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THE PERFORMANCE OF GOVERNMENT-FUNDED R&D IN THE PRODUCTIVITY OF U.S.A. MANUFACTURING INDUSTRY

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I. INTRODUCTION

Since World War II the implications of technical progress or productivity have received more attention. This is probably due to the evidence which has found the contribution of technical progress to economic growth to be as important as the traditional labor and capital factors. In the industrial organization the market performance of R&D competition has been thought of as the economic progress through productivity improvement. Recently, macroeconomic research (Kydland and Prescott, 1982; Long and Plosser, 1983) studying business-cycle fluctuations indicates that shocks that increase output by increasing productivity will also increase the marginal product of capital and hence increase investment demand. The supply shocks appear to have a permanent component. Much of innovation and invention is presumably regarded as permanent.

However, from the time that technical progress has been recognized as important for economic growth, dispute has occurred over the term—productivity or technical progress—its use, meaning, measurement, and interpretations. As will be shown, productivity cannot be viewed as something exogenous to the economic system. By and large, technical progress does not occur by accident but through the efficient allocation of resources in pursuit of profit or other motives.

The study of the determinants of productivity has a relatively short history. The conference of the Universities-NBER committee for economic research held in the spring of 1962 reached the conclusion that the "Residual" or productivity can be mainly explained by inventive activity rather than something exogenous to the economic system.

The publication of *The Rate and Direction of Inventive Activity* (Nelson, 1962), a collection of papers presented at the conference, is a volume that still serves as a major statement and source book of economic ideas in this field. The major themes of research in this field were already clear at the conference as in Griliches' (1981) and Nelson's summary:

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> The belief that innovation and technical change are the major driving forces of economic growth; that economists have to try to understand these forces, to devise frameworks and measures which would help to comprehend them and perhaps also to affect them; that much of technical change is the product of relatively deliberate economic investment activity which has come to be labelled "research and development."

At the conference there were attempts to relate R&D investments to their subsequent effects on the growth of total factor productivity (Minasian, 1962).

In assessing the importance of R&D investments, Griliches (1981) says that invention and technical change are the major driving force of economic growth. Although the investment in macroeconomics may be compared with R&D investments, the latter is accompanied by high risk for success or failure. Also the economic benefit of R&D investment cannot be calculated exactly. The result of R&D is not perfectly monopolized. R&D yields external effects in the diffusion of new information.

Given the importance of R&D expenditures in the process of economic growth and the problem of non-appropriation of R&D output, the question raised is "Who will do R&D investments for social or/and private benefit?" In considering the characteristics of R&D investment, its activity must be shared by the private firms and the government. The goal of private firms in performing R&D would be to continue production activity in the future and increase the profits with the growth of the firm. Since invention and technical change are the consequences of R&D expenditures and the main driving forces of economic growth, the government may decide to perform R&D activity directly, and indirectly through helping or funding company-performed R&D activity.

In view of the ultimate goals of R&D and different properties of varied R&D funds, there are two trends in the studies which are concerned with the role of R&D funds. The principal problem in them lies in the fact that there is no attempt to combine them in a model, for, as argued below, the trends eventually investigates the impact of FRD and IRD on fostering technical progress. The importance and reason to combine two trends will be emphasized throughout my paper. These will be developed more fully in a literature survey later in my paper. Briefly, the first one is to investigate the impact of R&D funds on productivity growth. Since productivity growth implies economic growth through R&D activity, the tendency may originate in Schumpeter's explaining the business-cycle fluctuations to emphasized the importance of entrepreneurship. According to him an economic stationary state in the long run can be avoided by creative destruction on the part of entrepreneur. The second trend in the literature is related to the relation between federally-funded[1] and company-funded R&D. The focus is

[1]Note that federally-funded R&D implies the R&D expenditures financed by the Federal but performed in the industry.

on whether the two types of R&D which are supported by different agents crowd each other out.

In fact, it has to be emphasized that two trends do not seek for absolutely different goal. More importantly, the second trend must be included in the first trend to investigate the effect of federal R&D on aggrgate technical progress. The first trend considers only the direct effect of govern–funded R&D funds (FRD) on productivity, but not their indirect effect through company–funded R&D (IRD). The second trend does neglect the goal in pursuit of R&D activity, i.e., profit maximization. Two trends in the previous literature have been analyzed on the simple ad hoc model not to be able to deal with them altogether. Hence, on the assumption that R&D investments are the source of productivity growth, the goal of my paper is simultaneously to examine the relation between FRD an IRD, and their respective contribution to productivity, in the structure of firm's optimal behavior. The model is supported by the argument mentioned above: *technical progress does not occur by accident but through the efficient allocation of resources in pursuit of profit or other motives.* This perspective serves as an impetus to aggregate the two previous trends of studies on the role of R&D expenditures. Especially, according to the different model and different data I reevaluate the role of government–funded R&D in fostering productivity growth.

In the previous literature[2], the simple regression tests generally lend scant support to the hypothesis generated by Blank, Stigler and Black's (1964) case study that federally–funded R&D simulates industry–funded R&D in the lower technology industry and there is a substitute relationship between FRD and IRD. Motivated by the conflicting empirical evidence on the role of FRD in the productivity growth, this paper seeks further insight in the framework of firm's profit–maximizing behavior. The empirical results based on my theoretical model suggest a possible resolution of the apparent conflict between the case study and regression analyses.

This paper is presented in the following order. After building a model of optimal firm behavior in an environment of federal R&D support, I derive the relation between FRD and IRD and then, that is utilized to examine the total

[2]Some Scholars' studies have shown estimates of a significantly positive impact of government–funded R&D on private R&D expenditures (Leonard, 1971; Levin and Reis, 1981; Link, 1982; Mansfield, 1981; Mansfield and Schwitzer, 1982; Scott, 1981; Terleckyj and Levy, 1983: Switzer, 1984). For example, Link (1982) finding suggests that a one–dollar increase in federally–funded R&D increase company–funded R&D by 9.4 cents. Others have published estimates of a significantly negative impact (Tilton, 1973: Kendrick, 1978; Schrieves, 1978; Carmichael, 1981). For example, Carmichael (1981) shows that each dollar of federal spending crowds out private investment by as little as eight cents in the dollar and adds around 92 cents to total R&D spending in the transport industry from the cross section data of annual R&D survey. Only Lichtenberg (1984) demonstrated indeterminate effect of government–funded R&D. His indeterminate effect is due to the different signs of lagged variables.

impact of FRD on technical progress. In the model I empirically investigate two hypotheses. That is, this study examines the direct and the indirect effect of R&D funds on productivity at the industry level and the relation between R&D funds as inputs to yield the productivity change.

The main finding is that, using the disaggregated data in the industry level, there exists no clear-cut relation between heterogeneous R&D funds. That is, FRD spurs IRD in some industries and FRD retards IRD in other industries. The remarkable point is that the issue of crowding-out (or pulling-in) in fundamentally dependent on industry-specific parameters. Second, I find that, when FRD's indirect effect is considered, its insignificant or significant effect on productivity is changed into uncertain magnitude. That is, my finding indicates that productivity returns to IRD is not always larger than those to FRD. I find a considerable support for the view that there is one-period lag effect of FRD on productivity growth.

