorate scientists more than other elements of the basic research process-technicians, secretaries, equipment and engineers.

A mathematical model of the Ph.D. scientist labor market demonstrates that subsidies of graduate training can be more cost effective than higher wages if the supply of doctorates is substantially more responsive to a $1000 of early subsidy than to higher future wages with a present discounted value of $1000. Whether this is the case is an unsettled empirical matter.

The reasons developed for targeting subsidies at Ph.D. scientists are three. As a condition of taking a job they demand some freedom to do basic research and publish their results. Because of their special knowledge and loyalty to professional values, hiring scientists and engineers contains an extra risk that trade secrets will be stolen or that one of them will turn out to be a "whistle blower." From the firm's point of view these factors reduce the scientist's productivity. They do not from society's point of view, so an externality is created by the employment of scientists.

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OF GRADUATE EDUCATION SUBSIDIES

How much should doctorate training be subsidized? The answer proposed is, "Doctorate education should be subsidized to the extent and only to the extent that it produces externality or public benefits--i.e., benefits received by people other than the one receiving the diploma." This value judgment derives from three propositions: (1) In general, an adult knows better than anyone else what is best for himself; (2) the price (measured in both time and money) he is willing to pay for graduate education is the best measure of how much he values it relative to other things;[1] and (3) graduate schooling should be expanded to the point where social (private plus public) benefits of an extra student equal the sum of private and public costs of an extra student.

Agreeing on these philosophical propositions does not, necessarily lead to a particular set of policy prescriptions, however. It does not because no one knows what the current level of subsidy is and how large the incremental public benefits of more doctorate trained scientists are. Not only do we not know, we are not likely to be able to find out. Why? Primarily it is because graduate education and the advancement of knowledge are inextricably tied together and there is no way of comprehensively measuring all the benefits of the extension of man's knowledge. Research and graduate education are jointly produced outputs of the interaction of faculty and graduate students. Without a good measure of the value of the research produced, there is no way of measuring the net cost of the training received by the students. Second, research, especially basic research, is one of the primary activities of people who have completed the doctorate. It has been demonstrated that firms do not capture all the benefits of the research and development they undertake.[2] Furthermore, it will be argued below that doctoral scientists tend more than other researchers to produce proportionately large public benefits. Just how large the public benefit is, however, is a matter of debate and in some respects is an unanswerable question.

I personally get a great deal of enjoyment from following the new discoveries in astronomy--black holes, quasars, etc. The advancement of knowledge in other fields also produces this type of consumption benefit. How large a value should be placed on a pure public good like this can only be determined by resorting to the political process.

While the framework economists bring to the issue does not provide ready answers to policy questions, it has the effect of focusing attention and research on the scientific and normative questions of importance and pointing out those issues that are irrelevant. For instance, "How large are the non-pecuniary benefits (autonomy, prestige and long vacations) of obtaining a Ph.D.?" is an interesting question, but not one we need to answer. The graduate student is responsible for paying for such benefits, so the optimal level of subsidy is not influenced by the size of the private nonpecuniary benefits.

A second part of the approach economists bring to the issue is the analysis of alternative ways of achieving the same objective. One name for this approach is cost effectiveness analysis. It cannot answer the fundamental question of whether the objective is important enough to warrant the cost, but it can provide an upper limit for the benefits obtained by achieving objective A in a particular manner. That upper limit is the cost of the cheapest alternative method of achieving A. One of the objectives of subsidizing graduate education is increasing the supply and lowering the cost of doctorate scientists employed in research and undergraduate teaching. An alternative means of achieving this same objective exists--direct government subsidy of industrial and university based research and of college instruction. The cost of this direct approach therefore, provides the upper limit on the benefits that can be obtained from increasing the supply of doctorates by subsidy of graduate education.[3]

It is this mode of analysis that will be applied to the question of the extent to which society should subsidize graduate education. The high levels of subsidy of graduate education are not a post Sputnik phenomenon. Fellowships, assistantships, and low tuition have characterized graduate education for the last 50 years.[4] The focus, therefore, is on long term effects of policy and not short run dynamics of the movement toward equilibrium.

Placing the issue in a long run cost effectiveness framework means we are not analyzing whether there should be more or fewer doctorate trained scientists but whether the most efficient way to obtain the number we need is to pay their way through graduate school or to pay higher wages and thereby induce people to finance their own way through a more expensive graduate program. One impact of subsidizing graduate education now is to lower the wage paid to doctorate scientists in the future. The government is a direct beneficiary of this effect for it is the direct or indirect employer of 82 percent of doctorate scientists. Of the 82 percent, 24 percent teach at public colleges, 8 percent teach at private colleges, 28 percent are primarily engaged in research at universities, 5 percent work for the government or a non-profit research agency, and 7 percent work in federally funded industrial R & D.[5] By purchase, subsidy, or direct institutional control, government (federal and state together) effectively control the supply of each of these services. The first part of this paper analyzes a world in which the government's reason for subsidizing graduate education now is to lower its costs of buying their services in the future. The objective is simply to expand the supply of Ph.D. scientists it employs and the issue is whether this can be accomplished more cheaply by subsidy of graduate education now or by paying higher wages in the future.

The second part presents some reflections on whether this is an appropriate goal. Is it desirable to subsidize an activity by subsidizing only one of its inputs, the doctorate scientist. This issue is especially important in markets where government directly controls neither the quantity of the externality creating activity nor the factor proportions by which it is produced. Industry financed research and development is such a market. Eleven percent of national register doctorate scientists were employed in industrially financed R & D. The doctorate group with the highest proportion doing industrial R & D was chemists--37 percent. One of the proportionally smaller participants were physics doctorates--5 percent.[6] (See Table A for other fields.)

Ph.D. scientists working in industrial R & D produce externalities. The firm that employs them cannot capture all the benefits of the research they do. This is especially true for doctorates for they tend to be employed in basic research rather than development and the benefits of basic research are typically the hardest to internalize. In industry Ph.D. doctorate wages and fringes are 20.6 percent of basic research costs, 6.6 percent of applied research costs and 0.3 percent of product development costs.[7] For all R & D combined, nonmanagerial Ph.D. scientists are 2.1 percent of costs while scientists and engineers of all qualifications are about 30 percent of costs. The effect of subsidizing their education is (a) to lower the relative price of basic research to a small extent (a 10 percent drop in doctorate scientist wages lowers the relative price of basic research by approximately 2 percent) and (b) to lower price of doctorate scientists relative to engineers and M.A. scientists by a great deal. Whether this latter effect is desirable is analyzed in section II.

I. COST EFFECTIVENESS OF SUBSIDIZING GRADUATE EDUCATION WHEN THE GOAL IS EXPANDING THE SUPPLY OF DOCTORATE SCIENTISTS IN TEACHING AND RESEARCH

The goal is an expansion of the supply of Ph.D. scientists working in externality creating activities (teaching and research). Which method of achieving that goal has the least social cost: (a) subsidizing graduate education, or (b) subsidizing the teaching and research activity directly?

