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COST-EFFECTIVENESS OF POTENTIAL FEDERAL POLICIES AFFECTING RESEARCH & DEVELOPMENT EXPENDITURES IN THE AUTO, STEEL AND FOOD INDUSTRIES

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COST-EFFECTIVENESS OF POTENTIAL FEDERAL POLICIES
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IN THE AUTO, STEEL AND FOOD INDUSTRIES

ABSTRACT

This paper contains our preliminary analysis of the demand for company financed research and development expenditures (CR&D) in three manufacturing industries: motor vehicles and other transportation equipment, ferrous metals and products, and food and kindred products. Based upon estimates of the demand for CR&D, we estimated the costs and effects of the following public policies that could be utilized to affect R&D expenditures: (1) changes in the level of federally financed R&D expenditures, and (2) changes in the cost of private R&D through tax credits.

A capital theoretic framework is developed in which we assumed that CR&D generates knowledge or "research capital" that may increase output demand or reduce costs. Based upon our capital theoretic framework, the demand for the research capital stock is estimated using industry level time-series data for the period 1956-74. These time-series data enable us to obtain the first measures of changes in the price of knowledge upon the demand for CR&D, and also to measure the impact of changes in federal R&D expenditures upon CR&D.

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INTRODUCTION

R&D is generally considered a growth industry, but this may no longer be true. According to the National Science Foundation's Survey of Science Resources, "real" company financed R&D expenditures (CR&D) peaked in 1969 after a period of virtually continuous growth. Table 1 reports nominal and real CR&D over the period 1953-74: between 1958 and 1969 increases in real CR&D averaged 6.84 percent per year; however, real CR&D declined in 1970 and 1971 and increased by an average of only 3.09 percent over the period 1972-74.

The observed decline in real CR&D in 1970 and 1971 will probably lead to a reduction in the rate of technological advance.[1] While one may argue about the desirability of a decline in CR&D, since the optimal rate of technological change is unknown,[2] policymakers ought to understand why the decline occurred and how public policies affect R&D expenditures.

Table 1

NOMINAL AND REAL COMPANY R&D FUNDS, 1953-1972
(Dollars in Millions)

Year	Company[a] Nominal	Real[b]	Growth Rate
1953	$ 2,200	$ 2,491	
1954	2,320	2,588	3.89
1955	2,460	2,707	4.60
1956	3,277	3,487	28.81
1957	3,396	3,483	- 0.11
1958	3,630	3,630	4.22
1959	3,983	3,918	7.93
1960	4,428	4,287	9.42
1961	4,668	4,462	4.08
1962	5,029	4,754	6.54
1963	5,360	5,001	5.20
1964	5,792	5,321	6.40
1965	6,445	5,814	9.27
1966	7,216	6,333	8.93
1967	8,020	6,820	7.69
1968	8,869	7,252	6.33
1969	9,867	7,967	6.14
1970	10,283	7,604	- 1.21
1971	10,645	7,518	- 1.13
1972	11,347	7,767	3.31
1973	12,696	8,228	5.94
1974	14,038	8,252	0.29

[a]Nominal funds include all funds for industrial research and development performed within company facilities and financed by the companies. These data do not include company financed research and development contracted to outside organizations such as research institutions, universities and colleges, or other nonprofit organizations. In 1972 industrial firms contracted $221 million in company financed R&D projects to outside organizations.

[b]The measure of real CR&D has been estimated using the overall GNP deflator to convert R&D from current dollars.

Source: National Science Foundation, "Research and Development in Industry, 1974," NSF-322, U.S. Government Printing Office, Washington, D.C., July 1974, p. 26, and Economic Report of the President, 1975, U.S. Government Printing Office, Washington, D.C., 1975, p. 252.

OBJECTIVES

In 1966, Schmookler described the economics of technological change as the terra incognita of modern economics.[3] Unfortunately, his observation is still valid, at least for CR&D. A recent comprehensive review of literature by Kaplan, Ijiri, and Visscher concluded that we know very little about the impact of tax policies on CR&D, and that empirical studies are needed to improve our understanding of the effects of tax policies and other factors on CR&D.[4] The objective of this paper is to help bridge this gap by analyzing two specific policies for affecting R&D expenditures: (1) changes in the level of federally financed R&D expenditures, and (2) changes in the cost of private R&D through income tax credits.

Overview of Technical Approach

Our analysis of public policies will be based upon estimates of industry level econometric models of the demand for privately financed research capital. The specification of econometric models will be based upon an explicit "Jorgenson type" capital theoretic model of the firm.[5] However, unlike standard models in which there is only one type of capital good, it will be assumed that decision-makers may allocate resources to increase their stock of research capital (K_t^r), as well as to their stock of physical capital (K_t^p) and labor (N_t).

We will assume that a firm's research capital stock itself consists of two components: privately financed research capital and federally financed research capital, which is given as exogenous. This dichotomy of research capital stocks is useful in identifying the relationship between federal and company financed investments in research capital.

Due to recruitment costs, investments in training, and other factors, firms may not adjust their R&D capital stocks to long-term equilibrium levels in a single year. Consequently, a partial adjustment model is used to estimate the demand for CR&D.

Our approach is to use industry level time-series data rather than firm level cross-sectional data which have been utilized by previous researchers. By using time series data, we obtain estimates for the first time of the own-price elasticity of CR&D. Data from the following three industries were utilized: (1) motor vehicles and transportation equipment (SIC 371, 373-75, 379), (2) ferrous metals and products (SIC 331-32, 3391, 3399), and (3) food and kindred products (SIC 20). These industries were selected to minimize errors in variables problems with respect to the measurement of CR&D.