II. THE RELATION AMONG HETEROGENEOUS R&D FUNDS AS INPUTS

The main purpose of this section starts with the arguement that different opportunities for doing R&D, are in different ecological niches, and hence have different coefficient in their production function. This would explain why different industries are observed to spend different amounts on R&D. Hence this section is devoted to tackling at the industry level two problems, namely, the influence of two types of R&D funds on productivity and the relation between them as inputs in the firm's optimal behavior. The latter is designed to test the hypothesis that increases in federally-funded R&D tend to be associated with significant reductions or increases in company R&D. It criticizes the first trend mentioned above and gives a motivation to examine the role of government-funded R&D. The former answers the quesion, to what extent does R&D activity funded by the Federal affect the productivity?' To examine their effects here, I would assume the firm's optimal behavior in R&D activity using heterogeneous R&D funds.

1. Does the Term 'crowding-out' Appropriately Explain the Role of Public R&D Expenditures?

In the previous literature it is shown that a branch of study on the role of federally-funded R&D is to investigate the relation between public and private R&D investments in an simple ad hoc model and then to check whether the former has negative or positive effect on the latter. The previous works have never built the model to look at theoretical crowding-out or pulling-in. I doubt that such a method by following 'crowding-out' concept does justice to the evaluation of external economy of public R&D activity. Now the crucial question appears to be; "Is the discussion of 'crowding–out' relevant to the assessment of government R&D activity?" The answer to the question must start with building the theoretical model to support the properiety of the concept in this field.

The term 'crowding–out'[3] has been used in previous literature to judge the contribution of federally–funded R&D to company funded R&D. Before proceeding to point out the appropriateness of the concept in the study of the role of federally–funded R&D, it is worthwhile to investigate the implications of the concept more specifically.

Originally, the concept appeared in macroeconomics to argue against the fundamental achievement of the Keynesian revolution which increased the economic power of the government sector, contrasted with the classical view that government spending was powerless. 'Crowding–out'[4] refers specifically to the displacement of private economic activity by public economic activity. Crowding out, frequently refered to as ultrarationality in the economy, concerns the sings and magnitudes of public policy. As shown in Buiter (1977), the term discusses both direct and indirect crowding out. Direct crowding out which is relevant to the previous work is the concept which has been used to focus on the effect of public R&D investments on private R&D investments. The degree of direct crowding out is the extent to which the government sector can be subsumed under the private sector in specifying the structural behavior relationships of the economy. In such a framework, direct crowding out is a multi–dimensional concept.

The importance of the implicantions of pulling–in versus crowding–out is immediately obvious when one considers that the federal government in the United States supports a considerable amount of the R&D performed by the industry in this country (30% for 1978 in total manufacturing industry and 45% in the electric industry) and that R&D affects not only the state of the art in many techniques but also is an important determinant of international trade pattern and industrial organization. The previous literature to study crowding out in R&D markets can be criticized in two aspects: first, theoretical background appearing to date, and second, in light of not treating heterogeneous R&D funds as inputs in fostering productivity growth. I start with the first one. Economists often argue that from the viewpoint of welfare economics, opportunities for private profit draw resources where society must desire them. Optimal resource allocation for invention interpreted as the production of knowledge and as the source of productivity has

[3]The pulling–in/crowding–out relationship hypothesis was first introduced by Blank and Stigler (1954), to explain the consequences of federal funding R&D perfomed by private organizations. See Fisher and Black (1979) for detail.

[4]The detailed treatment of crowding out refers to Blinder and Solow (1973), Buiter (1977), Tobin and Buiter (1976), and Friedman (1978). Especially, Friedman (1978) and Buiter (1977) are recommendable to understand the concept. The discussion in my paper about it comes out of Buiter's and Friedman's paper.

been analyzed in this framework. Since Nelson (1959) and Arrow (1962), the classic question for R&D expenditures with regard to welfare economics has been raised: does perfect competition draw into R&D expenditure as great a quantity of resources as is socially desirable? Theoetically, perfect competition gruantees the achievement of a Pareto optimum under certain assumptions. It has been generally accepted, however, that indivisibilities, inappropriablity, and uncertainty may result in the failure of perfect competition to achieve optimality in resource allocation.

Nelson demonstrates that, in light of the inappropriability of outcome especially in basic research, the allocation of R&D resources that maximizes private profits through the market mechanism cannot be optimal. In Arrow(1962), it is emphasized that, in the absence of common stocks to completely insure against the risk involved with R&D activity, the market cannot lead to its optimal allocation. Dasgupta and Stiglitz (1981) at theoretical level have shown that the socially optimal level of R&D is larger than that level in which occur under monopoly or oligopoly. More recently, DeBrock and Masson (1985) have demonstrated that no unambiguous ranking is available.

Theoretical literature has shown conclusively that market failure appears to hold in the case of inventive activity and that underinvestment results when R&D activity is accompanied by risk. The underinvestment in the social level does justice to the necessity of federally–funded R&D expenditures. At the empirical level, earlier studies (Griliches, 1964; Mansfield, 1968; Minasian, 1969) reveal two trends. They all indicate underinvestment in R&D, and all consider only the private and not the social return.

From the previous studies, I can infer that the government, with its superior risk bearing ability, should consider undertaking R&D to achieve a socially optimal level. Consequently the role of government–funded R&D funds must be analyzed in a different dimension other than the typical 'crowding out' analysis.

Let me proceed to the second argument. The concept of direct crowding out can be utilized in studying the influence of public R&D activity on private R&D activity. R&D expenditures are inputs to produce productivity or technical progress as their output. Since the ultimate purpose of R&D expenditure is accepted to yield productivity growth in the economy, the effect must be examined in the model which should include productivity growth. Hence the production function approach in what follows gives a new perspective from which policy makers evaluate public R&D activity. According to the approach, it is shown in my paper that there are good theoretical and empirical reasons to believe in the efficacy of government–funded R&D activity in an economy with limited resources. Hence the results based on this porduction function approach will call into question the crowding out' association of federally–funded R&D with company–funded R&D based on the simple regression equation.

The previous literature has shown that the relationship between federally–

funded and company-funded R&D is determined as follows. If the sign of regression of the former on the latter is negative, government-funded R&D expenditures are powerless to affect productivity growth or, at best, inefficient resource allocation, and vice versa. But such a conclusion based on the simple regression erroneously ignores the fact that R&D expenditures must be considered and evaluated in light of their ultimate goal, economic growth via productivity. Reasonable policy recommendations for the efficient allocation of public R&D investment must be based on a more elaborate model which takes into account the goal of investment rather than emphasizing their process.

But in my paper the explicit crowding-out effects associated with financing the R&D activity by the Federal but performing it in the firm assume primary importance in the different model specification. The specification of different structure from the traditional to understand crowding-out effects can be found in Friedman (1978). He uses the concept of substitutability among variables in examining the concept in issue. It is similar aspect to my model. The underlying mechanisms of the different model are more complicated and less familiar than those used in the previous literature. Introducing productivity growth as ultimate goal of R&D activity into the model is an essential first step. The incorrect but nevertheless currently widespread view results from the ad hoc single equation approach in which federally-funded R&D is due to the failure to consider adequately the ultimate purpose of R&D activity such as productivity growth. Clearing up this misunderstanding of the impact channel of federally-funded R&D into company-funded R&D is an important precursor to sensible analysis of the contribution of the former to the latter in fostering productivity growth.