Stephen Dresch has cogently argued that the case for subsidizing graduate education must be based on the public benefits received from what the scientists do in professional employment after graduate school.[9] With the minor caveat that the dissertation itself makes some contribution to the advancement of knowledge, we adopt this position as well. Dresch points out that (a) not all Ph.D.s work in activities that create externalities,

(b) lowering their future wage will cause flows out of the occupations (teaching and research) that create externalities into activities that don't (private consulting, management of non-R & D, unemployment, emigration). Therefore, he argues subsidizing graduate education is an inefficient way of trying to increase the employment of scientists.

While these effects do lower the efficiency of the graduate school subsidy approach, they are not conclusive arguments. Relative cost effectiveness depends as well on the relative size of (a) the long run elasticity of doctorate supply with respect to the expected future wage, ϕ, and (b) the elasticity of doctorate supply to the availability of subsidy during graduate school, θ. If many potential graduate students are averse to going deeply into debt, it is possible for the subsidy elasticity to be so much larger than the lifetime wage elasticity that the subsidy approach is cheaper.

The critical determinants of relative cost effectiveness will be determined by building a mathematical model of long-run equilibrium in the Ph.D. scientist labor market. Let us define the following terms.

S = Stock of Ph.D.s working in externality creating activities

S_T = Stock of American trained Ph.D. scientists

P = Lifetime earnings of doctorate scientists discounted at the social rate of discount to receipt of doctorate

W = Discounted lifetime compensation paid by employers (taxes are neglected)

F = The ratio of the sum of graduate school subsidy and lifetime earnings to lifetime earnings, $F = (P_O + X)/P_O$ where X is subsidy discounted to the receipt of the doctorate. X is the average value of fellowship and assistantship stipends plus the difference between instructional cost per student and tuition. P_O is the standard lifetime wage.

$k = 1 +$ (the proportionate subsidy of scientist wages)

Let demand for the employment of science doctorates in externality creating activities be:

1) $S = DW^{\alpha}$

The elasticity of demand, α, has been estimated by Richard Freeman and David Breneman to be -.5.[10] Its size, however, does not affect our analysis. The supply of doctorates working in externality creating activities is given by:

2) $S = .93P^{.4}S_T$

P and, therefore, W are indexed on their values in 1968 ($P_o = W_o$) when 93 percent of employed doctorates were in either teaching, research, or research management.[11] The proportion of Ph.D. scientists employed in the externality creating activities is responsive to their relative wage because of unemployment, immigration and emmigration flows, and shifts into managerial and consulting work. Freeman and Breneman estimate the elasticity of occupational choice given the stock of Ph.D.'s to be .4.[12]

The stock of American trained doctorates is given by:

3) $S_T = G\, P^{\phi}\, F^{\theta}$

where ϕ is the long run elasticity of the stock of doctorates to discounted lifetime earnings (discounted at social rate of discount), and θ is the long run elasticity of the stock of doctorates to F, i.e., to 1 plus the ratio of graduate school subsidy to lifetime earnings.

The subsidy program for teaching and research determines the extent to which P exceeds W. The size of that subsidy program is given by k.

4) $P = kW$

The size of the alternative subsidy technique, graduate school subsidies, is indexed by F.

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Now set supply equal to demand, take logs and

5) $.93P^{.4}GP^{\phi}F^{\theta} = DW^{\alpha} = D(\frac{P}{k})^{\alpha}$

6) $\ln .93G + (\phi + .4)\ln P + \theta \ln F = \ln D + \alpha \ln P = \alpha \ln k$

Calculate a total derivative with P, F, and k endogenous.

7) $(\phi - \alpha + .4)\, d \ln P + \theta\, d \ln F + \alpha\, d \ln k = 0$

Fixing F we may calculate the impact of a change in k: because $\alpha < 0$

8) $$\frac{d \ln P}{d \ln k} = \frac{-\alpha}{\phi - \alpha + .4} > 0$$

Thus, the wages received by the scientists go up.

9) $$\frac{d \ln W}{d \ln k} = \frac{d \ln P}{d \ln k} - \frac{d \ln k}{d \ln k} = \frac{-\alpha}{\phi - \alpha + .4} - 1 = \frac{-\phi - .4}{\phi - \alpha + .4} < 0$$

The cost of scientists to the firm goes down.

10) $$\frac{d \ln S}{d \ln k} = \left(\frac{d \ln S}{d \ln W}\right)\frac{d \ln W}{d \ln k} = \frac{-\alpha\ (\phi + .4)}{\phi - \alpha + .4} > 0$$

The number of scientists employed in teaching and R & D goes up.

Fixing k we may calculate the impact of a change in F.

11) $$\frac{d \ln P}{d \ln F} = \frac{d \ln W}{d \ln F} = \frac{-\theta}{\phi - \alpha + .4} > 0$$

12) $$\frac{d \ln S}{d \ln F} = \frac{-\alpha\theta}{\phi - \alpha + .4} > 0$$

Larger fellowships and assistantships lowers both the wage paid by employers and received by scientists and increases the number of scientists employed in teaching and research.

The cost of a given change in ln F or ln k are not quite the same because some of the subsidized doctorates will not enter teaching or research. The direct subsidy has to be paid to only 93 percent of the stock of American doctorates. On the other hand, some of the direct subsidy goes to foreign trained doctorates. In 1960 only 2 to 5 percent of Ph.D.

scientists were aliens and many of these were trained in the U.S.[13] We shall therefore, neglect a possibly greater elasticity of supply of foreign trained doctorates.

13) Incremental cost of fellowships $= d\,C_F \simeq S_T\,P \cdot m(d \ln F)$ where m = the increment in subsidy as average stipends increase. m is less than 1 because part of the increase in stipends comes from funding a larger proportion of students on assistantships where they provide real services to the department. Note that increases in the wage rate of an assistantship doesn't lower m.

14) Incremental direct subsidy $= d\,C_k \simeq S_T \cdot P(.93)(d \ln k)$

Substituting (14) into (10) and (13) into (12)

$$15)\quad \frac{d \ln S}{d\,C_k} = \frac{-\alpha\,(\phi + .4)}{.93\,S_T\,P\,(\phi - \alpha + .4)}$$

$$16)\quad \frac{d \ln S}{d\,C_F} = \frac{-\alpha\theta}{m\,S_T\,P\,(\phi - \alpha + .4)}$$

The fellowship and assistantship approach to expanding scientist employment is the most efficient when

$$\frac{d \ln S}{d\,C_F} > \frac{d \ln S}{d\,C_k}$$

which occurs when

$$17)\quad \frac{.93\,\theta}{m} > \phi + .4$$

Graduate student subsidies become more efficient (a) the higher the proportion of Ph.D. s that enter externality creating activities, (b) the smaller the subsidy share of the stipend, (c) the larger the response to subsidies, and (d) the smaller the response to future wages. If what I perceive to be Richard Freeman's view of the relative size of ϕ and θ (that they are almost equal) is correct, direct subsidy is the most cost effective method of increasing scientific employment. On the other hand, if the student were to choose whether to enter and complete graduate school using a present value calculation with a real discount rate 1.5 times the social rate (because of risk and debt aversion), graduate school subsidies would become the more efficient approach.[14] If graduate students were supported only with assistantships (thus lowering m) and the students were not averse to the extra work, an assistantship strategy would most likely prove more efficient than direct subsidies of scientist employment.