PREVIOUS EMPIRICAL STUDIES

Introduction

In this section, we will first review the findings and methodologies utilized by previous R&D researchers. We will conclude that previous studies based upon cross-sectional firm level data can be usefully extended by utilizing industry level time-series data. While this approach may introduce its own problems, at least it helps to avoid generally recognized specification and measurement errors inherent in estimates of the demand for CR&D at the firm level.

More important, we can focus our study on the estimation of factor input price elasticities, which have not been estimated due to data problems and lack of variation in prices at the firm level. Estimates of factor input price elasticities will provide the foundation for our analysis of the costs and effects of alternatives.

A third innovation of our approach is the application of the neoclassical investment model to R&D. While the analogy between physical capital and R&D is far from exact, we believe that utilizing a formal neoclassical model to analyze the demand for R&D usefully merges two important literatures, their insights, techniques and findings.

Review of Previous Studies[6]

The basic econometric model utilized by previous researchers involved relating a measure of R&D intensity, e.g., CR&D per unit of sales, employment, or assets, to deflated measure of explanatory variables.[7] Many of the earlier studies have sought to determine the impact of market structure and sales on R&D performance, and invariably included sales and other control factors as explanatory variables. The results of these studies were summarized concisely by Markham[8], who observed that for firms in a given industry CR&D appeared to increased with sales but at a decreasing rate.

Subsequent studies attempted to explain this phenomenon. Using a single equation model and pooled time-series cross-sectional data on firms in the chemical, drug, and petroleum industries, 1959-62, Grabowski provided evidence that the relationship of CR&D to sales was due to the fact that certain explanatory factors that, say, positively affect the demand for CR&D, initially increased more than proportionately but then increased less than proportionately with sales.[9] Explanatory variables included in Grabowski's study were: sales, lagged total internal funds, and other control variables. Grabowski found that internal funds, i.e., lagged profits plus depreciation, was an important factor affecting the level of CR&D of the firms in his sample.

Hamburg[10] estimated a similar single equation model with data on 405 large firms in 1960 grouped by industry. His study is unique in that it included both Federal R&D and lagged R&D as explanatory variables. Hamburg found that, in general, FR&D had a positive effect on CR&D. Unlike Grabowski, however, Hamburg found that measures of internal funds had a negative impact on company R&D.

Mueller estimated a series of cross-sectional models with data for the period 1957-60 using a simultaneous equations model in which CR&D competed with other uses of funds for a share of available funds.[11] He found that CR&D and fixed plant and equipment were substitutes and that CR&D tended to increase during periods of slack demand for products, apparently obtaining a larger share of funds as a result of the decline in the relative attractiveness of fixed plant and equipment investments and due to the quasi fixed nature of other uses of funds, e.g., advertising and dividends.

A firm level time-series study on CR&D was undertaken by Grabowski and Baxter, who were concerned with providing evidence on the impact of competition on a firm's R&D performance.[12] They utilized annual data on eight chemical firms pertaining to the period 1947-66. The change in R&D performance was estimated by firm as a function of changes in a firm's (1) own lagged R&D, (2) rival's R&D, (3) cash flow, (4) market value, and (5) dummy variables reflecting sales or earnings declines. Their results were inconclusive, but cash flow was the most important explanatory variable. The impacts of changes in rival's R&D expenditures, firm's valuation, and dummy variables were not consistent across firms.

Critique

Previous empirical studies suggest directly or indirectly that return on investment is an important consideration affecting the demand for R&D. However, not all the implications of this economic model have been fully analyzed theoretically or empirically. Despite the central role of prices in economic theory, the relationship between the price of R&D and its demand has not been analyzed.

Previous researchers have utilized firm level cross-sectional data.[13] However, firms probably include substantially different activities under the rubric of R&D, so that interfirm differences in company R&D expenditures are due to some extent to their different "rulers." Consequently, measurement errors will probably be an important component of measured CR&D when using cross-sectional firm level data. However, intertemporal differences in a firm's reported R&D expenditures are likely to reflect actual differences in R&D, thereby favoring a time-series analysis.[14]

In order to evaluate the costs and effects of alternative policies which may be implemented to affect the demand for CR&D, it is necessary to obtain estimates of the impact upon CR&D of both changes in the price of R&D and federal R&D expenditures. It would also be desirable to have estimates of the speed with which prices affect demand.[15] Such evidence is currently unavailable.

In this proposed study we will attempt to theoretically analyze and measure the effects upon CR&D of the price of R&D and federal R&D expenditures. Our empirical work will be undertaken using industry level data which have a number of advantages. First, there is evidence that substantial changes occurred in critical factors over time which may enable us to accurately measure their impact upon the demand for research capital and thereby CR&D. Second, using these data may enable us to mitigate the effects of certain measurement errors encountered when using firm level data. Third, we may be able to estimate both the short- and long-run effects of critical factors upon CR&D.

THEORETICAL ANALYSIS OF THE DEMAND FOR CR&D

Introduction

In this section we will present a theoretical model of the demand for inputs by a firm. Inputs will include the usual physical capital and labor, as well as an additional input "research capital," i.e., knowledge, which is itself the output of an R&D production function. Implications of the model will be utilized to specify econometric models of the long-run demand for privately financed research capital.

To use a physical capital type paradigm for R&D will require that we make a number of simplifying assumptions. Still, these simplifications will allow us to fruitfully utilize an entire literature. The introduction of complexities to further tailor the model to R&D will be a useful avenue for future research.