In this section, I explain two facts that serve as the motivatien for this study. The first purpose of my paper is to assume that heterogeneous R&D funds are invested to maximize firm's profit in view of the production function approach specifically with productivity as an output and heterogeneous R&D funds as inputs and to reexamine the underlying basis of the relation between them. That is, when federal-funded R&D is studied in combination with company-funded R&D in the production function, their relationship is evaluated from the condition of firm's optimal behavior. The most fundamental achievement of the approach using the firm's optimal behavior is the reorientation of the way economists view the influence of government-funded R&D activity on company-funded activity. The second purpose is to estimate the total impact of federally-funded R&D on productivity. The aggregate impact is the sum of its direct effect, and indirect effect through crowding out or pulling in. The failure of most econometric studies to find FRD's significant direct effect on productivity leads me to hypothesize and investigate an indirect path of stimulus to productivity, via an inducement to perform IRD. This kind of evaluation in the role of government-funded R&D in productivity is never performed in the previous literature which I have read, because the previous work focus on whether federally-funded R&D is crowding out or not and whether it is significant or not in productivity growth. The importance of such issue is mentional in Lichtenberg (1984) and Levy and Terleckyj (1983).

2. A Theoretical Framework to Evaluate the Contribution of Federally-funded R&D to Productivity

In this sub-section, I undertake to build the model to explain two roles of federally-funded R&D; first, pulling-in effect of federally-funded R&D on productivity and second, the total impact of federally-funded R&D on productivity.

In the previous literature, some scholars show that, in a simple regression model, government-funded R&D expenditures crowd-out company-funded ones. Such studies use company-funded R&D as the dependent variable and federally-funded R&D as one of independent variables. Hence the conclusions derived from these models have not taken into account the purpose of R&D, i.e., the profit maximization via the effect of R&D on productivity growth through process or product innovation. In examining the role of heterogeneous R&D, I will analyze the relation between these two factors in light of their end by using two approaches; one is based on frim's optimal behavior and the other relies on the theory of economics of scale. The second is a by-product of the first way. I will start with the first way.

I study how the firm's optimal behavior is connected with R&D investments. It is assumed that a representative firm maximizes its profit through R&D investments. As pointed out above, there are heterogeneous R&D investments in the firm, i. e., firm-funded R&D funds and federally-funded. Suppose that the federally-funded R&D in the firm is given in its optimal behavior. To examine profit maximization with respect to heterogeneous R&D funds, all variables except firm-funded R&D expenditures are regarded as fixed. Public investments in research are not constrained or guided by the profit motive. There is a wide scope for potential bureaucratic bungling in them. Federal funding of R&D is not designed for fostering technical progress, i.e., easy commercialization, which is shown in Rhee (1987). The two facts do justice to the assumption that the federally-funded R&D expenditures are treated as fixed in the firm's optimal behavior. Suppose the technology is Hicksian neutral. In order to more clearly focus on the role of R&D, I will assume the firm is a price taker in the product market as well as the input market (P,w,r,g are all fixed). In addition, to simplify, the production process is multiplicatively separable in technology. Under these assumptions, the optimal behavior of a representative firm[5] can be denoted as follows,

$$\Pi = P\,F(K,L)\,f(IRD, FRD) - wL - rK - gIRD \qquad (1)$$

[5]The assumption of a representative firm is only a convenience as the solutions to the optimization problem for each firm can be aggregated to obtain industry R&D demand equation.

Where

P = the price of product,
F(k,L) = the production function,
f(IRD, FRD) = the technical progress,
K and L = capital and labor,
w and r = the rental prices of capital and labor, respectively,
g = the rental price of IRD,
IRD = the firm-funded R&D, and
FRD = the federally-funded R&D.

f(IRD, FRD) corresponds to A, total factor productivity in Kendrick (1980). The endogenous variables are K, L, and IRD. As shown in the APPENDIX A, the logvalue of production function does justice to dealing with only IRD.

Equation (1) is maximized with respect to IRD,

$$\max_{IRD > 0} \Pi \tag{2}$$

The first-order condition for equation (2) is

$$\frac{d\Pi}{dIRD} = P\,F(K, L)\,f_1 - g = 0 \tag{3}$$

To derive the relation between IRD and FRD, I perform comparative statics on equation (3). The demand for input IRD can be driven from equation (3). Taking the differential with respect to IRD and FRD, then

$$P\,F(K, L)\,\{f_{11}dIRD + f_{12}dFRD\} = 0$$

From this it is possible to determine the effect on the optimal level of IRD due to change in FRD. This is written:

$$\frac{dIRD}{dFRD} = \frac{-f_{11}}{f_{12}} \tag{4}$$

Equation (4) presents the relation between heterogeneous R&D funds which is the consequence of firm's optimal behavior in R&D activity. If f is assumed to be quasiconcave, f_{11} is negative, but the sign of f_{12} is indeterminate. The sign of (dIRD/dFRD) is dependent on that of f_{12}. As will be shown, this will become a partially indirect effect.

In order to make the model operational and provide more substance, I assume that the explicit form for heterogeneous funds is the CES production function instead of Cobb–Douglas form widely used in the ad hoc model of the previous literature. That is, the f(IRD, FRD) in equation (1) can be written:

$$f(IRD, FRD) = \gamma\,(\alpha\,IRD^{-\rho} + (1-\alpha)FRD^{-\rho})^{-\frac{u}{\rho}} \tag{5}$$

where γ is constant term and α, ρ and u are parameters.

To obtain the explicit form of equation (4) from equation (5), I take the first derivative of equation (5) with respect to IRD,

$$f_1 = \alpha \text{ u IRD}^{-\rho-1}\gamma(\alpha \text{ IRD}^{-\rho} + (1-\alpha) \text{ FRD}^{-\rho})^{\frac{u}{\rho}-1}$$
$$= \text{h IRD}^{-\rho-1} f^{1+\frac{\rho}{u}} \tag{6}$$

Where h denotes $\alpha u \gamma^{-\frac{\rho}{u}}$. The derivative of f with respect to FRD is ,

$$f_{12} = \text{h IRD}^{-\rho-1} (1 + \frac{\rho}{u}) f^{\frac{\rho}{u}} (\frac{df}{dFRD})$$

$$= h(u + \rho)(1 - \alpha) \text{ IRD}^{-\rho-1} \text{ FRD}^{-\rho-1} f^{1+2\frac{\rho}{u}} \gamma^{-\frac{\rho}{u}}$$

The second derivative of f with respect to IRD is

$$f_{11} = h(-\rho - 1) \text{ IRD}^{-\rho-2} f^{1+\frac{\rho}{u}} + \text{h IRD}^{-\rho-1} (1 + \frac{\rho}{u}) f^{\frac{\rho}{u}} (\frac{df}{dIRD})$$

$$= h(\frac{1}{\sigma}) \text{ IRD}^{-\rho-2} f^{1+\frac{\rho}{u}} (\frac{\sigma(u + \rho)}{1 + ((1-\alpha)/\alpha)(FRD/IRD)^{-\rho}} - 1)$$

where $\sigma = 1/(1 + \rho)$. Then equation (4) in the absolute value becomes

$$\frac{f_{12}}{f_{11}} = (\frac{IRD}{FRD}) \frac{(\frac{\sigma(u + \rho)}{(\alpha/(1-\alpha))(IRD/FRD)^{-\rho} + 1})}{(\frac{\sigma(u + \rho)}{((1-\alpha)/\alpha)(FRD/IRD)^{-\rho} + 1} - 1)} \tag{7}$$

In equation (7), let us denote $(\alpha/(1-\alpha))(IRD/FRD)^{-\rho} = ((1-\alpha)/\alpha)^{-1} (FRD/IRD)^{\rho}$ by B. B is closely related to the marginal product of heterogencous R&D funds when FRD is regarded as a variable factor. I show that B is the ratio of the marginal product of IRD to that of FRD.

$$\frac{df/dIRD}{df/dFRD} = \frac{\alpha}{(1-\alpha)} (\frac{FRD}{IRD})^{\frac{1}{\sigma}} = \frac{\alpha}{(1-\alpha)} (\frac{FRD}{IRD})^{\rho+1} \quad \alpha \quad \frac{\alpha}{(1-\alpha)} (\frac{FRD}{IRD})^{\rho}$$

Hence B is interpreted as the share of IRD in the technical progress relative to the share of FRD. Combining equations (7) and (4) becomes

$$-\frac{f_{12}}{f_{11}} = -(\frac{IRD}{FRD}) \frac{\frac{\sigma(u + \rho)}{B + 1}}{(\frac{\sigma(u + \rho)}{(1/B) + 1} - 1)} \tag{8}$$

I derive the effect of federally–funded R&D on industry–funded R&D from equation (8) which is the product of firm's optimal behavior. Equation (8) is utilized to test the hypothesis that increases in federal R&D tend to be associated with significant reductions or increases in IRD. This equation is evaluated by the parameters of equation (5) obtained by the non–linear estimation and the average ratio of industry–funded R&D to federally–funded R&D, i.e., (IRD/FRD). This relation overcomes a difficulty in standard estimation of the relation between heterogeneous R&D funds. This is solidly based in the technology that derives the firm's short–run R&D investment decision despite the serious simultaneity problem.