II. SHOULD RESEARCH BE SUBSIDIZED IN A MANNER THAT LOWERS THE RELATIVE COST OF DOCTORATE SCIENTISTS?

What is the objective: subsidizing the use of Ph.D. scientists in R & D or subsidizing basic and applied research in general no matter who does it. Stephen Dresch argues that who does the research--engineers, masters scientists, technicians--implies little about the size of the externalities created.[15] An examination of the unique character of Ph.D. scientists reveals that there are three significant reasons for subsidizing the scientist component of R & D more than the other cooperating inputs -- engineers, technicians, materials, capital and overhead. The professional ethic (of research and publishing for its own sake) taught in graduate schools means that the bargain he strikes with his industrial employer gives him a freedom to choose his research problem and to publish most of his research findings. As a consequence, the firm tends to internalize a smaller proportion of the fruits of a Ph.D. scientist's labor. The second reason why firms tend to underinvest in scientists and engineers relative to technicians, capital and materials is that professionals are capable of carrying valuable trade secrets with them when they change employers while technicians and secretaries are not. The third reason is that the firm takes the risk one of its scientists will "blow the whistle" if the firm acts against the scientists view of the public interest. In all of these cases the behavior that the employer finds detrimental to his own interest is in the public interest.

IIA. THE GOAL CONFLICT BETWEEN SCIENTISTS AND THEIR EMPLOYERS

During graduate school the young scientist is socialized into an ethic that treasures independence, that considers the process of pushing out frontiers of knowledge intrinsically worthwhile and that makes the favorable judgment of ones colleagues the only opinion that matters.[16] This ethic generally coincides with society's interest for it creates strong incentives for immediate publication of new findings. Early disclosure helps other scientists with their work and where it is unpatentable prevents the economic fruits of a discovery from being monopolized by one company. Internalizing the goal of discovery reduces the need for extrinsic reward systems for accomplishment. It makes it easier to award scientists job security. It promotes cooperation among scientists working on the same problem. Competition for credit for a discovery may also inhibit cooperation. Credit, however, is easier to share than money. Their preference for basic research is also socially desirable for the profit motive naturally tends to result in underfunding of basic research. Only a small fraction of the benefits of basic research accrue to the company that undertakes it. The discoveries that result are seldom patentable and are often useful only in other firms' product lines.

Such a socialization process requires that the moral authority of the socializers, the faculty, be pre-eminent. The financial power of the graduate department over its students tends to reinforce the moral authority of the faculty and thus may contribute to the socialization process. Whether the degree of subsidization effects the nature of the graduate education in the manner hypothesized above, is an open question that needs extensive research. It is not central to our argument, however. The important point is that doctorate training does produce such an ethic and that we desire scientists to be governed by such an ethic.

The goal conflict between the professional ethic of the scientist and the profit aims of his industrial employer is one of the main themes of the sociological and management studies of the R & D scientist.[17] Industrial scientists desire to receive wide recognition for their discoveries by publishing in professional journals. Thirty-one percent of a sample of 390 scientists and engineers of whom only 100 or so were Ph.D.s, said they "would most like to publish a paper in the leading journal in any profession even though the topic might be of minor interest to the company" rather than "make a major contribution to one of the company's projects." Sixty percent said it was "important to me that I be able to publish the results of my research in professional journals."[18]

The scientist generally prefers basic research to applied research. Sixty-six percent said they "wanted to do the kind of research that will contribute to scientific knowledge." Seventy-seven percent wanted to "be able to pursue and carry out my own research ideas."[19]

The frustration of not being able to do as much basic research as he desires was verbalized by a scientist in another research organization.

> If there is no government contract or no gadget involved management is not very enthusiastic. For this reason basic research suffers.[20]

A research supervisor who had one of his own projects vetoed by higher management had a similar complaint:

> Basic research represents only a small activity. It is not handled the way applied research is.... In some ways the older members of management are against basic research. These men do not realize the actual importance of this activity.[21]

A more senior research manager took the contrary view:

> The trouble with these research people is that they go ahead and do research without any appreciation of the cost. There is a great deal of research done which should never have been taken on without careful analysis of the product possibilities.[22]

As one would expect, it is the Ph.D. scientist who experiences this conflict most acutely. In comparison to engineers and masters degree scientists working in R & D his identification with the professional ethic is stronger and with the firm weaker.[23] The scientific ethic the graduate student brings from school is maintained in the face of the firm's attempts to resocialize him. Studies have found that length of tenure's negative effect on professional orientation and positive effect on commitment to the firm's values are tiny and statistically insignificant.[24]

How is this conflict resolved? The astute scientist faced with such a conflict persuades (cons in some cases) his superiors to support the line of research he has chosen:

> He is working on an extremely sophisticated problem. Before he began his work he defined the problem very carefully so that it might <u>appear</u> (italics added) useful to the lab. You have to be careful and watch your step. You cannot do things that simply suit your fancy.[25]

The astute manager gently leads people into the research areas that are management's priority. Scientists will generally consider assignment to a task without consultation as demeaning. Referring to such an incident one scientist said:

> Since I had heard of the research program as a kind of dictum, I had to resist it. Otherwise one is willing to get pushed around a great deal.[26]

The astute manager also realizes that to maintain some men's morale, he must permit some unfunded basic research that has little profit potential.

> Intellectual contributions are also rewarded. Sometimes you have to lean over backwards to incorporate this into the profit system. If the intellectual contributions are not recognized, the men can turn sour because of lack of recognition for intellectual efforts.[27]

The conflict over the publication of research results is resolved generally by requiring a review by company officials of basic research papers. Directors of R & D and patent department officials were the most frequently sited reviewers. Of 174 companies who did at least 50,000 worth of basic research a year surveyed by the National Science Foundation 14 percent allowed substantially all findings to be published, 26 percent most, 45 percent some and 16 percent allowed none to be published.[28] Weighted by dollars spent on basic research 28 percent allowed substantially all and 42 percent allowed most. While the review process is often justified as a quality control measure it allows the firm to prevent the publication of papers that would divulge ideas that have substantial profit-making potential.

The reasons given for allowing the publication of basic research findings were in order of importance; (a) prestige of the company, (b) the professional prestige of company scientists and engineers, (c) recruitment, (d) maintaining staff morale, and (e) public responsibility. Reasons b, c, and d are a reflection of the pressure placed on the firm by the scientific ethic of its R & D workers. That publishing is tolerated not encouraged is further supported by the fact that while all but two permitted the preparation of articles on company time; only twelve had a company reward for publication.