Perhaps the most important simplifying assumption concerns the research capital production process. We will assume that research capital is produced by using fixed proportions of inputs, consisting of scientists and engineers, technicians and supporting personnel, materials, physical capital and other resources. This assumption enables us to set aside issues related to the substitutability among R&D inputs which would unnecessarily complicate our analysis at this point.

Furthermore, assuming a fixed proportions production function for research capital enables us to more easily measure its price and quantity. We can let one unit of research capital equal the output produced by one scientist and a bundle of other inputs.

Consequently, the price of a unit of research capital can be measured with data on costs per scientist which are readily available by industry. Furthermore, the research capital stock can be developed from data on R&D scientists which are also readily available by industry.

Derivation of the Long-Run Demand for Privately Financed Research Capital

Sketched below is the derivation of a structural model for factor inputs, including research capital, physical capital and labor. It is assumed that firms are price takers who maximize profits and that they accumulate research capital for the purpose of affecting the supply of output.[16]

Following Brechling,[17] it can be shown that the after-tax cash flow equation for each firm is given by equation (1):

$$
\begin{aligned}
(1)\quad RN_t = {} & (1 - \mu_t)\,(P_tQ_t - w_tN_t) - q_{1t}(K^p_{t+1} - K^p_t + \delta^p K^p_t) \\
& + \mu_t q_{1t} K^p_t\,(r_{dt}d_t + v_t\delta^p - \gamma_t g_{1t}) \\
& - (1 - \mu_t)(1 - a_1)\,q_{2t}(K^r_{t+1} - K^r_t + \delta^r K^r_t) \\
& - q_{1t}a_2\,(K^r_{t+1} - K^r_t + \delta^p K^r_t) \\
& + \mu_t q_{1t} a_2 K^r_t (r_{dt}d_t + v_t\delta^p - \gamma_t g_{1t}) \;.
\end{aligned}
$$

where

RN_t = after-tax cash flow

μ_t = marginal income tax rate

P_t = price of output

Q_t = quantity of output

w_t = average and marginal outlay per unit of labor employed

N_t = quantity of labor employed

q_{1t} = average and marginal outlay per unit of gross addition to the stock of physical capital

K_t^p = stock of physical capital used in the production of output

δ^p = rate of depreciation of physical capital

q_{2t} = average and marginal outlay per unit of gross addition to the stock of privately financed productive research capital

K_t^r = stock of privately financed productive research capital.

δ^r = rate of depreciation of research capital stock, K_t^r.

r_{dt} = long term, real marginal cost of debt per dollar borrowed per period

v_t = ratio of tax allowable depreciation to actual depreciation

γ_t = ratio of taxable capital gains on physical capital to actual capital gains

$$g_{it} = \frac{q_{it} - q_{it-1}}{q_{it-1}} \qquad i = 1,2$$

a_1 = percent of R&D outlays per scientist accounted for by depreciation expenses on physical capital

and

a_2 = percent of physical capital stock utilized to produce research capital.

Let the production function for output be given by equation (2),

$$(2)\quad Q_t = f\,(K_t^p, K_t^r, K_t^f, N_t)$$

Where

K_t^f = a second stock of research capital produced by federally financed R&D projects.

Maximizing RN_t subject to the production function one derives the following marginal conditions,

$$(3)\quad (1 - \mu_t)P_t f_{N_t} = X_{1t}$$

$$(4)\quad (1 - \mu_t)P_t f_{K_t^p} = X_{2t}$$

$$(5)\quad (1 - \mu_t)P_t f_{K_t^r} = X_{3t}$$

where the X_{it} are after-tax user prices for factor inputs:

$$X_{1t} = (1 - \mu_t)w_t$$

$$X_{2t} = q_{1t}\,[d_t r_{dt}(1 - \mu_t) + (1 - d_t)r_{et}$$

$$+ \delta^p(1 - \mu_t)v_t - g_{1t}(1 - \mu_t\gamma_t)]$$

$$X_{3t} = (1 - \mu_t)\;(1 - a_1)q_{2t}(r_t + \delta^r - g_{2t}) + a_2X_{2t}$$

$$r_t = d_t r_{dt} + (1 - d_t)r_{et}$$

and

r_{et} = long term, real, marginal cost of equity funds per dollar per period

These marginal conditions indicate that for an optimum allocation of resources in the ith period, the <u>after-tax</u> marginal receipts should equal the after-tax marginal user cost for each factor input.

To exemplify, one could let the production function have the Cobb-Douglas specification, where in the t-th period

$$(6) \quad Q_t = A_0 (K_t^f)^{\Theta} (K_t^r)^{\Psi} (K_{1t}^p)^{\alpha} N_t^{\beta}$$

Equations (3)-(6) would then be a system of structural equations which are the basis for the firm's long-run demand for inputs. Solving this system of equations for the optimal level of K_t^r would yield a log-linear reduced form equation for each firm in the industry in which P_t, μ_t, input prices and K_t^f are explanatory variables.[18]

We will assume that the marginal product of K_t^f is positive. Furthermore, since firms do not finance the production of K_t^f, they have an infinite demand for federal R&D. Consequently, the actual level of K_t^f produced by a firm will be determined by the supply of federal R&D expenditures. As a further simplifying assumption, we will ignore efforts by firms to obtain federal R&D and assume that the supply of federal R&D to the firm is exogenous.

Our model implies that the demand for K_t^r is a negative function of its own after tax real price, $X_{3t}/(1-\mu_t)P_t$. In addition, it is a function of the after-tax real price of other factor inputs, e.g., labor $(X_{1t}/(1-\mu_t)P_t)$. In general, the sign of after-tax real user prices for other factor inputs is indeterminant a priori. If it is positive,then another factor, say, physical capital, is a net substitute; if negative,it is a net complement.