For evaluation of the role of federally–funded R&D expenditures in productivity growth, equation (8) is more complicated than the significance or insignificance in the previous literature based on a single regression equation. What is important is that the information on all parameters is used to understand the effect of federally–funded R&D on industry–funded one in productivity growth. The sign of right–hand side in equation (8) is crucial in deciding the relation between company–funded and industry–funded heterogeneous R&D funds. A positive sign implies that the federally funded R&D has a positive influence in productivity growth through stimulating the privately optimal level of R&D. A negative sign implies that the federally–funded R&D yields an opportunity cost in productivity growth; equilibrium levels of industry–funded R&D decline. Hence equation (8) and equation (5) are used to evaluate the impact of federally–funded R&D on industry–funded R&D. In the next section, empirical evidence as to the sign of equation (8) is presented.

Firm's optimal behavior approach, applying the theory of production between R&D expenditures and productivity growth, yields the economy of scale in R&D expenditures. Stigler (1983) emphasizes the importance of the economies of scale:

> The theory of the economies of scale is the theory of the relationship between the scale of use of a properly chosen combination of all productive services and the rate of output of the enterprise. In its broadest formulation this theory is a crucial element of the economic theory of social organization, for it underlies every question of market organization and the role of governmental control over economic life.

In my paper the theory of the economies of scale is crucial in investigating the role of government–funded R&D expenditure to productivity growth yielded in the industry. The decreasing returns to scale in R&D expenditures may imply the high uncertain reward for them. Such high uncertainty requires the government with its superior risk bearing ability to consider undertaking R&D to achieve a socially optimal level of productivity growth. The information on the economies of scale is obtained from the parameters u in equation (5).

Now I move to the discussion of FRD's total effect. Especially, unlike the direct productivity effects of IRD on technical progress, the effects on productivity of much of FRD have been mostly indirect and have involved stimulation of additional IRD. Its importance is emphasized in Levy and Terleckyj (1983) and

Lichtenberg (1984). From the first condition (3) I get the functional relation between IRD and FRD.

$$IRD = I(FRD) \tag{9}$$

Then equation (5) becomes

$$A = f(IRD, FRD) = f(I(FRD), FRD) \tag{10}$$

By differentiating equation (10) with respect to FRD, FRD's total effect on productivity is obtained as follows:

$$\frac{dA}{dFRD} = \frac{df}{dFRD} + \frac{df}{dIRD}\frac{dIRD}{dFRD} \tag{11}$$

The first term in the right-hand side of equation (11) presents the direct effect and the second term is the indirect effect. What attracts my attention is the second term which consists of two terms. (dIRD/dFRD) is called as partially indirect effect. This is distinguished from total indirect effect. Hence the total effect of federally-funded R&D on productivity consists of the direct effect and the indirect effect through crowding-out or pulling-in. df/dFRD and df/dIRD are derived from the differentiation of equation (5). Note that the value of dIRD/dFRD utilizes the calculated value in equation (8). Equation (11) can be directly derived by utilizing the envelope theorem.

This equation is served to test two hypotheses. First, the hypothesis that in the presence of any effect of FRD on IRD, the productivity returns to FRD are no smaller than those to IRD is tested in the equation. The marginal contribution of IRD to productivity is defined as dA/dIRD. Second, this equation is also used to evaluate whether federally-funded R&D incurs social cost because its reward is less than the discount rate. The discount rate is defined (1 + r), where r is the interest rate. If (dA/dFRD) is larger than (1 + r), it can be concluded that federally-funded R&D increases social welfare in the U.S. economy. If not, the cost of R&D investment is not recovered.

The rates of return of FRD in my model deal only with the producer surplus and, hence, are undervalued, because they consist of two benefits, the consumer surplus and the producer surplus in the market.[6] For that reason, I prefer the equation (11) to test the first hypothesis rather than the second.

III. EMPIRICAL RESULTS

In this sub-section I perform empirical work to investigate the role of hetero-

[6]Both the demand and the supply must be considered exactly to compare the rates of return with social cost. Such attempts in the field of industry funding R&D are found in Mansfield, et al (1977) and Ulrieh, et al (1986).

geneous R&D in productivity growth. The empirical work in my paper requires to make an ad hoc compuation to investigate two hypotheses. Especially, my model supports empirically the hypothesis in Blank, Stigler and Black (1964) that FRD stimulates IRD in the lower technology industry and there is a substitute relationship between FRD and IRD in the high technology industry. The computation of returns to R&D investment and of the relation between heterogeneous R&D funds cannot be made without first making some arbitrary assumptions. Were it not for the tremendous importance for policy of such a calculation, it should be avoided. The procedure of an ad hoc computation is explained in the course of working out the principal work. The principal work is performed to test two hypotheses. First, I calculate the relation between FRD and IRD obtained from equation (8). According to it, I seek to study the extent to which, given productivity, federal R&D affects company-funded R&D. This will also be used to derive the indirect effect of FRD on productivity growth. The results of my model are compared with those obtained from the simple ad hoc model. The comparison reveals the merit of my model more conspicuously. Second, the total impact of government-funded R&D funds on productivity is obtained by adding the direct and indirect effect in equation (11).

In calculating equations (8) and (11), I face difficult problems to estimate the parameters, to choose the appropriate time dimension to measure presently unobservable research capital and to calculate the ratio of FRD to IRD. It is worthwhile to specify which assumptions or procedures are used to solve the problems. They are discussed in order.

The unknown parameters in equations (8) and (11) are obtained from the estimation of equation (5). The CES functional form is estimated by the non–linear model which accompanies more difficult tasks than the linear model. Furthermore, since parameters α, ρ, and u take a specific domain, I impose constraints on them which make sense in an economic theory standpoint. In the absence of constraints, even though the convergence criterion is satisfied in some industries, the estimated values are outside known prior domain. Estimating a model without known prior constraints involves a "price" of inefficient estimates. Moreover, the estimation results are hard to interpret if the constraints are not imposed. Marquardt's[7] method in the SAS 1985 package is used to estimate the parameters in CES functional form. Convergence criterion is 0.01. 60 iterations are performed with respect to the chosen starting values. By changing the starting values, I look at the convergence measures reported at the point of failure. If the estimates appear to be approximately convergent, I accept them as the nonconvergent but reported results.

For the reasons explained below, the average values of FRD and IRD discounted by their respective 1967 value are used to calculate the ratio (FRD/IRD).

[7]This method is popular because it is speedier than other methods for nonlinear estimation.