Higher management was not unaware of the slack that existed in their research laboratories toward the end of the sixties. When federal funding of research was cut or the company had a bad year, they reduced the size of their research staff and reoriented research toward more immediate and applied objectives. One scientist who survived the cutbacks described it this way:

> Budgets have tightened up, really, the overhead budget's gotten quite tight.... It's cut down on alot of pure research for research's sake.[29]

These cutbacks are not without their costs in the effectiveness of the research organization, however. The cooperative spirit that is essential if scientists are to be productive tends to break down.

> I think there is also a tendency for a breakdown in communication. I think there is tendency to, when money is tight, develop one's own empire, make sure you have your groceries and not worry about the other guy. And the result of that is that many people have today's groceries, but they're not worried about the groceries the company's going to have tomorrow.[30]

The outcome of this conflict between the scientist and his employer is a compromise. Despite the fact that it is against the interest of the firm, the scientist is generally allowed to publish the results of his basic research. In many cases the opportunity to do basic research part of the time or on a rotating basis are part of the negotiated prerequisites of the job and as a consequence the firm does more basic research than it otherwise would. The scientist is given some freedom to choose even his area of applied research and, as a consequence, a smaller portion of the benefits of applied research will accrue to the firm.

From society's point of view the resolution of this conflict has both good and bad aspects. On the one hand, a higher proportion of scientist time is spent on basic research and disclosure occurs more quickly. This is good. On the other hand, fewer scientists are employed, for the effective price of the research that contributes to profits has risen. These effects are much weaker for engineers and bachelor and master's scientists so firms tend to substitute them for Ph.D. scientists in applied research and product development work. This means it is socially desirable that the subsidy of Ph.D. scientist employment be larger than the subsidy of engineers and masters scientists.[31]

If the effect of graduate education subsidies is to create dynamic surpluses of Ph.D. scientists, there may be a counteracting tendency due to reduced bargaining power of the Ph.D. scientists. A reorientation toward applied work was observed in the three firms that suffered a reduction in organizational slack.[32] Whether such cutbacks are a temporary result of disequilibrium or a permanent result of the greater availability of scientists is not clear. The recruitment motive for allowing and publishing basic research is not operative when no new hiring is contemplated. Organizational theories of the firm would also imply that the basic research cutbacks are temporary. On the other hand, the new equilibrium at a lower wage will lower the share of time devoted to basic research if the income elasticity of demand for time spent on basic research is greater than the price elasticity. One advantage of the direct subsidy approach to promoting scientist employment is that the high wage levels are maintained and this may embolden scientists to demand more basic research time.

The main difficulty with a direct subsidy is, however, that it is almost certainly politically impossible to subsidize the Ph.D. scientist more than the other participants in R & D. If our argument is accepted, even employment subsidies targeted at technical personnel in basic research will not be as target effective as graduate school subsidies.[33]

IIB. EXPECTED LOSSES OF TRADE SECRETS

The second reason why firms will not hire as many scientists and engineers as is socially optimal is the risk they take that technological trade secrets will be "stolen." Technological trade secrets are divulged within a company on a need to know basis. Technicians and secretaries in the R & D department do not have a need to know and generally wouldn't have the background necessary to learn a secret.

It was recently estimated that "US companies now realize nearly $2 billion under trade secret agreements with foreign companies."[34] The managing editor of Dun's Review, John Perlham, has reported that "estimates of losses to US industry caused by espionage run as high as $4 billion a year." Leakage of R & D discoveries and in place production technology are the primary type of information lost and "careless," "disloyal," and mobile employees the major source of the leaks. If the 372,000 engineers and scientists in R & D are responsible for only $500 million in losses, the average loss per employee is $1344 per year or over 7 percent of compensation. If the 739,000 other engineers and scientists who work in private industry are responsible for another $500 million, their average loss per employee is $677 per year. Inevitably new employees are greater risks than old employees, so the expected loss at the margin, new hires, should be greater than the average loss. Thus, underutilization of scientists should be greatest when R & D programs are expanding and when turnover is high.

Despite the protection presumably provided by laws against developing one firm's trade secrets to another, high technology companies are very concerned about the problem. In a recent article in Management Review, a management consultant and director of security for Aerospace Corporation complained that:

> Trade secrets often are an important part of a departing employee's total capabilities . . . . Because of unintentional release of information and subconscious utilization of trade secrets, it often is difficult to prove that a violation has occurred.[36]

Proving that a trade secret has been violated is costly and difficult. The plaintiff must prove:[37]

(1) That the defendant is using the technique which they consider a secret.

(2) That the knowledge embodied in the technique was obtained from the plaintiff (i.e., that it was not developed independently).

(3) That the information was in fact not generally known.

(4) That the plaintiff made an effort to keep the information secret.

In patent litigation the plaintiff only needs to prove (1). It can also take a long time to win a case. It took 13 years of litigation before Carter Products won a judgement against Colgate Palmolive for obtaining the secret behind Rise shaving cream.

Techniques that one side of the fence considers espionage the other side considers ethical information gathering activities. For instance, most executives (50 percent in one survey) approve of hiring key employees away from a competitor as a useful and ethical information gathering technique.[38] Only 25 percent of the executives expected a new employee in their firm to withhold competitor's secrets. If a competitor "has done valuable research you don't have," 41.5 percent suggested hiring a key employee from the competitor as a means of gathering information. The same executives were asked whether they would accept the offer of a better job in another firm. Twenty-three percent said they would accept it immediately; 55 percent said they would "inform superior, consider a counteroffer if made, then make a decision." If not obligated (by contract) to their previous employer not to reveal his secrets only 16.5 percent (3.4 percent in engineering industries) said they would "withhold key information from new employer."

The ex-employer has a different perspective. In order to impress upon their employees the seriousness with which the firm views the matter and to satisfy (4), many firms require as a condition of employment that all R & D employees sign a secrecy agreement. A 1965 study found that a majority of the companies made such a contract a condition of employment for R & D employees.[39] A large number of firms are also conducting exit interviews in which employees who have been entrusted with trade secrets are reminded of their obligation.[40] Often the new employer is warned as well.

There have even been attempts to prevent ex-employees from working for competitors. Sometimes a prohibition against working for a competitor for a specified period after employment is written into the employment contract. Sometimes the portability of pension or profit sharing plans is made contingent on not working for a competitor. Such contracts and pension provisions have not generally been enforceable in the courts, however.[41]

The learning of trade secrets while working is analogous to on-the-job general training. Theory tells us that on-the-job training that produces knowledge and skills useful to other employers is effectively paid for by the employee.[42] Because of the opportunities to learn, people offer to work for less than they could get in alternate employment where learning opportunities are not as great. The employee is willing to be paid less because he will be paid more later.