Similarly, the sign of the coefficient of K_t^f indicates whether federally financed research capital is a net substitute (-) or a net complement (+) of K_t^r in the long-run. If federally financed research capital generally just replaces K_t^r, then we would expect the sign of K_t^f to be negative due to the existence of diminishing returns to research capital. However, if the effect of K_t^f is to enhance the productivity K_t^r, then the demand for K_t^r will increase in K_t^f. However, the relationship is probably a complicated one with effects going in both directions.

While we cannot say what is the expected net impact of K_t^f over time, we speculate that K_t^f is a gross complement in the long-run and a gross substitute in the short-run. The production of K_t^f might yield long-run marketing advantages and over time augment the physical productivity of R&D personnel engaged in the generation of K_t^r.

With respect to short-run substitutability, human capital costs incurred when hiring and employing scientists might induce firms to adjust their total demand for R&D personnel to their long-term expected rates of investments in both K_t^r and K_t^f. Consequently, firms might reduce their short-run rate of investments in K_t^r if they perceive an increase in FR&D to be temporary, and thereby avoid the costs of excess research capital production capacity in the long-run.

In the next section we report on our test of the hypothesis that K_t^f is a gross substitute in the short-run and a gross complement in the long-run for K_t^r.

ECONOMETRIC ANALYSIS OF THE DEMAND FOR PRIVATELY FINANCED RESEARCH CAPITAL

Introduction

In the previous section we presented a theoretical analysis of the demand for privately financed research capital. The long-run demand for K_t^r was shown to be a function of real, after-tax user prices for factor inputs and K_t^f. In turn, user prices were defined in terms of a number of variables, including tax parameters, debt equity ratios, interest rates, etc., in addition to the wage and marginal outlays per unit of research and physical capital. To rigorously test this model, one must collect data on all of these variables so that real after-tax user prices are measured properly. We intend to do this in a future study.

In this section, we report the results of a preliminary test of our theoretical model. For this pilot test we used simplified and, strictly speaking, incomplete measures of variables which were readily available. Nevertheless, the results are interesting and seem to indicate that our approach is potentially useful.

The econometric model consists of a long-run demand function for K_t^r and a short-run adjustment equation. The model is specified in terms of growth rates of variables and estimated using this formulation. To test the hypothesis that K_t^f is a gross substitute in the short-run and a gross complement in the long-run, the adjustment equation is specified to be a function of changes in the growth rate of K_t^f as well as the difference between the desired and lagged growth rates of the stocks of privately financed research capital.

Specification of Econometric Models and R&D Data

Let the long-run demand for K_t^r be a log-linear function, so that the net growth rate, g_t^{r*}, is given by a linear function of growth rates:

$$(7) \quad g_t^{r*} = \underset{?}{a_1} T + \underset{?}{a_2} p_{2t} + \underset{<}{a_3} p_{3t} + \underset{?}{a_4} g_t^f$$

where g_t^f = the net growth rate of K_t^f

p_{it} = the growth rate of the real, after-tax user price of X_{2t} and X_{3t}

T = time

and a_i = elasticity of K_t^r with respect to the level of a factor, i=2,3, and 4.

For this pilot test, data were collected for three industries on important components of the growth rate of real factor prices for only research and physical capital. The growth rate of the real after-tax user price of labor is an omitted variable. We have included time as a variable to help capture effects on included variables of omitted variables that have changed over time, and to test whether the growth rate of private R&D has been trending given the factors included in the model.

Let the adjustment function for the net growth rate of the privately financed capital stock be given by equation (8).

$$(8) \quad \Delta g_t^r = \underset{>0}{b_1}(g_t^{r*} - g_{t-1}^r + \underset{<0}{b_2}(g_t^f - g_{t-1}^f))$$

where g_t^r is the actual net growth rate of privately financed research capital in year t.

We have indicated the sign of b_2 to be negative to reflect the hypothesis that changes in the growth rate of K_t^f would cause the growth rate of K_t^r to decline in the short-run. The <u>net</u> long-run impact of a change in the growth rate of K_t^f is simply a_4, the coefficient of g_t^f in equation (7).

Since the <u>net</u> rate of investment in the research capital stock equals the gross rate of investment minus the rate of depreciation, we can rewrite equations (7) and (8) in terms of gross rates of investment,

$$(9)\quad \frac{I_t^r}{K_t^r} = g_t^r - \delta_t^r$$

$$(10)\quad \frac{I_t^f}{K_t^r} = g_t^f - \delta_t^f$$

where

I_t^r = flow of gross investment in K_t^r

δ_t^r = rate of depreciation for K_t^r

I_t^f = flow of gross investment in K_t^f

and δ_t^f = rate of depreciation for K_t^f.

Substitution of equations (9) and (10) into (7) and (8) and solving for I_t^r/K_t^r yields the following reduced form equation:

$$(11)\quad I_t^r/K_t^r = c_0 + \underset{?}{c_1} T + \underset{?}{c_2} p_{2t} + \underset{<}{c_3} p_{3t} + \underset{?}{c_4}\frac{I_t^f}{K_t^f} + \underset{>}{c_5}\frac{I_{t-1}^f}{K_{t-1}^f} + \underset{>0}{c_6}\frac{I_{t-1}^r}{K_{t-1}^r}$$

where $0 < c_6 < 1$

As mentioned previously, data were collected on the price of only two factor inputs, research and physical capital. Specifically, p_{3t} was measured by the change in the cost of R&D per scientist deflated by the price of output for the industry; and p_{2t} was measured by the change in the price index for nonresidential fixed investment deflated by the price of output for the industry.