How the values of IRD and FRD are defined has an important role in deciding the magnitude of dollar value of pulling–in or crowding–out in equation (8). In viewing its trend, I can decompose it into the permanent and the transitory term. Assuming that the transitory term is not associated with productivity growth, only permanent term indicates the long term trend of heterogeneous R&D funds. More importantly, it means the average value at each time period. The average value can be used as the optimal value on the long term trend.[8]

The appropriate time dimension for unknown amount of research capital which is effective in contemporaneous productivity growth is based on the empirical results yielded in Rhee (1987). The main reason to do so is due to the fact that there are probably some time lags between the time when the R&D investment decisions are made and the time where they become productive. I emphasize that lagged variables are likely to have an important role in current productivity. Only lagged variables motivated by the simple theoretical and tested by standard statistical method will enter the equation.

The data are described in detail in the APPENDIX B. In short, they are described here. The productivity data are the index derived from putting the 1967 value equal to 100. To make R&D data consistent with productivity, I take the same procedure as the productivity index. The data of productivity and heterogeneous R&D funds in 8 two–digit industries are covered. Productivity data are quoted from Kendrick and Grossman (1980). The data for heterogeneous R&D expenditures are quoted from the periodic publication by the National Science Foundation and cover the period from 1953 to 1978 in total maufacturing industry, from 1956 to 1976 in the electric, machinery, fabricated metal, chemistry, and primary metal industires. The data for the petroleum industry cover the period from 1956 to 1974, theose for the rubber industries from 1957 to 1974, those of the food industry from 1958 to 1974.

1. Is Federally–funded R&D Crowding–out?

The import of empirical findings on crowding–out or pump–priming hypothesis of federal funding R&D was to support the promise of government potential in modernizing traditional industries and rejuvenating mature industires. Hence the term "crowding–out" is important in investigating the role of federal funding R&D in the economy.

In the previous works, the effects of FRD on IRD are estimated as regression coefficient in the equation for private R&D expenditures. In the analysis pre-

[8]Shapiro (1986) uses the average value to parameterize the model. The model is linearized form of the general specification. Hence he needs optimal value to utilize Taylor's expansion. The principal difference between his model and mine is that in his model the average value is insignificant in testing the hypothesis claimed, but is significant in calculating the magnitude of a certain effect in my model.

sented here I concentrate on an ad hoc computation, following maroeconomic research (Friedman, 1978). Tables 1 and 2 present empirical results of equation (5) and calculated results of equation (8), by industry. They also give the mean value and their 1967 value of heterogenous R&D funds. Note that the difference between two tables lies in the choice of different time dimension of exogenous

Table 1. The Effect of Federally-funded R & D on Industry-funded R & D

Industry	Total	Elect	Petrol	Chem	Fabm
γ	31.268	23.448	24.780	8.1800	55.243
	(2.236)	(5.866)	(15.86)	(8.512)	(6.120)
u	0.2641	0.5013	0.4260	0.5350	0.1987
	(0.0174)	(0.078)	(0.048)	(0.051)	(0.048)
α	0.9999	0.6499	0.6630	0.8114	0.9990
	(0.0005)	(0.238)	(1.573)	(3.327)	(0.019)
ρ	29.893	−0.5248	−0.7738	−1.0000	1.5936
	(146.72)	(2.169)	(2.900)	(11.44)	(6.726)
$\overline{IRD}$	8496.1	1558.4	373.95	1328.5	167.98
IRD67	8020	1552	409	1357	161
$\overline{FRD}$	6850.7	1954.79	31.95	195.58	25.67
FRD67	8395	2246	46	211	11
(dIRD/dFRD)	0.931	−0.016	−0.041	LN	0.0431

Industry	Rub	Mach	Prim	Food
γ	38.31	28.452	32.266	37.93
	(8.08)	(6.473)	(319.2)	(3.375)
u	0.3254	0.2259	0.3270	0.3426
	(0.067)	(0.040)	(0.124)	(0.037)
α	0.5601	0.9990	0.8492	0.9999
	(0.638)	(0.013)	(41.52)	(0.0001)
ρ	2.788	8.9821	−1.000	1.773
	(7.164)	(16.20)	(120.4)	(3.661)
$\overline{IRD}$	151.61	1168.1	220.96	167.9
IRD67	165	1066	234	164
$\overline{FRD}$	33.77	339.9	11.21	2.50
FRD67	35	391	8	1
(dIRD/dFRD)	0.8366	0.913	LN	0.629

Notes: [a]$\overline{IRD}$ and $\overline{FRD}$ denote the mean value of industry-funded and federally-funded R & D, respectively. The unit in the average valued of IRD and FRD is millions of dollars. dIRD and dFRD denotes their small increment.

[b]The value in the parenthesis is the standard error.

[c]LN denotes the large negative number. That is, equation (8) is a very large negative number.

[d]IRD67 and FRD67 denote the 1967 values of IRD and FRD, respectively.

Table 2. The Effect of One-lagged Federally-funded R & D on One-lagged Industry-funded R & D.

Industry	Total	Elect	Petrol	Chem	Fabm
γ	31.521	30.559	15.966	10.518	17.807
	(2.468)	(8.908)	(3.637)	(4.322)	(9.598)
u	0.2673	0.4278	0.5059	0.6060	0.5589
	(0.019)	(0.091)	(0.629)	(0.081)	(0.183)
α	0.9999	0.8189	0.9999	0.2282	0.8244
	(0.0003	(0.378)	(0.001)	(0.631)	(0.126)
ρ	34.659	−0.9727	2.1875	−1.0000	−1.000
	(185.98)	(4.444)	(4.860)	(1.857)	(1.144)
$\overline{\text{IRD1}}$	7951.4	1482.4	362.62	1257.2	158.93
IRD67	8020	1552	409	1357	161
$\overline{\text{FRD1}}$	6677.2	1924.13	32.61	192.01	24.70
FRD67	8395	2246	46	211	11
(dIRD1/dFRD1)	0.9277	−0.2658	3.540	LN	LN

Industry	Rub	Mach	Prim	Food
γ	59.370	41.340	37.137	16.028
	(16.95)	(6.545)	(176.7)	(3.226)
u	0.2008	0.1940	0.1735	0.3600
	(0.083)	(0.040)	(0.062)	(0.046)
α	0.8557	0.9990	0.9658	0.9999
	(3.019)	(0.001)	(41.57)	(0.006
ρ	−1.000	7.3563	−1.000	1.004
	(19.16)	(15.04)	(475.7)	(12.47)
$\overline{\text{IRD1}}$	145.17	1079.0	208.06	160.12
IRD67	165	1066	234	164
$\overline{\text{FRD1}}$	34.0	330.0	10.43	2.593
FRD67	35	391	8	1
(dIRD/dFRD)	LN	0.887	LN	0.8360

Notes: [a] $\overline{\text{IRD}}$ and $\overline{\text{FRD}}$ denote the mean value of one-lagged industry-funded R & D and federally-fudned R & D, respectively. The unit in the averge of IRD1 and FRD1 is millions of dollars. dIRD1 and dFRD1 denotes their small increment.

[b] The value in the parenthesis is the standard error.

[c] LN denotes the large negative number. That is, equation (8) is a very large negative number.

[d] IRD67 and FRD67 denote the 1967 values of IRD and FRD, respectively.

variables. Table 1 is produced on the assumption that current productivity growth depends on current R&D funds. The model in which current productivity growth is affected by one-lagged R&D expenditures yields Table 2. The sign of (dIRD/dFRD) in Table 1 and of (dIRD1/dFRD1) in Table 2 tells us the relation between heterogeneous R&D funds which is chosen by firm's optimal behavior.

