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Introduction

In recent years, studies of a possible relationship between the changes in productivity growth and the investment in R&D have been of interest to many researchers mainly due to the productivity decline in early 70s. Table 1 shows a statistical summary of the growth rates of different measures of productivity in the United States since 1948. Productivity, measured by National Income per person employed in the United States economy, which had grown at an average annual rate of 2.16 percent during 1948-73, fell to an average annual rate of 0.06 percent during 1973-82. The average growth rate of National Income per person employed in the non-residential business sector decreased from 2.45 percent per year during 1948-73 to -0.26 percent during 1973-82. Other measures of productivity also show a similar decline in the seventies. Scherer and Denison have shown that growth in the

Table 1
1948-73 Growth Rates Compared with Later Periods, Selected Series

	1948-73	1973-79	1979-82	1973-82
Whole Economy				
National Income	3.70	2.61	-0.54	1.55
National Income/Person Employed	2.16	0.36	-0.54	0.06
National Income/Hour of Work	2.70	0.98	0.28	0.75
Non-residential Business				
National Income	3.58	2.50	-1.18	1.26
National Income/Person Employed	2.45	0.08	-0.93	-0.26
National Income/Hour of Work	2.96	0.77	0	0.51

Source: E.F. Denison: *Trends in American Economic Growth*, 1929-1982, Table 1.1.

labor productivity in the private sector declined from 3.1 percent during 1947-68 to almost zero during 1977-81.[1]

Investment in R&D has been generally acknowledged as a major source of productivity growth. During the early 70s, company-financed R&D stopped growing. It later resumed but at a much slower rate. Denison, in his work on the sources of economic growth, estimated that advances in knowledge accounted for nearly two-thirds of the growth in productivity.[2] Both the growth rate of R&D as well as the R&D-GNP ratio showed a decline during the early 70s. In 1970, R&D expenditure accounted for 1.83 percent of GNP while in 1977, it had fallen to 1.61 percent. Subsequently, R&D climbed to 1.88 percent of GNP in 1983.

However, findings from studies in this area are not conclusive. Scherer, Griliches, Bosworth, and Denison argued that most of the decline in productivity since 1973 cannot be explained by declines in R&D expenditure.[3] Research by others such as Brinner, Kendrick, and Mansfield suggest that declines in R&D expenditure may be quite important in explaining the productivity decline.[4]

Despite the amount of work in this field, there has been no attempt to test directly the presence of causal relationship, if any, between changes in R&D expenditure and productivity growth. This paper aims to fill that gap in the literature. The approach followed in this paper is significantly different from that of previous studies. The focus here is upon three different measures of productivity in the nonresidential business sector, and their possible relationship with R&D expenditure.[5] A test proposed by Granger is employed to test the hypotheses of this study.[6] However, instead of assuming the same lag length for all variables, a statistical technique described in McMillin is used to determine the appropriate lag length for each variable.[7]

The Theoretical Issues section provides a theoretical discussion of the relationship between R&D and productivity and reviews the existing literature. The Estimation Technique section explains the estimation technique and presents and analyzes empirical results. The final section contains a summary and conclusions.

Theoretical Issues

In recent years an important debate has centered on the contribution of investment in R&D to productivity. Several studies have looked at various aspects of the debate. However, no consensus has emerged. There exist disagreements and uncertainty about (1) the nature (direct or indirect) of effects, (2) the magnitude of influence, and (3) the effects of alternative funding methods (private or government).[8]

Griliches found a consistent positive relationship between various measures of company productivity and the investment in R&D.[9] Explaining the phenomenon in the 70s, he suggests that the slow down in productivity growth may be partially linked to the decrease in the productivity of R&D in the manufacturing sector. Indirect effects of R&D have also been suggested by Scherer. He stated, "R&D yields technological advances that in turn foster productivity growth, but the magnitudes involved have been poorly understood".[10]

Kendrick's analysis of the production function includes intangible capital stock as an explanatory variable.[11] He argues that the intangible capital stock accumulates through investment in R&D, which may be viewed as the major element behind the productive efficiency in the economy. On the other hand, Mansfield et al. have suggested that it is uncertain whether the slowdown in productivity in the 70s is at all due to a slackening of technological advance.[12]