The flow of investment in research capital was measured by the number of full time equivalent scientists and engineers engaged in private and federal R&D. Unfortunately, data on "company" or "federal" scientists collected by the Census are reported only for the period 1962-1974. Rather, expenditures for company and federal R&D and scientists for the entire industry are reported for 1956-1974. To obtain accurate measures of the number of company scientists, we chose two industries, "Food" and "Steel" which performed virtually no federal R&D. We derived the number of company scientists by reducing FTE scientists for the industry by the (small) percent of federal R&D relative to total R&D performed in these industries. When estimating the demand for K_t^r for Food and Steel, changes in the rate of current and lagged investment in K_t^f were omitted as explanatory variables.

Our third industry, "Autos," exhibited substantial changes in the ratio federal to private R&D over the period 1956-1974. Furthermore, the cost per scientist for private and federal projects were roughly equal in the earliest periods for which we have observations. Consequently, we chose the Auto industry for analysis, and estimated private scientists for the earlier period 1956-61 according to the formula,

$$\text{Company scientists} - (\text{total scientists})\left(1-\frac{FR\&D}{FR\&D+CR\&D}\right)$$

Except for the base period, research capital stocks were computed according to the formula

$$(12)\quad K_{t+1} = (1-\delta)K_t + I_t$$

Our observation for the base period was obtained by using the following formula

$$(13)\quad K_o = \frac{I_o}{g+\delta}$$

where g = average long run growth rate of K in the periods preceding time period zero

δ = rate of depreciation of K in the periods preceding time period zero.

Assuming that the growth rates for K are constant, g can be estimated by the average growth rate of I over the earlier period.[19] Unfortunately we do not have data on the earlier period, e.g., 1946-1955, and in 1956 R&D spending increased dramatically making it a poor choice for a base period.

Over the period 1953-1956, data on industrial R&D performance were collected by the Bureau of Labor Statistics for the National Science Foundation.[20] Starting in 1957, however, the NSF Survey data have been collected by the Bureau of Census. Unfortunately, there were differences between surveys which make tenuous data comparisons for a given industry.[21] For example, BLS collected data on an establishment basis whereas Census collected data by company. Comparison of R&D performance by <u>industry</u> for 1956, the only year in which data are available from both the BLS and Census Surveys, revealed substantial differences between the surveys with respect to measured R&D performance. However, the surveys yielded very similar results for total and company R&D. Consequently, it would be difficult to develop a meaningful R&D series for each industry for the period 1953-1975.

Our approach was to use the following procedure.

- <u>Growth rates</u> for K_t^r and K_t^f over the period 1953-1956 were estimated from earlier surveys on R&D collected by the Bureau of Labor Statistics.[22]
- These growth rates from BLS were used to estimate 1953-1956 levels of federal and company scientists using the <u>Census</u> observations in 1956 as base points.
- An estimate of the growth rate in company scientists over the period 1957-1974, with slight adjustments to account for BLS growth rates, 1953-1956, was used as a measure of g for company scientists: in percents, one for steel, three for food, and five for autos.
- For the growth rate of federal scientists in the auto industry, we used the growth rate of real federal R&D for a corresponding industry classification over the period 1953-1956. We estimated it to be about 14 percent.

- With respect to depreciation rates, we assumed that they were equal to one-half of the estimated base period growth rate, allowing thereby for growth in the net capital stock in each industry: in percents, .5 for steel, 1.5 for food and 2.5 for autos.
- With respect to the rate of depreciation for federal research capital, we conjectured that it was probably greater than the depreciation rates for private research capital, since firms would tend to select projects having low depreciation rates. We chose three percent for the auto industry.
- The base period capital stock was estimated to be the 1953 observation on scientists divided by g plus δ.
- The econometric models were estimated using only observations for the period 1956-1974, so that data on scientists were comparable over time.

Empirical Findings

Our estimation procedure was as follows. Equation (11) was estimated for the auto industry. Since, for practical purposes, steel and food do not undertake federal R&D, the econometric model was estimated for them excluding terms I_t^f/K_t^f and I_{t-1}^f/K_{t-1}^f. After examining the results for each industry, we concluded that certain variables had substantially different effects across industries: (1) time was not statistically significant for autos; (2) the real price of physical capital was not statistically significant for steel; and (3) the real price of physical capital had a positive impact for food but a negative impact for autos.[23] The data were then pooled, and a model was estimated which took these differences in our findings among industries into account.

Our findings are summarized in table 2. For each industry, the own-price effect is negative and statistically significant at or better than the .1 level using a one-tailed test. The lagged gross growth rate of K_t^r is statistically significant at the .01 level for each industry. The estimates of these lagged coefficients .605 (steel), .725 (food), .861 (autos) imply long-term adjustment periods of 2.5 years (steel), 3.6 years (food), and 7.2 years (autos). The estimates among industries for both p_{3t} and I_{t-1}^r/K_{t-1}^r range within a standard deviation of each other, which suggests that pooling of data might be appropriate for estimating the effects of these variables.

The impact of I_t^f/K_t^f is negative (-.129) and statistically significant at the .05 level using a two-tailed test. The impact of I_{t-1}^f/K_{t-1}^f is positive (.128) and virtually identical to the impact of I_t^f/K_t^f. It is also statistically significant at the .01 level (using a one-tailed test). The equal but opposite signs of current and lagged I^f/K^f is an important finding: although it substitutes for private R&D in the short-run, there is no long-term impact of federal on private R&D. However, in the short-run we found an average decline of approximately 0.4 private scientists for each additional federal scientist employed.