In the following, I discuss the results in two tables and derive policy implications from them.

First, let me investigate the results in Table 1. The ratio of the increment of IRD to that of FRD, i.e.(dIRD/dFRD) takes the positive sign (called pulling–in effect) in total manufacturing industry and the machinery, fabricated metal, rubber and food industries. The sign is negative (called crowding–out effect) in the electric and petroleum, industries. The positive sign supports the argument that FRD stimulates IRD in the lower–technology industries. The negative sign in the electric industry is consistent with the finding that there is a substitute relationship between FRD and IRD in the higher–technology industries[9]. It is questionable whether the petroleum industry is a high–technology or not. The average amount of FRD in the electric industry surpasses that of IRD. The dominant investment of government in this industry may be one of the reasons incurring the negative sign. The cause of negative sign in the petroleum industry is not distinguishable. Since ρ for the industries goes approximately to -1, the ratio in the primary metal and chemical industries becomes a negative large number. As long as the primary metal and chemical industries are considered as the high–technology industries, the substitute relationship in the industries is consistent with the previous finding.

The negative value of ρ is crucial in the determination of the sign of ratio (dIRD/dFRD). The federally–funded R&D expenditures in the industries with the positive sign of ratio can be said to be effective or pulling–in in fostering productivity growth, but those in the industries with negative sign of ratio, to be ineffective or crowding–out by bringing the misallocation of resources. In my model to allow the substitutability between heterogeneous R&D funds, the effect of FRD on IRD is industry–specific. The high–technology industries do not always have a crowding–out relation between them.

Now it is investigated how much of FRD with respect to a dollar of current IRD is pump–priming or crowding–out. The results presented here are compared with those in the previous literature that the estimated effect ranged in size from 8 to 12 cents of private expenditures induced by a dollar of the federal outlays, and Levy and Terleckyj (1983) present about 27 cents of IRD induced by FRD's a dollar. The dollar value in equation (8) is calculated as follow. The estimated parameters in CES functional form are utilized. The problem is associated with how the ratio (IRD/FRD) is calculated. As explained above, IRD and FRD variables which are used in the nonlinear estimation are discounted by their 1967 value. The reason of such data transformation is to make the other variables consistent with the productivity index divided by its 1967 value. Since the esti-

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[9]Fisher and Black (1979) review the empirical results of empirical analyses which consider government–industry R&D relationship. Conclusively, they emphasize the importance of federal funding of R&D from the interview data.

mated values are the parameters with respect to the discounted variables, the average values of IRD and FRD used in the an ad hoc calculation of the ratio (IRD/FRD) are also discounted by their respective 1967 value.

The crowding-out amount per a dollar of FRD in Table 1 is 0.0163 in the electric industry, 0.4417 in petroleum industry, and a large negative number in the chemical and primary metal industries. The pulling-in amount per dollar is 0.9312 in total manufacturing industry, 0.8366 in the rubber industry, 0.913 in the machinery industry, and 0.629 in the food industry. The crowding-out effect is less than 50 cents in the electric and petrolecum industires, but large in the chemical and primary metal industries. The pulling-in effect is higher than 50 cents in all industries except the fabricated metal industry. Excluding two extreme results of large negative number, the calculated crowding-out effect is much smaller than that of pump-priming.

The measure of economies of scale in R&D expenditures is denoted by u in equation (5). Such low returns to scale indicate one aspect of high uncertainty in the reward for R&D expenditures. The high level of uncertainty points to a need for the government to play a role as common stocks to completely insure against the risk involved with R&D activity. Hence the concept of returns to scale supports the necessity of government-funded R&D expenditures in another angle[10]. My model provides an evidence of government support of industrial R&D in the U.S.A. economy empirically.

The intensity of industry-funded R&D is high in the industries with the positive sign of the ratio (dIRD/dFRD). The U.S.A. government arranged the special draft to improve the rubber product and develop synthetic rubber products, especially in the rubber industry before 1956. After 1956, the government supported basic research in the general area of high polymers. Such strong support of the government may lessen the high risk of R&D activity confronted in the firm level and push the industry-funded R&D activity.

Second, I turn to the findings in Table 2. The ratio of one-lagged IRD to one-lagged FRD, i.e., dIRD1/dFRD1, takes the positive sign in total manufaturing industry and the machinery, petroleum, and food industries. The sign of the ratio is negative in the electric industry. The large negative number is obtained in the fabricated metal, chemistry, primary metal, and rubber industries. The main reason of negative sign in the ratio is due to the negative value of ρ. The intensity of industry-funded R&D expenditrues is also so high in the industries with the positive sign in the ratio.

[10]Fisher and Black (1979) enumerates motivations for government support of industrial R&D, which are adopted from K. Pavitt's "Government Support for Industrial Research and Development in France: Theory and Practice," *Minerva*. vol. 14, Autumn, 1976. One item is aversion to risk of R&D by industrial firms. My paper provides its rationale by using economies of scale in the U.S.A. economy.

The surprising finding is that when the time dimension of exogenous variables is changed, the reverse of the sign of the ratio in the petroleum and fabricated metal industries occurs. The sign in the petroleum industry is changed from negative to positive, while that in the fabricated metal industry is changed from postive to negative. My paper shows that the use of lag variable gives a different view on the same problem to policy makers. This presents the reason that the time lag between FRD and productivity growth have to be emphasized in this research field.

Although the time dimension of both FRD and IRD is changed, the economies of scale are low as in Table 1. As argued earlier, such low returns to scale indicate one aspect of high uncertainty in the reward for R&D expenditures and, in trun, points to a need for the government to play a role as common stocks to completely insure against the risk involved with R&D activity. This is the same as the outcomes obtained from the current R&D variables.

Let me take a look at how much of one–lagged FRD with respect to each dollar of one–lagged IRD is pulling–in or crowding–out from Table 2. The crowding–out effect per a dollar expenditure of federally–funded R&D is 0.2048 in the electric industry and large negative number in the chemical, fabricated metal, rubber, and primary metal industries. The pulling–in amount per a dollar expenditure of federally–funded R&D is 0.9277 in total manufacturing industry, 3.540 in the petroleum, 0.8878 in the machinery, and 0.836 in the food industry.

Also in the analysis presented here, excluding the industires with extreme value of large negative, the magnitude of crowding–out is smaller than that of pulling–in. The remarkable finding is that when the time dimension of variables is changed, the pulling–in impact in the petroleum industry occurs and the crowding–out effect in the fabricated metal industry does. The principal finding which is emphasized repeatedly in that prior to investigating the crowding–out (or pulling–in) effect of FRD on IRD in productivity growth, which time period is most significant in current productivity must be showed.

The distinguishable fact of Table 2 from Table 1 is that the ratio (dIRD1/dFRD1) in the rubber industry is a large negative value. It is notable that if the lag effect of heterogeneous R&D funds is assumed, the sign of ratio is changed. Such difference also demonstrate the importance of study to determine the appropriate lag structure in the impact of R&D funds on productivity (see Rhee (1987)).