The prospect of being able to learn trade secrets does not produce similar competition for jobs because the typical employee does not expect to gain anything from the trade secrets he will learn. Even if there were no ethical qualms about stealing a secret, it is very difficult to capitalize on the secret knowledge. Going into business for oneself using the secret, results in certain detection. To hide the fact that the secret is being used the ex-employee is forced to take the secret to another large employer. The employee's lack of options, the prospect of being caught, of harassing litigation, and the possibility the employee might steal a secret from the new employer means that the carrier of the trade secret does not receive full market value. Much of the time the employee does not realize the value of the information. In 1964 Eugene Mayfield, a management trainee at Procter & Gamble, was caught offering Crest's marketing plan for 1964/65 to Colgate. While Procter and Gamble later estimated the plan could be worth as much as 100 million to a competitor, the price Mayfield had set was $20,000.[43] Thus, when one more scientist is hired, the value of the firms expected loss of trade secrets is much greater than scientists' expected gain from selling them.

IIC. WHISTLE BLOWING

Another risk a firm takes when it hires a professional is that it is hiring a "whistle blower." A "whistle blower" is an employee who goes public (leaking a story to a reporter, resigning in protest, contacting a congressional committee or regulatory agency), when he is unable to persuade his superiors to act in what he views to be the public interest. Despite the fact that whistle blowing often involves release of information considered secret by the employer, trade secrecy law seldom applies. The consequence for the whistle blower are typically being demoted or fired and ostracized by other potential employers. Of the 30 "whistle blowers" described in a book edited by Ralph Nader, 10 were engineers, 3 Ph.D. physicists, 4 MDs, 1 a veterinarian, and 7 others were college graduates in a non-technical field.[44] The association of college and graduate training with "whistle blowing" reflects (a) their access to the critical information, (b) the fact that their professional training provides credibility to their story and (c) the assignment of scientists and engineers to jobs where their professional standards may come into conflict with the company's interests. Lawyers whose ethics prohibit them from turning on their clients will be substituted for scientists where possible.

From the firm's perspective "whistle blowing" is "sabotage." From society's perspective, however, what is damaging to the firm benefits the public or at least a competitor.[45] "Sabotage" by other employees is different. Their hostility generally lowers the quality or quantity of production, costs are raised. What hurts the firm hurts the consumer as well. Thus hiring fewer workers because of the fear of "sabotage" coincides with the public interest in most cases. The fear of whistle blowing and secret stealing is the exception.

III. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Is the subsidy of graduate education a cost effective means of encouraging research and undergraduate teaching in the long run? The answer is: It depends. It depends on whether extra dollars of discounted expected future wages or extra dollars of current subsidy have a bigger effect on the future supply of scientists teaching and doing research. It depends on the strength and effect of the goal conflict between the scientist and his employer. It depends on how large the firm perceives the risk of hiring a "whistle blower", a spy or indiscreet talker is. Before a judgment can be made about the long run cost effectiveness of heavy subsidies of graduate education, there is need for a great deal of careful empirical work on the above issues.

There is also a need for relaxing some of the simplifying assumptions made in this paper. The analysis has been restricted to long-term effects on the supply of all scientists. The current state of supply and demand for scientists is an important determinant of optimal policies. We have abstracted from such issues. Future work should attempt to integrate short- and long-run analysis.

The case for subsidy of graduate education is generally made on a field by field basis. We have not explicitly considered which fields should be subsidized more than others. A valid interpretation of our approach, however, is that the fields that should be subsidized least are:

(1) Those which have the largest proportion in profit-making non R & D (see Table A).

(2) those fields where firms can internalize the largest proportion of the benefits of R & D such as telephone technology or fields where patents are effective. While across fields this is correlated with the basic versus applied research distinction, it is by no means an exact relationship.

(3) Fields where more employer specific human capital is built up on the job. Turnover and therefore the loss of trade secrets should be lower in such fields.

(4) Fields where issues do not arise which may result in "whistle blowing."

(5) Fields which do not have the knowledge for its own sake ethos (possibly engineering).

(6) Fields such as medicine and law that have historically been self-financed. Wage levels have adjusted to the high costs of entry and awarding fellowships which can be used in these fields as the Newman report recommends simply produces a rent for the recipients.

However, as can be seen in Table C there is a very high rate of mobility between fields. This makes graduate program subsidies a very blunt instrument of promoting a particular line of research. Where possible, direct support of the specific favored activities will generally be a more efficient allocative mechanism than supporting specific training programs.[46]

This paper has not attempted to do an exhaustive analysis of all proposed externalities of graduate education. We will, however, briefly comment on some of the other arguments proposed for graduate education subsidies.

Social and technological issues are becoming increasingly complex and the influence of expertise in the councils of government and industry is growing. In the view of many, the experts to which we delegate more and more decision-making authority should be recruited from a variety of social backgrounds. When graduate education must be self financed (as has historically been the case in law and medicine), entry is limited to those who are both able and wealthy. While the traditional method of financing graduate education seems to result in substantial representation from low-income backgrounds, the same result could be achieved by government guaranteed loan programs and by financial aid based on parental income.

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A second argument is that training more scientists has a possibility of identifying another Steinmetz. The contribution of a genius is uniquely his own. This does provide support for subsidizing the scientist as opposed to the technician, capital or overhead component of R & D. However, currently 1.62 percent of the age cohort are receiving Ph.D., EdD, MD, or D.D.S. degrees (44,771 in 1970 vs 2,768,000 17 year olds in 1961). It does not seem likely that if a potential genius has not been identified by the sixteenth year of schooling a small change in the proportion of an age cohort getting a Ph.D. will discover a genius. The public benefits produced by a genuis are potentially huge, however, so the expected benefit might be significant nevertheless.

FOOTNOTES

[1]Here we are implicitly assuming that unsubsidized loans with extended repayment terms are available to help cash flow problems. Note that in July 1974 an unsubsidized long-term loan would have to have an interest rate over 12 percent.

[2]Kenneth Arrow, "Economic Welfare and the Allocation of Resources for Invention" in National Bureau of Economic Research, The Rate and Direction of Inventive Activity (Princeton: Princeton University Press, 1962). For a matehmatical demonstration of the optimality of greater investment in R & D when some of the benefits are external to the firm, see Appendix A.

[3]Here we assume that there is no constraint on the system that prevents the direct subsidy approach from being undertaken. Government already heavily subsidizes college teaching and research so there seems to be none here. A possible constraint on the subsidy of industrial R & D will be examined.

[4]In 1962,70 percent of physical and biological scientists, 67 percent of mathematicians, and 44 percent of social scientists with doctorates reported that fellowships or assistantships were their primary source of support in graduate school. Another 10 percent were reported in the GI Bill as their main support. Seymour Warkov and John Marsh, The Education and Training of America's Scientists and Engineers: 1962 (National Opinion Research Center, University of Chicago, 1965).

[5]National Science Foundation, American Science Manpower: 1968, A Report of the National Register of Scientific and Technical Manpower, NSF 69-38, p. 73. The proportions of industrial R & D that were federally funded in 1968 were .28 for basic, .33 for applied and .54 for development. National Science Foundation, National Patterns of R & D Resources: 1953-1973, NSF 73-303.