Controversy also exists with respect to the impact of government financed and privately financed R&D on productivity. Griliches argues that company-financed R&D has no superiority over the federally-financed R&D. Terleckyj concluded in favor of indirect effects of privately financed R&D on productivity growth. He also observed that government financed R&D might have had some indirect effects but he did not observe any significant direct effect of private or government financed R&D on productivity growth. However, Link suggested that federally financed R&D increases the efficiency of privately financed R&D.[13]

It can be seen from the above discussion, that scholars agree that R&D expenditures influence productive efficiency, though the nature and the magnitude of that relationship has not been clearly understood. Moreover, the possibility of a reverse causality from productivity decline to decline in R&D investment has not been empirically investigated in the literature. Although Mansfield et al. have pointed out that a diminishing return on R&D investment may be responsible for reduced investment in R&D.[14]

Estimation Technique

Identification of causal relationships among variables has been a major objective of economic research in recent years. Granger's definition of causality between two variables in a time series context has stimulated great interest among researchers. Causality in Granger's sense implies that a variable X causes another variable Y if the past values of X can be used to predict Y more accurately than simply using the past values of Y.

Granger' s method is employed in this study for investigating the causal relationship between R&D expenditure and productivity.[15] Akaike's final prediction error (FPE) criterion is used to specify the lag length of these two variables. An exhaustive study by Thornton and Batten advocates using this criterion for choosing the lag lengths. They argue that the FPE criterion 'performs well' compared to other criteria.[16]

Hypotheses Tests and Empirical Results

There are three plausible hypotheses that will be tested in this paper. First, the hypothesis derived from the studies by Brinner, Kendrick, and Mansfield suggesting that the productivity declines in the 70s were due to the decline in R&D spending. Second, the alternative hypothesis of Scherer, Griliches, Bosworth, and Denison that argues that most of the decline in productivity in recent years cannot be explained by the declines in R&D spending. Third, the possibility of a reverse causation from productivity to R&D spending will also be tested.

The Granger causality tests are performed using annual time series data for the sample period 1956-83. Three different measures of productivity are used - National Income, National Income per person employed, and National Income per hour of work in the non-residential business sector. R&D expenditure is measured by the total expenditure in R&D by industries in the non-residential business sector.[17] The test presumes the use of stationary data and, typically, some transformation of the data is made in order to attain stationarity. A first difference of log transformation is required to transform each of the original data series into a stationary series. The adequacy of these transformations are tested by regressing the transformed series on a constant and time. These regressions yield insignificant coefficients on time while similar regressions of the untransformed series show the presence of a trend.

To test the hypothesis that changes in R&D expenditure cause changes in productivity, the following equation is specified

$$P_t = a_0 + b_i(L)P_{t-i} + c_i(L)R_{t-i} + U_t$$

where P represents the growth rate of various measures of productivity, R represents the growth rate of R&D expenditure, U is a white-noise error term and L is the lag operator, such that, $L^k X_t = X_{t-k}$. To examine Granger causality from R to P, the null hypothesis that all the coefficients of the lagged values of R are jointly insignificant ($c_i = 0, i = 1...n$) is tested. Rejection of the null hypothesis implies that R causes P. On the other hand, failure to reject the null hypothesis indicates the absence of a causal relationship from R to P. F-tests are used to test for the presence of Granger causal relations.[18]

The test results are presented in Table 2. Column 1 shows the three different productivity measures employed. Columns 2 and 3 give the optimal values of b, the number of lags of three different productivity measures (P), and c, the number of lags of R&D spending (R), respectively. The optimal values of b and C are calculated using the minimum final prediction error (FPE) criterion. The F-statistics reported in column 5 are calculated under the null hypothesis that the coefficients of the lagged values of R&D are zero (all $c_i = 0$). Following the F- statistics, a sign in parentheses indicates the sign of the sum of the coefficients of the causal variable. Finally, column 6 shows the relevant degrees of freedom of the F-test.