In summary, there are four major findings in the role of FRD in this section. First, using disaggregated data by industry, I show that there exists no unambiguous findings in examining FRD's relation to IRD. That is, FRD spurs IRD in some industries and FRD retards IRD in other industries. Second, FRD's role in total industry level is not the same as that by the industry level. Pulling–in is incurred in total manufacturing industry and some industries, while crowding–out is incurred in the other industries. Hence the important point in my finding is that the issue of crowding—out (or pulling–in) is fundamentally dependent on industry–specific parameters. Clearly, decision of policy based on the investigation of total manufacturing industry can not be expected to be useful in the industry level. In light of FRD's inventive effcet its optimal allocation must be more selective, using information collected from the industry level studies. Third, excluding a few industries having extreme values, FRD's crowding–out effect is small relative to their pulling–in effect except a few industries. This may indicate the positive side in the role of FRD's expenditures for technical progress. Finally, in the model allowing time lag between the time when the investment decision are made and the time when they become productive, the calculated effect and the sign of the relation between heterogeneous R&D are changed. This finding supports the necessity to study the lag structure of the contribution of R&D funds to productivity growth.

Finally, I turn to the comparison of the results in my model with those obtained from an ad hoc model. The latter is in Table 3. To eliminate extreme values, all data except tax rate are discounted by their own 1967 values. The reason to choose it as the discounted rate is just to compare Table 3 with Table 2. FRD pulls in IRD in all industries except total manufacturing industry and the chemical industry. That is, the pulling–in effect of FRD on IRD is dominant. The evidence in Blank, et al. (1964) which is emphasized in Fisher and Black (1979) is not supported in the ad hoc model. My model in the framework of firm's optimal behavior provides a considerable evidence that FRD pull in IRD in the lower technology industries, but FRD crowds out IRD in the high technology industries. It is worthwhile to realized that the dollar value of FRD's pulling–in effect in Table 3 are much smaller than those in my model. The possible reason for the difference may be that the value in my model is calculated by including more

Table 3. The Effect of Federally–funded R & D on Industry–funded R & D

Industry	Total	Elect	Petrol	Chem	Fabm
CONT	−0.070	−0.291	−0.316	0.683	0.172
	(−0.09)	(−0.72)	(−3.69)	(1.554)	(0.182)
FRD	−0.004	0.298	0.096	−0.009	0.043
	(−0.021)	(1.391)	(2.294)	(−0.13)	(1.080)
TAX	−1.064	−0.250	−1.349	−1.429	−1.009
	(−0.74)	(−0.35)	(−1.89)	(−1.76)	(−0.46)
UNPR	−0.543	−0.158	−0.436	−0.149	−0.369
	(−6.304)	(−2.09)	(−6.77)	(−3.65)	(−1.05)
GNP	2.121	1.340	1.959	1.114	1.668
	(13.12)	(9.514)	(8.028)	(18.69)	(4.24)
DW	1.139	1.631	1.329	2.287	2.301
R^2	0.9930	0.9869	0.9456	0.9887	0.9682

Industry	Rub	Mach	Prim	Food
CONT	0.613	−0.6737	0.020	0.441
	(1.89)	(−1.27)	(2.139)	(0.853)
FRD	0.042	0.443	2.511	0.005
	(0.589)	(3.324)	(2.039)	(0.475)
TAX	−1.131	−0.116	−0.049	−2.237
	(−1.87)	(−0.11)	(−2.59)	(−1.973)
UNPR	−0.160	−0.181	−0.007	0.020
	(−2.48)	(−1.57)	(−5.07)	(0.170)
GNP	0.994	1.644	0.029	1.658
	(16.70)	(14.49)	(10.67)	(9.406)
DW	0.840	1.020	1.430	1.658
R^2	0.9842	0.9937	0.9785	0.9797

Notes: [a]IRD, FRD, UNPR, and GNP are discounted by their respective 1967 value to eliminate the extreme value. CONT denotes the constant term.

[b]UNPR denotes the undistributed profit. Since it is negaitve in the electric industry in a couple of years, the profit after deduction the tax.

[c]The value in the parenthesis is t–value. DW denotes the Durbin–Watson statistics.

information on the role of FRD.

Some previous works mentioned in Notes 2 support crowding–out effect of FRD on IRD, while others support the pulling–in hypothesis. But my empirical findings show no answer, one way or the other, regarding the true effect on federal expenditures. FRD's role in the model considering productivity growth is industry–specific. Such evaluation in my model is parameter–sensitive, because the elasticity of substitution is crucial in deciding either crowding–out or pulling–in. Allowing the substitution between IRD and FRD, I conclude that blanket statements regarding "crowding–out" or "pulling–in" mentioned in the previous literature are unsupportable. Hence, in order to allocate the limited resources optimally, policymakers must take into account whether the government investment for R&D activity in an industry is pulling–in or crowding–out in fostering productivity growth.

2. Total Impact of Federally–funded R&D on Productivity

The statistical techniques employed to establish a link between FRD and productivity were appropriate primarily for estimating a direct effect of FRD on productivity. Apparently, unlike the direct effect of IRD on technical progress, FRD has been mostly indirect and has involved stimulation of additional private R&D investment (Levy and Terleckyj, 1983). In light of the importance of such argument in the role of FRD, I built the model to involve FRD's two effects. Here I go around the shortage of statistical methods and, hence, evaluate the effect indirectly by making an ad hoc computaion.

I have investigated the relation between heterogeneous R&D funds. The results are used here to calculate in equation (11) FRD's total impact on productivity. The average values of FRD and IRD discounted by their 1967 values are utilized in the evaluation. df/dFRD and df/dIRD in equation (11) are derived from the differentiation of equation (5) and calculated by utilizing the average values of FRD and IRD and the estimated parameters in the CES function. Table 4 presents empirical results. As mentioned above, equation (11) serves for two purposes in my paper. Remember that the rates of return to FRD in equation (11) deal with only the producer surplus and are undervalued. Hence I prefer the equation to be used to investigate the argument that in the presence of any effect of FRD on IRD, the productivity returns to FRD are no smaller than those to IRD.

First, consider the case in which current productivity is affected by current R&D expenditures. FRD's direct effect in the rubber and primary metal industries is higher than the critical rate (1.07) which is the sum of 1 plus the interest rate. FRD's indirect effect is almost zero in total manufacturing industry, a negative number lager than -1 in the electric and petroleum industries, a positive number in the range (0,1) in the fabricated metal, rubber, and machinery industries, and relatively so high in the food industry. The industry in which total effect is higher than the discount rate is only the rubber and food industries. The rate of returns in federal R&D investment is generally low in my findings. But the findings are not enough to induce that FRD incurs social cost in the U.S.A. economy, because the marginal benefit in my work neglects the consumer surplus.

Let us examine the claim that in the presence of any effect of current FRD on current IRD, productivity returns to FRD are smaller than those to IRD. Total returns to FRD are larger than those to IRD in total manufacturing industry and the petroleum, rubber, and machinery industries. But the indirect effect in those industries is trivial and rather the direct effect is dominant. FRD's indirect effect does not make as much contribution to the marginal productivity as I have expected.

I move to the second case in which one-lagged R&D expenditures have an influence on current productivity. The direct effect is higher than the discount rate only in total manufaturing industry and the chemical industry. The indirect effect is higher than the discount rate only in the petroleum industry and a negative number higher than -1 in the electric industry. Hence the industry in which total effect is higher than the discount rate is total manufacturing industry and the petroleum industry.