[6]Assumes chemical and petroleum industries employ chemists; and electrical equipment, aircraft and missiles employ physicists.

[7]The number of doctorate scientists in each type of research was obtained from the national register, American Science Manpower 1968, op. cit. Total expenditures for each type are in National Patterns of R & D Resources 1953-73, op. cit. Median salary for Ph.D. researchers in industry was $16,000 in 1968 and this was adjusted to $20,000 for fringes and skewness. Thirty-six percent of doctorate scientists involved in R & D are managers of R & D. They, as well as MDs, are considered other inputs in the above calculation. The number of doctorate scientists was multiplied by 1.5 to adjust for the nonresponse rate. This may overestimate

7 (cont.) the correction for the 1972 Census scientist followups gives lower estimates of numbers of doctorates than the 1970 National Register, Characteristics of Persons in Engineering and Scientific Occupations: 1972, Technical Paper 33, U.S. Bureau of the Census.

[8]National Science Foundation, Research and Development in Industry, 1970, NSF 72-309, p. 14.

[9]Stephen P. Dresch, An Economic Perspective on the Evolution of Graduate Education (Washington, D.C.: National Board of Graduate Education Publications, March 1974).

[10]Richard Freeman and David W. Breneman. Forecasting the Ph.D. Labor Market: Pitfalls for Policy (Washington, D.C.: National Board on Graduate Education Publications, April, 1974), p. 33.

[11]American Science Manpower: 1968.

[12]Freeman and Breneman, op cit., p. 32.

[13]Characteristics of Americas Engineers and Scientists: 1960 and 1962 Technical Paper #21, p. 10. Since then, flows have increased. Between 1966 and 70, gross immigration of scientists and engineers from abroad was 11,300 a year. This is a large share of the average yearly increase in U.S. employment of scientists of 45,000. Sixty-one percent of these immigrants were trained abroad. About a-half of the immigrants who were trained in the U.S. received support from U.S. sources. National Science Foundation, Immigrant Scientists and Engineers in the United States, NSF 73-302, pp. 1, 38, and 39.

[14]Throughout this argument we have been assuming that unsubsidized loans with extended repayment terms are available. Unsubsidized means that the loan program has no interest forgiveness and must pay costs for collection and at least a part of default costs. Such a loan would currently have a nominal interest rate of at least 12 percent.

[15]Dresch, op. cit. He also argues there is no reason to cause substitutions of scientists for capital and material inputs in the production of R & D.

[16]A study of graduate students found that graduate students, who had completed one or more years of a doctoral program were more research and profession oriented than first year students. Professional orientation was determined by their answer to "In the long run would you rather be known and respected (a) throughout the institution where you work or (b) among specialists in your field in different institutions?" Sixty-one percent chose (b). Time in the graduate program was associated with

16 (cont.) a sharp rise in professional orientation (10 to 18 point change in the percent choosing b) when the student had been an undergraduate at a 4 year liberal arts college. Students who had been at universities as undergraduates arrived already socialized. James Davis, "Locals and Cosmopolitans in American Graduate Schools," International Journal of Comparative Sociology 2: 2 (September 1961), p. 221.

[17]Their word for scientists who place the values of the profession first is cosmopolitans, see Barney Glazer, "The Local-Cosmopolitan Scientists," American Journal of Sociology 69: 249-260; William Kornhauser, Scientists in Industry (Berkeley, University of California Press, 1962); Norman Kaplan, "Professional Scientists in Industry, an Essay Review," Social Problems 13: 88-97 (1965). A similar conflict occurs between the scientist and a small liberal arts college.

[18]Questionnaire administered in 1965 to a sample of R & D employees in a large aero space firm. George A. Miller and L. Wesley Wager, "Adult Socialization, Organizational Structure and Role Orientations," Administrative Science Quarterly 16: 2 (June 1971), p. 154.

[19]Ibid., p. 154.

[20]Scientist quoted by Simon Marcson, The Scientist in American Industry (Industrial Relations Section, Princeton University, 1960), p. 105.

[21]Ibid.

[22]Ibid., p. 19.

[23]In a path analytic model the standardized regression coefficients of length of training and field predicting Miller and Wagner's professional orientation scale were positive and strong even when length of service and working in a basic research lab were controlled. The path coefficients were .25 and .09 respectively. Field was a zero one dummy for scientist. In an identical model predicting bureaucractic orientation the path coefficients were negative: -.12 and -.18 respectively. Miller and Wagner, op. cit., p. 156. See also Doris Shepherd, "Orientations of Scientists and Engineers," Pacific Sociological Review (Fall 1961), pp. 79-83.

[24]Miller and Wagner, op. cit., p. 156; Hall and Schroeder, "Correlates of Organizational Identification as a Function of Career Pattern and Organizational Type," Administrative Science Quarterly (September 1972), p. 345. Not suprisingly the studies that find a positive relationship between organizational identification, tenure and professional identification are of government agencies. Because government can internalize the benefits

[24] (cont.) of basic research there is no necessary conflict between professional and bureaucratic orientations. Sang M. Lee, "An Empirical Analysis of Organizational Identification," Academy of Management Journal (June 1971), pp. 213-226; Glazer, op. cit., pp. 249-259. In a lab that had very recently been transfered from government to a nonprofit corporation doing contract research Sheldon found a negative relationship between professional and bureaucratic orientation and a decline in professional commitment with length of services. Mary E. Sheldon, "Investments and Involvements as Mechanisms Producing Commitment to the Organization," Administrative Science Quarterly (June 1971), pp. 143-150.

[25] Marcson, p. 103.

[26] Ibid., p. 79.

[27] Ibid., pp. 77-78.

[28] National Science Foundation, Publication of Basic Research Findings in Industry, 1957-59 NSF 61-62.

[29] Quoted in Douglas T. Hall and Roger Mansfield, "Organizational and Industrial Response to External Stres," Administrative Science Quarterly 16: 4 (December 1971), p. 540.

[30] Ibid., p. 542.

[31] The case for subsidizing Ph.D. scientists more than engineers derives primarily from the alteration of their utility functions. Often interpersonal comparisons of utility functions are considered impossible. In another context Burton Weisbrod has argued that certain utility functions have pareto superiority over others. Burton Weisbrod, "Yes Utility Functions Can be Compared in Efficiency Terms," unpublished, University of Wisconsin, Madison.

[32] Hall and Mansfield, p. 542.

[33] A governmental reward system for significant published contributions made by profit making sector employees is the most direct way of compensating for externalities. Negotiated contracts also might serve but here patent assignability and trade secrecy issues may make the firm reluctant to participate.

[34] Hope Ladlow, "Will It Get Harder to Keep a Trade Secret-Secret?", Conference Board Record (January 1972), p. 19.