Time has a small, negative and statistically significant impact in the steel and food industries. The real price of physical capital has mixed effects: negative for autos but not statistically

TABLE 2

RESULTS OF ESTIMATING EQUATION (11), BY INDUSTRY*

	Variables							Statistics		
Industry	Constant	T	P_2	P_3	I^r_{t-1}/K^r_{t-1}	I^f_t/K^f_t	I^f_{t-1}/K^f_{t-1}	$F_{n,m}$	D-W N	SE $\bar{R}^2$
Autos (A)	.0111	NE[a]	-.149 (1.76)	-.0182 (1.42)[e]	.861 (4.98)[c]	-.129 (2.67)[d]	.128 (2.74)[e]	6.387 5,12	1.571 1.345	.00346 .61
Steel (S)	.0101	-.00025 (4.01)[c]	NE[a]	-.00902 (2.82)[c]	.605 (4.25)[c]	NA[b]	NA[b]	20.256 3,14	1.79 0.559	.00105 .77
Food (F)	.0150	-.00015 (1.951)[e]	.0228 (2.11)[e]	-.0160 (2.45)[d]	.725 (4.60)[c]	NA[b]	NA[b]	10.759 4,13	1.978 .062	.00149 .71
Pooled	.01118 (A) .00341 (1.23) (S) -.00545 (1.99)[e]	(SF) -.00020 (2.56)[d]	(A) -.151 (3.05)[c] (F) .0165 (1.62)	-.01288 (3.07)[f]	.811 (8.92)[c]	(A) -.132 (4.76)[e]	(A) .133 (4.96)[e]	721 9,44	1.745 1.25	.00212 .98

[a]NE indicates this variable's impact was estimated; it had "no effect" and was dropped.

[b]NA indicates variable's impact was not estimated.

[c]Statistically significant at .01 level.

[d]Statistically significant at .05 level.

[e]Statistically significant at .1 level.

*Source: Data sources were as follows: (1) National Science Foundation series on Research and Development in Industry, 1957-1974 for private and federal R&D; (2) The Economic Report of the President for the price of fixed plant and equipment; and (3) The National Income and Product Accounts of the United States, 1929-74 for the prices of output. Numbers in parentheses are t-values.

significant; positive and statistically significant at the .1 level in the food industry (using a two-tailed test); and no effect in the steel industry.

The F values given indicate that each equation is significant at the .01 level. The Durbin-Watson statistic is given as a reference point; it should not be used to test for autocorrelation when the model includes a lagged endogenous variable. The appropriate test statistic is

$$(14)\quad N = \hat{\rho}\sqrt{\frac{T}{1-TV(I^r_{t-1}/K^r_{t-1})}}$$

where $\hat{\rho}$ = the (biased) estimate of the autocorrelation coefficient from the OLS regression[24]

T = sample size

$V(I^r_{t-1}/K^r_{t-1})$ = variance of the coefficient of I^r_{t-1}/K^r_{t-1}.

This N statistic is distributed as a unit normal. One rejects the hypothesis of no autocorrelation at the .05 level if N is greater than 1.65. As indicated in the table, the N-statistic is less than 1.65, so we accept the hypothesis of no autocorrelation for each industry.[25]

The adjusted R^2 for each industry is consistent and reasonably good for a growth model, ranging from a low of .613 for autos to a high of .773 for steel. The standard error of the estimates (SE) is similar for steel (.00105) and for food (.00149), but it is substantially larger for autos (.00346).

Based upon our findings for each industry, we specified a pooled regression having the following restrictions:

- Constant terms were different for each industry[26]
- The coefficient of time was zero for autos and the same for steel and food
- The coefficient of p_2 was zero for steel and different for autos and food
- The coefficient of p_3 was the same for each industry
- The coefficient of I^r_{t-1}/K^r_{t-1} was the same for each industry
- The coefficients of I^f_t/K^f_t and I^f_{t-1}/K^f_{t-1} were zero for steel and food.

As expected, pooling data had the effect of increasing the t values for variables p_{3t} and I^r_{t-1}/K^r_{t-1}. It also increased the t values for I^f_t/K^f_t and I^f_{t-1}/K^f_{t-1}. The $\bar{R}^2$ increased to .985, the F statistic increased to 721, and, as expected, estimates of coefficients generally were similar to averages of estimates for individual industries. A statistical test of the pooled regression was undertaken, indicating that it was appropriate to pool the data.[27]

The results reported in table 2 indicate that the own-price elasticity of demand for research capital in the short- and long-run is inelastic. Holding other factors fixed, it follows from equations (7) and (11) that the own-price elasticity of K^r_t in the short-run is given by C_3; in the long-run it is given by $C_3/1-C_6$

where $1-C_6$ is our estimate of the partial adjustment coefficient, i.e., b_1 given in equation (8). Furthermore, since I_t^r/K_t^r depends upon the growth rate of its own-price, a change in the level will not cause it to vary. Thus the elasticity of I_t^r equals that of K_t^r for changes in the level of prices.

Estimates of K_t^r and I_t^r own-price elasticities for each industry are given in table 3. Two estimates for short- and long-term coefficients are reported, based upon the individual industry and pooled regression results.

TABLE 3

SHORT AND LONG-TERM OWN-PRICE ELASTICITIES FOR K_t^r AND I_t^r, BY INDUSTRY AND REGRESSION

Industry	Regression	Short	Long
Autos	Industry	-0.0182	-0.131
Food	Industry	-0.0160	-0.0288
Steel	Industry	-0.00902	-0.058
All	Average[a]	-0.0144	-0.0707
	Pooled	-0.01288	-0.0681

[a]Obtained by averaging estimates from individual industry regressions.