When the lag effect of FRD and IRD on productivity is considered, the hypothesis that productivity returns to FRD is no smaller than those to IRD is supported only in the petroleum industry. The indirect effect in the industry is dominant. But the hypothesis in the other industries is not accepted. Returns to IRD is larger than those to FRD only in the electric and food industries. The

Table 4. Total Impact of Federally-funded R & D on Productivity

Industry	Total	Elect	Petrol	Chem
(1) $\frac{df}{dFRD}$	0.0197	0.946	0.902	0.825
(2) $\frac{df}{dIRD} \cdot \frac{dIRD}{dFRD}$	0.000	−0.013	−0.021	U.D
$\frac{dA}{dFRD}$ ((1)+(2))	0.0197	0.933	0.881	U.D
$\frac{dA}{dIRD}$	0.0002	1.0597	0.5104	U.D
(1) $\frac{df}{dFRD1}$	1.255	0.489	0.203	1.569
(2) $\frac{df}{dIRD1} \frac{dIRD1}{dFRD1}$	0.002	−0.454	3.918	U.D
$\frac{dA}{dFRD1}$ ((1)+(2))	1.257	0.035	4.121	U.D
$\frac{dA}{dIRD1}$	0.0024	2.228	1.107	U.D

Industry	Fabm	Rub	Mach	Prim	Food
(1) $\frac{df}{dFRD}$	0.001	5.693	0.048	1.592	0.004
(2) $\frac{df}{dIRD} \cdot \frac{dIRD}{dFRD}$	0.585	0.077	0.001	U.D	8.432
$\frac{dA}{dFRD}$ ((1)+(2))	0.586	5.770	0.125	U.D	8.436
$\frac{dA}{dIRD}$	13.58	0.092	0.0019	U.D	13.391
(1) $\frac{df}{dFRD1}$	0.515	0.277	0.033	0.018	0.006
(2) $\frac{df}{dIRD1} \frac{dIRD1}{dFRD1}$	U.D	U.D	0.008	U.D	0.812
$\frac{dA}{dFRD1}$ ((1)+(2))	U.D	U.D	0.041	U.D	0.818
$\frac{dA}{dIRD1}$	U.D	U.D	0.027	U.D	0.972

Notes: [a]The symbols on the industry are explained in the appendix. dX/dY denotes the differentiation of X with respect to Y, where X and Y are the variables in the tables. (1) is FRD's direct effect, (2) its indirect effect and (1) + (2) its total effect.

[b]U.D denotes 'undetermined'. Since the elasticity of substitution converges to large number, the direct and indirect effects of FRD and IRD are not determined but known to be negative.

comparison of them in other industries turn out to be undetermined.

In both cases, the rates of return in productivity of R&D investment are not higher than the discount rate. It bears an interpretation that R&D expenditures incur social cost. Note that I consider only producer's side and hence, the conclusion must be carefully interpreted. When I turn to investigating the direct and indirect effects of FRD, the evaluation of FRD and IRD in the contribution to productivity growth is more complicated. These findings thus make more difficult the burden of proof on those who would claim that FRD makes a positive contribution to productivity growth. It has been known that R&D activity may be accompanied by a high risk in its failure. The low reward of R&D investment may support the role of the government taking a high risk in the R&D activity in the U.S. economy.

When I try to make an ad hoc computation, the argument that IRD is significant in productivity is not likely to be important in viewing its marginal effect on productivity. The significance or insignificance of FRD and IRD on fostering technical progress turns out to neglect their different aspect to it and only to be the means to simply evaluate their effect in the economy. Social benefit of heterogeneous R&D ought to be studied in further research to investigate the role of FRD and IRD in the economy.

IV. SUMMARY AND DISCUSSION

In Table 1 and 2, I report the impact of FRD on productivity growth in the framework of firm's optimal behavior and in the theory of economies of scale. FRD has a positive (or pulling–in) influence on IRD in total manufacturing industry and the machinery and food industries, in either current or one–lagged R&D expenditrues. The electric industry takes the negative (or crowding–out) relation between heterogeneous R&D funds in spite of adopting the different time dimension of variables. The electric industry takes the negative (or crowding–out) relation between heterogeneous R&D funds in spite of adopting the different time dimension of variables. The large negative value of the ratio of heterogeneous R&D funds in the chemical and primary metal industries is obtained in two different time dimensions. When the time dimension of indpendent variables is changed, the variation of the ratio of the increment of heterogeneous R&D funds occurs in the fabricated metal, petroleum and rubber industries. Stated differently, since my model considers not only the substitutability between FRD and IRD, but also several parameter values, the estimated values here is larger than those in the previous work based on the estimated coefficient of regression in the simple ad hoc model.

My approach is different from that previously used. The empirical results in my paper are different from those derived from an hoc model. The policy implication from this study is that if R&D expenditures are not for defense, they must be spent selectively for fostering productivity growth efficiently. dIRD/dFRD to measure 'crowding–out' in this paper is higher in the industries with a positive sign than those with a negative sign. Also, since how the unobservable R&D expenditure effective in current productivity growth is measured brings different conclusions in some industires, the policy maker must choose the time dimension of R&D variables for a specific purpose. The wider diffusion of FRD's returns to productivity over time and across industries can occur but is difficult to measure.

The total impact of federally–funded R&D on productivity is analyzed by using the solution of firm's optimal behavior in R&D activity. Such contribution is shown to be low except in a few industries. These findings thus make heavier the the burden of proof on those who would claim that federal R&D makes a positive contribution. It may still support the role of the government bearing a high share of the total dollar amount of risk.

The theory of the economies of scale is used to support the necessity of FRD expenditures in different angle. The low reward of R&D investments may require the government to take the risk incurred in R&D activity.

In light of empirical results, the behavior of each industry is distinguished from that in total manufacturing industry. This raises the aggregation problem.

Besides discussing the empirical results, some caveats must be mentioned. They are due to the estimation of nonlinear model. In the estimation of the CES functional form, I restricted the inequality constraints to provide possible economic meaning. The restriction resulted in non–convergence. If the convergent criterion is not satisfied, it implies that the local minimum values of parameters has not been found. As mentioned above, to economize on the number of iteration I used the convergence measures reported at the point of failure. If the estimates are to be approximately convergent, I accept them as the non–convergent but reported results. The important reason of non–convergence is due to the restriction of the values of parameters to known prior interval. If the equation is linear with respect to the parameters, the parameter estimates always converge in one iteration. However, as with any nonlinear estimation procedure, there is no guarantee that the estimation will be successful for a given model and data.

APPENDIX A Log Value of Production Function

Using the log value of variables, firm's profit–maximizing model is

$$P \ln Q(l, k)\ A(IRD, FRD) - w \ln l - r \ln k - g \ln NRD \qquad (A.1)$$

Equation (A.1) can be denoted like equation (1) in the text,

$$P\ F(L,K)\ f(IRD, FRD) - wL - rK - g\ IRD$$

Equation (A.1) becomes

$$P \ln A(IRD, FRD) - g \ln NRD - P \ln Q - w \ln l - r \ln k \qquad (A.2)$$

Equation (A.2) can be divided into two groups. Hence, the first-order condition of equation (A.2) indicates that the comparative static results of the optimal solution are blocked each other. As a result, this paper focuses on IRD in the framework of firm's profit-maximizing and treats F(L,K) as constant.

APPENDIX B Data and Their Sources

The main data used consist of R&D, total factor productivity, profit, tax, and the national income by industry. The source of R&D data by industry is *Research and Development in Industry*, annually published by U.S. National Science Foundation from the year 1953 to 1985. The missing data in R&D are complemented by those from *Impact of Federal Research and Development Programs*, published by U.S. Congress. The data of total factor productivity come from the book, *Productivity in the United States-Trends and Cycles*, written by J.W. Kendrick, and E.S., Grossman, who used the data in *Survey of Current Business* to calculate total factor productivity. Their classification of industry for total factor productivity is the same as that in *Survey of Current Business*. The classification of industry in *Research and Development in Industry* is the same as that in *Survey of Current Business*. The source of other variables is *Survey of Current Business* (July, 1978 and 1980), and *The National Income and Product Accounts of the United States*, 1929–1976, published by the Department of Commerce.

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