[35] Another way to estimate the value of customer good will, patents, and trade secrets is to compare the market value of a firm to its book value. With a book value of $77 per share IBM sells for $200+. This difference between IBM's market value and book value is in excess of 14 billion dollars. If $10 billion is adopted as the value of all technological trade secrets within the US and each secret is known by an average of 20 people, the typical scientist carries in his head or his files proprietary information worth $537,000 on the open market. About 4 percent of scientists and engineers change jobs every year (see Table B). If only 5 percent of this proprietary knowledge an old employee knows is communicated to his new employer, the employer's expected loss of trade secrets is $1075 (or about 6 percent of compensation) for every year of employment. This estimate assumed that the size of the temptation, the value of the trade secrets an individual knows, is unrelated to his likeihood of passing them to another firm. A more realistic view of human nature would imply a positive correlation between temptation and the leakage of secrets.

[36] Richard Healy and Timothy Walsh, "Trade Secrets: Is There a Fifth Column in Your Company," Management Review (August 1971), p. 17.

[37] John Stedman, "Employer-Employee Relations" in Fredrick Neumeyer, The Employed Inventor in the United States (MIT Press, Cambridge Mass., 1971), pp. 55-62.

[38] "Problems in Review - Industrial Espionage," Harvard Business Review Nov.-Dec., 1959

[39] Roger O'Meara, Employee Patent and Secrecy Agreements, Studies in Personnel Policy #199 (National Industrial Conference Board, New York, 1965). Eighty-six firms that conduct R & D were surveyed.

[40] Roger O'Meara, "How Smaller Companies Protect Their Secrets," the Conference Board, 1971.

[41] BF Goodrich vs. Wahlgemath (192 NE and p. 99), and Ware vs. Merrill, Lynch, Pierce, Fenner and Smith, Inc., C.C.H. 1972 Trade Cases, para. 74.136 (Calif. Sup. Ct. 1972), holding a restriction in a profit-sharing agreement barring an ex-employee from engaging in competition, illegal under California antitrust law.

[42] Timothy Walsh & Richard Healy, Protecting Your Business Against Espionage (American Management Association, 1973) p. 10.

[43] Serwin Rosen, "Learning and Experience in The Labor Market," Journal of Human Resources VII: 3, Summary 1972, p. 326; Gary Becker Human Capital (National Bureau of Economic Research, New York).

[44] Ralph Nader, Peter Petkas, and Kate Blackwell, eds. Whistle Blowing, Report of the Conference on Professional Responsibility (Grassman Publ., New York, 1972).

[45] Even if Nader and his engineer informant were wrong about the danger of Covairs much of what GM lost was gained by Ford, and the plaintiffs in law suits against GM.

[46] In some fields there are philosophical differences within the field in which government might have an interest. In research government can merely purchase the type of research it thinks is useful. In a profession like public administration or special education, the independence of lower level or local government bureaucrats might make it impossible for the federal government to change the character of the governmental service directly. An indirect approach of supporting policy studies or behavior modification training programs might be the only policy available.

Table A - Employer and Primary Work Activity by Field of PhD Scientists

	Educational Institutions	Fed. Gov't. Other Gov't. Non-profit org. Military	Industry/Business/Self Employed					
			Total	Basic Research	Applied Research	Industry R&D Funded by Ind.	Industry R&D Funded by Fed.	Profit Making non R&D
All Fields-Doctorate	.599	.154	.241	.041	.064	.111	.070	.062
Chemistry	.360	.097	.537	.098	.144	.391	.047	.102
Earth and Marine Sci	.597	.190	.207	.019	.042	--	--	.121
Physics	.594	.134	.271	.072	.091	.132	.052	.029
Math	.791	.072	.132	.016	.046	--	--	.039
Ag Sciences	.675	.229	.091	.003	.031	--	--	.029
Biological Sciences	.687	.206	.102	.020	.029	--	--	.018
Psychology	.603	.246	.145	.003	.016	--	--	.113
Economics	.760	.159	.079	.002	.012	--	--	.050
Sociology	.876	.098	.019	.004	.006	--	--	.013
Political Science	.870	.109	.018	.002	.003	--	--	.013
Anthropology	.862	.061	.017	.001	.004	--	--	.030
Linguistics	.893	.075	.025	.007	.002	--	--	.018
All Fields-Master's	.437	.212	.344	.013	.068	.100	.071	.180
All Fields-Bachelor's	.169	.260	.564	.015	.069	.119	.093	.357

Source: Appendix Table A-9B. Number of Doctorate Scientists, by field, primary work activity, and type of employer, 1968, in American Science Manpower 1968: A Report of the National Register of Scientific and Technical Personnel.

Table B

Percent of Engineers and Scientists Changing Employer between 1960 and 1962

	Engineers	Physical Scientists	Biological Scientists	Mathematicians	Social Scientists
Ph.D.	7	7	3	6	5
Master's	6	9	6	8	8
Bachelor's plus	8	12	12	14	16
Bachelor's	6	5	6	11	7
No Degree	5	6	7	8	9
25-34 years	8	11	11	14	12
35-44 years	5	6	3	4	7
45-54 years	4	3	2	1	4

Source: Bureau of the Census. Characteristics of America's Engineers and Scientists: 1960 and 1962. (Washington D. C.: Government Printing Office, 1969), Table 26, p. 28.

Table C: Percent of Ph.D.s in Selected Occupations in 1970

Ph.D.'s	Occupations in 1970						
	Computer Specialists	Engineering	Mathematics	Biological Sciences	Other Life Sciences	Chemistry	Physics
Computer Science & Data Processing	30.5	23.7	30.0	0.0	0.0	8.6	0.0
Engineering	3.4	84.9	1.3	0.3	0.3	4.6	3.6
Mathematics	3.5	2.6	90.2	0.3	0.0	1.0	0.3
Biological Sciences	1.1	0.9	0.5	64.2	5.2	24.7	0.9
Health Fields	5.1	9.7	1.3	42.8	0.0	17.9	5.6
Agriculture & Other Biological Sciences	2.2	2.1	1.0	26.3	48.6	12.8	1.3
Chemistry	1.0	6.7	0.6	1.3	0.1	86.3	3.1
Physics	2.5	7.7	2.3	0.7	0.0	1.2	83.0
Other Physical Sciences	1.1	7.1	1.4	1.7	0.9	3.2	14.9
Economics	2.6	0.4	4.5	0.0	2.0	0.0	0.0
Psychology	0.4	1.7	0.6	1.9	0.0	0.3	0.8
Other Social Sciences	1.6	0.0	2.0	0.7	0.3	1.4	0.0
Business & Commerce	1.7	23.1	9.7	0.0	0.0	0.0	0.0
Education	3.4	3.7	30.9	11.6	3.1	6.4	4.4
Other Fields	9.8	26.1	4.1	15.0	2.0	5.4	1.7
TOTAL	2.2	16.9	8.1	11.6	2.8	18.6	9.9

Percent of Ph.D.'s in Selected Occupations in 1970 (cont.)