Short-term coefficients estimated using individual industry regression results ranged from -0.00903 (steel) to -0.0182 (autos). The pooled regression yielded an estimate of -0.01288 for each industry, which was similar to the average among estimates (-0.0144).

Long-run elasticities were -0.0228 (food), 0.058 (steel) and -0.131 (autos). The pooled regression yielded an estimate of -0.0681, which was similar to the average among industries (-0.0707). It seems that to avoid biases it would be more appropriate to use the individual regression results to obtain estimates for each industry; the pooled regression results, however, probably yield reasonable estimates of the own-price elasticity among industries.

COST-EFFECTIVENESS ANALYSIS OF FEDERAL POLICIES

Introduction

Our results suggest that the demand for privately financed R&D can be affected by changes in the real after-tax price of research capital. We also found that FR&D has a short-term negative impact on the demand for private R&D, but that this adverse impact is only transitory. We found no long-term impact of federal R&D on private R&D.

These findings suggest two potential federal policies for affecting an industry's total R&D performance, i.e., FR&D plus CR&D, in the long-run: (1) use a tax credit per scientist to reduce the price of research capital, and (2) increase federal R&D expenditures. In this section, we analyze the cost-effectiveness of these policies.

For our analysis of a tax credit, let us assume that the after-tax price per unit of research capital is proportional to $1-\mu_t$ times the average cost of R&D per scientist (CPS_t), and that after-tax receipts per unit of output equals $(1-\mu_t)P_t$. We will also assume that the program is organized so that firms receive tax credits only for employment of scientists generated by the tax credit.

Without a tax credit, the level of the after-tax real price of K_t^r, P_{3t}^1, would be $kCPS_t/P_t$ where $k = r_t+\delta^r-g_{2t}$. In the event of a tax credit per scientist equal to Θ, and assuming that the marginal income tax rate, μ_t, is .5, the after-tax real price of K_t^r becomes

$$(15)\quad P_{3t}^2 = \frac{kCPS_t}{P_t} - \frac{k\Theta}{.5P_t} .$$

The percent change in P_{3t}^1 as a result of the tax credit equals

$$(16)\quad \frac{P_{3t}^2 - P_{3t}^1}{P_{3t}^1} = -\frac{2\Theta}{CPS_t} < 0$$

It follows from equation (16) and the definition of an elasticity, that to achieve a percentage change of Ψ in the demand for scientists in the long-run requires a tax credit per scientist of

$$(17)\quad \Theta = -.5\Psi CPS_t/\varepsilon_{I^r,P_3} > 0$$

where

ε_{I^r,P_3} = long-run elasticity of I^r and K^r with respect to changes in P_{3t}.

We will use equation (17) to estimate the cost to the federal government in terms of lost tax revenues of generating employment of scientists using a tax credit, and compare it to the cost of increasing employment of scientists by increasing federal R&D

expenditures. Differences in the value of research capital to society produced by a private versus federally financed scientists will be ignored. Such differences should be imputed by decision-makers when evaluating the cost-effectiveness of alternatives.

In general, lost tax revenues to the federal government per private scientist using a tax credit equal the usual tax savings per scientist of .5 CPS plus the tax credit. If instead the federal government attempted to increase an industry's R&D through increased FR&D, it would incur the cost per scientist plus the additional "overhead" costs per scientist incurred by society (A) when undertaking federally financed R&D. Therefore a tax credit per scientist would be a more cost-effective federal policy for increasing an industry's R&D performance if the tax credit, θ, is less than .5 CPS + A.

Equation (17) indicates that the tax credit would be greater than .5 CPS for targeted percentage increases in the demand for scientists equal or greater than the long-run price elasticity. Including generous allowances for overhead costs does not substantially alter the nature of our findings. For small percentage increases in the employment of scientists, i.e., 13.1 (autos), 2.28 (food, and 5.8 (steel), a tax credit is more cost-effective. For larger percentage increases a federal program combining tax credits and federal R&D expenditures would be more cost-effective.

SUMMARY AND CONCLUSIONS

A theoretical model of the demand for research capital was developed. It was shown that the long-run demand is a function of real after-tax prices and the level of federally financed research capital. Implications of the model were tested using time series data for three industries - autos, steel and food.

We found the theoretical model to be consistent with the data: the own-price effect of research capital was negative and statistically significant. We also found that, although it substitutes for private R&D in the short-run, federal R&D has no long-term effect on the demand for private research capital.

Our findings were utilized to analyze the cost-effectiveness in generating increased R&D, i.e., federal plus private, of two federal policies: changes in the level of federally financed R&D expenditures, and changes in the cost of private R&D through a tax credit per scientist. Ignoring differences in the outputs of private versus federally financed R&D, analysis of alternatives indicates that a tax credit would be more cost-effective only to achieve small percentage increases in the employment of scientists.

FOOTNOTES

1. The rate of technological change probably also declined in the early 1970s due to the declines in real federally funded R&D over the period 1967-71. For evidence, see source table 1.

2. Roger Noll, "Government Policies and Technological Innovation," Project Summary, Vol. 1, California Institute of Technology, 4, 1975, p. 4.

3. J. Schmookler, Invention and Economic Growth, Howard University Press, Cambridge, Mass., 1966, p. 3.

4. See Kaplan, R., Ijiri, Y. and Visscher, M., "Tax Policies for R&D and Technological Innovation," NTIS, March 1976.

5. For example, see Jorgenson, D.W. and Stephenson, J.A., "Investment Behavior in U.S. Manufacturing, 1947-60," Econometrica, April 1967; Gould, J.P. and Waud, R.H., "The Neoclassical Model of Investment Behavior: Another View," International Economic Review, February 1973; and Berndt, Ernst R., "Reconciling Alternative Estimates of the Elasticity of Substitution," Review of Economics and Statistics, February 1976. For an excellent review and critique of these models, see Brechling, Frank, Investment and Employment Decisions, Manchester University Press, 1975.