Ph.D.s	Other Physical Sciences	Economics	Other Social Sciences	TOTAL
Computer Science & Data Processing	0.0	0.0	7.2	100%
Engineering	1.3	0.1	0.1	100%
Mathematics	0.8	0.5	0.9	100%
Biological Sciences	0.7	0.5	1.3	100%
Health Fields	1.2	1.6	14.8	100%
Agriculture & Other Biological Sciences	2.7	2.6	0.5	100%
Chemistry	0.3	0.6	0.1	100%
Physics	2.4	0.0	0.2	100%
Other Physical Sciences	68.0	0.8	1.0	100%
Economics	0.3	90.1	0.0	100%
Psychology	0.0	0.2	94.1	100%
Other Social Sciences	1.8	3.6	88.8	100%
Business & Commerce	0.0	65.4	0.0	100%
Education	1.1	3.8	31.6	100%
Other Fields	3.7	7.3	25.0	100%
TOTAL	3.9	6.4	19.5	100%

Source: "Number of Ph.D.'s in Selected Occupations in 1970" taken from Table 11 (pp. 92-96) of Characteristics of Persons in Engineering and Scientific Occupations: 1972.

Mathematical Appendix

Model of the Firm's R & D Investment Decision

The firm maximizes a profit function: 1

1) $\pi = V - C =$ Value of Research - Cost

where V is discounted cost savings in production and/or Gross Profit from sale of new products

2) Research Activity $= AS^{\alpha}K^{1-\alpha} = R$

Research Activity is produced with homogeneous of degree one Cobb Douglas technology; where S = scientist input; K = all other inputs (engineers, technicians, capital, overhead)

The private demand for the research activity R has an elasticity of γ

3) $R_d = (\frac{1}{B})^{\gamma}(\frac{\partial V}{\partial R})^{\gamma}$

where $\frac{\partial V}{\partial R}$ is the marginal value of an increment in research activity R and $\gamma < 0$

4) $\frac{\partial V}{\partial R} = BR^{\lambda}$ where $\lambda = \frac{1}{\gamma}$

Total value of research activity above R = 1 is

5) $V = \int_1^R BR^{\lambda}$

6) Cost of Research Activity $= C = wS + \gamma K$

The profit maximizing research output of the firm is given by examining the first order conditions for a maximum.

The profit function becomes

7) $\pi = V - C = \int_1^R BR^{\lambda} - wS - rK = \frac{1}{\lambda+1} BR^{\lambda+1} - \frac{1}{\lambda+1} B - wS - rK$

8) $\pi = \frac{1}{\lambda+1} BA^{\lambda+1} S^{\alpha(\lambda+1)} K^{(1-\alpha)(\lambda+1)} - wS - rK$

9) $\frac{\partial \pi}{\partial S} = \frac{\partial V}{\partial R}\frac{\partial R}{\partial S} - \frac{\partial C}{\partial S} = BR^{\lambda}\frac{\alpha R}{S} - w = 0$

10) $\frac{\partial \pi}{\partial K} = \frac{\partial V}{\partial R}\frac{\partial R}{\partial K} - \frac{\partial C}{\partial K} = BR^{\lambda}\frac{(1-\alpha)R}{K} - r = 0$

The input demand functions are:

11) $S_o = \frac{B\alpha R^{1+\lambda}}{w}$

12) $K_o = \frac{B(1-\alpha)R^{1+\lambda}}{r}$

Model of Social Welfare Maximizing R & D Investment

We will now develop a model of demand for scientist employees if social welfare were to be maximized.

Assumption 1. Production function for R is unchanged but the marginal social value of research output is larger than and proportional to the private value.

13) $\frac{\partial U}{\partial R} = B^*R^{\lambda}$ where $B^* > B$

In other words, the marginal externality of research = $\frac{\partial E}{\partial R} = (B^*-B)R^{\lambda}$

The real resource cost of R & D scientist employees is the integral of the reservation wage:

14) $C_S = \int_o^S w$

The level of R & D investment that maximizes social welfare--the difference between the benefits of R & D and the real resource costs of R & D can be obtained by maximizing:

15) $U - C = B^*\int R^{\lambda} - \int_o^S w - \int_o^K r$

where the cost of scientist and other inputs are assumed independent.

The first order conditions for a social welfare maximum are:

16) $\frac{\partial U\text{-}C}{\partial S} = \frac{\partial U}{\partial R}\frac{\partial R}{\partial S} - \frac{\partial C}{\partial S} = B^*R^{\lambda}\frac{\alpha R}{S} - w = 0$

17) $\frac{\partial U\text{-}C}{\partial K} = \frac{\partial U}{\partial R}\frac{\partial R}{\partial K} - \frac{\partial C}{\partial K} = B^*R^{\lambda}(1-\alpha)\frac{R}{K} - r = 0$

Optimal use of input from a social welfare maximizing point of view

18) $S_* = \alpha \frac{B*}{w} R_*^{\lambda+1} = \alpha \frac{B*}{w} (AS_*^{\alpha} K_*^{1-\alpha})^{\lambda+1}$

19) $K_* = (1-\alpha) \frac{B*}{r} R_*^{\lambda+1} = 1-\alpha \frac{B*}{r} (AS_*^{\alpha} K_*^{1-\alpha})^{\lambda+1}$

The ratio of social optimum number of scientist employees to the profit maximizing level is:

20) $\frac{S*}{S} = \dfrac{\alpha \frac{B*}{w} (AS_*^{\alpha} K_*^{1-\alpha})^{\lambda+1}}{\frac{\alpha B}{w} (AS^{\alpha} K^{1-\alpha})^{\lambda+1}} = \frac{B*}{B} [(\frac{S_*}{S})^{\alpha}(\frac{K_*}{K})^{1-\alpha}]^{\lambda+1}$

21) $\frac{K*}{K} = \dfrac{\frac{(1-\alpha)B*}{r} (AS_*^{\alpha} K_*^{1-\alpha})^{\lambda+1}}{\frac{(1-\alpha)B}{r} (AS^{\alpha} K^{1-\alpha})^{\lambda+1}} = \frac{B*}{B} [(\frac{S_*}{S})^{\alpha}(\frac{K_*}{K})^{1-\alpha}]^{\lambda+1}$

22) $\frac{S_*}{S} = \frac{K_*}{K}$

23) $\frac{S*}{S} = \frac{B*}{B} [\frac{S_*}{S}]^{\lambda+1}$

24) $(\frac{S*}{S})^{-\lambda} = (\frac{S*}{S})^{-\frac{1}{\gamma}} = \frac{B*}{B}$

25) $\frac{S*}{S} = \frac{B*}{B}^{-\gamma}$ remember that $\gamma < 0$

The proportionate increase in employment of scientists that achieves the social welfare maximum is the ratio of the social to private marginal benefit of R & D to the power of the absolute value of the elasticity of demand for research output.

This result generalizes for any homothetic production function for the research activity.