6. For examples see J. Schmookler, op. cit., E. Graue, "Inventions and Production," Review of Economics and Statistics, 25:221-23 (Nov 43); Z. Griliches and J. Schmookler, "Inventing and Maximizing," American Economic Review, LIII: 725-29 (Sep 63); F.M. Scherer, "Firm Size, Market Structure, Opportunity, and Output of Patented Inventions," American Economic Review, LV:1097-1125 (Dec 65); J. Schmookler and O. Brownlee, "Determinants of Inventive Activity," American Economic Review, (LII(2):165-76 (May 62); E. Mansfield, Industrial Research and Technological Innovation, Norton, New York, 1968; H.G. Grabowski, "The Determinants of Industrial Research and Development: A Study of the Chemical, Drug and Petroleum Industries," Journal of Political Economy, 76 (2):292-306 (Mar/Apr 68); D. Hamburg, Essays on the Economics of Research and Development, Random House, New York, 1966; Dennis Mueller, "Firm Decision Process: An Econometric Investigation," Quarterly Journal of Economics 81:58-87 (Feb 67); J.W. Elliott, "Forecasting and Analysis of Corporate Performance with an Econometric Model of the Firm," Journal of Financial and Quantitative Analysis, 7:1499-1526 (Mar 72); L. Goldberg, "The Demand for Industrial R&D," unpublished Ph.D. dissertation, Brown University, 1972; and L. Goldberg, "The Impact of Firm Size upon the Demand for Industrial R&D," unpublished paper, 1974. William S. Comanor, "Research and Technological Change in the Pharmaceutical Industry," Review of Economics and Statistics, 47:182-87

6. (Cont'd)
(May 65), James S. Worley, "Industrial Research and the New Competition," Journal of Political Economy, 69:183-86 (1961); and John E. Tilton, "Research and Development in Industrial Growth, A Comment," Journal of Political Economy, 81:1245-52 (1973). For a good review of the empirical literature, see David M. Grether, "Market Structure and R&D," California Institute of Technology, June 1974.

7. Deflating of variables was undertaken in order to correct for heteroscedasticity, a common econometric problem encountered when estimating functions with cross-sectional data. For a discussion on hetroscedasticity, see James L. Murphy, Introductory Econometrics, Richard D. Irwin, Inc., Homewood, Illinois, 1973.

8. Jesse Markham, "Market Structure, Business Conduct, and Innovation," AER, 55:323-32 (May 65).

9. Grabowski, op. cit.

10. Hamburg, op. cit.

11. For another simultaneous equations model, designed to explain each major line in a corporate income statement including R&D, estimated with time series data pertaining to 9 firms, 1948-68, see Elliott, op. cit. Elliott also emphasizes the importance of discretionary funds as a factor affecting the demand for R&D.

12. H.G. Grabowski and N.D. Baxter, "Rivalry in Industrial R&D," Journal of Industrial Economics, 21:209-35 (Jul 73).

13. The exception of Grawboski and Baxter who utilized time series firm level data was noted above.

14. For evidence on the substantial comparability of the R&D time series data, see section "Comparability of Data over a Period of Several Years" in NSF 74-312, p. 21.

15. Hamburg, op. cit., and Mansfield, op. cit., p. 10, included a lagged endogenous variable in their cross-sectional studies to estimate the adjustment lag. However, those measurements of short-term and long-term elasticities are not as reliable as the measurements which would be obtained from a time-series study.

16. In future work we will consider other cases involving alternative market structures, behavioral condition and purpose of R&D, i.e., to affect demand rather than supply.

17. Ibid., Chapter 2.

18. However, it is unreasonable to assume that the price of output is exogenous at the <u>industry level</u>. Consequently, to derive the demand for K_t^* for the <u>industry</u>, one should modify the above model to reflect the fact that P_t is endogenous at the industry level. This extension will be made in future work.

19. It follows from equation (11) that if $\frac{dK}{K}$ equals a constant and if δ is a constant then $\frac{dK}{K}$ equals $\frac{dI}{I}$.

20. See <u>Science and Engineering in American Industry, Final Report on a 1953-54 Survey</u>, NSF 56-16, and <u>Science and Engineering in American Industry</u>, 1956, NSF 59-60, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 1956 and 1959.

21. See <u>Research and Development in Industry</u>, NSF 64-9, pp. 1-5.

22. Although actual levels of scientists are not comparable for industries between the Census and BLS Surveys, we believe growth rates may be reasonably comparable for similar industries.

23. Time for autos and the real price of physical capital for steel had very low t values and their exclusion did not materially change estimates of included variables. Consequently, they were dropped.

24. The estimate of $\hat{\rho}$ was obtained from the D-W statistic: $\hat{\rho} = 1-d/2$.

25. For discussion, see G.S. Maddala, <u>Econometrica</u> (McGraw-Hill: New York, 1977), pp. 371-73.

26. Although the constant terms for each industry were similar, we assumed different constant terms thereby utilizing the least squares with dummy variables (LSDV) procedure. With mostly time series data, LSDV is an efficient estimation procedure for pooled time series cross-sectional data. For discussion, see G.S. Maddala, <u>Ibid</u>., pp. 326-331.

27. See G.S. Maddala, <u>Ibid</u>., pp. 322-26.

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