In Table 2, the values of all the F-statistics indicate rejection of the null hypothesis (all $c_i = 0$) at the 5 percent significance level. Results on all three productivity measures suggest that growth

Table 2
Granger Causality Tests*

Productivity Measure	b	c	R^2	F-Statistics	D.F.
National Income	2	3	.40	8.62(+)	3,22
National Income/Person Employed	2	3	.38	7.14(+)	3,22
National Income/Hour of Work	2	1	.46	8.15(+)	1,24

* b = the number of lags of the productivity measures
c = the number of lags of R&D expenditure
The positive sign in parentheses indicates the sign of the sum coefficients of R&D expenditure.

in R&D expenditure causes growth in productivity in the Granger sense. Moreover, the sum of the effects of R&D growth on each individual measure of productivity growth is significantly positive at the 5 percent level. This implies that productivity growth and R&D expenditure growth move in the same direction.

The coefficient estimates of the regression results are given in Table 3. The R^2 and the standard error of the equation (S.E.E.) show that the equations fit the data quite well. The Durbin (h) statistic calculated for each equation suggests absence of significant first-order autocorrelation.[19]

The possibility of a reverse causation from productivity to R&D expenditure is also tested. Irrespective of the productivity measure used, the null hypothesis that productivity growth does not cause R&D expenditure growth cannot be rejected at a reasonable level of significance.[20] These results along with the findings reported in Table 2 indicate the presence of a unidirectional causality from R&D expenditure to productivity. Hence the change in the growth rate of productivity can be, at least partly, attributed to the change in the growth rate of R&D expenditure. These results are consistent with the findings reported in Brinner, Kendrick, and Mansfield et al. and are contrary to the results reported in Scherer, Griliches, Bosworth, and Denison.[21]

Further analysis is done by examining the effects of the growth rate of R&D expenditure on the growth rate of different measures of productivity. This is done by estimating dynamic multipliers using dynamic simulation of the estimated equations. Initially, a base dynamic simulation using historical data for all variables is performed. Then a dynamic simulation is run with the growth rate of R&D expenditure increased by 1 percent above its historical

Table 3

Coefficient Estimates of the Reqression Equations

	Productivity Measures		
	National Income	National Income/ Person Employed	National Income/ Hour of Work
Constant	0.68 (3.61)	1.20 (0.87)	0.77 (1.26)
b (-1)	0.73 (1.66)	1.62 (2.68)	0.06 (1.20)
b (-2)	1.02 (0.81)	0.71 (3.66)	0.16 (1.32)
c (-1)	0.86 (2.68)	0.33 (2.91)	0.25 (4.78)
c (-2)	0.09 (3.14)	0.47 (3.86)	
c (-3)	0.42 (2.41)	0.30 (3.04)	
Summary Statistics			
R^2	0.40	0.38	0.46
S.E.E.	0.02136	0.001468	0.012016

* Figures in parentheses besides the coefficient estimates represent the t-statistics.

values; historical data is used for the other variable in the equation. The difference between these two simulations give an estimate of dynamic multipliers for R&D expenditure for each period. These multipliers should be of interest to researchers because the multipliers describe the effects and timing of R&D spending on the various measures of productivity. The results are presented in Table 4.[22]

The figures in each column in the Table represent the responses of various measures of productivity at the indicated period (in the column headed by period) to a 1 percent change in R&D spending. The responses are expressed in percent of changes. Responses for four periods are presented here. Irrespective of the productivity measure employed, a positive shock to R&D spending has a positive impact on productivity in all the periods reported here.[23] A shock to R&D spending initially raises National Income. The peak effect occurs in the second period when a 1 percent change in the growth of R&D expenditure leads to a 0.26 percent change in National Income. The effect gradually declines in the third period and becomes extremely small in the fourth period. A similar trend exists for National Income per person employed and National Income per hour of work. The peak effects occur in the second period and gradually become negligible at the end of the fourth period. The magnitude of the peak effect for these two variables is also similar to that of National Income. Thus R&D expenditure has a lag effect on these three measures of productivity and the effect usually lasts for three periods. Moreover, the immediate effect of a 1 percent growth in R&D expenditure on the three different measures of productivity is significant. These results reinforce the earlier findings that a unidirectional causality exists from R&D expenditure to various measures of productivity.

Summary and Conclusions

Results from this study suggest that there exists a causal relationship between various productivity indices and R&D expenditure. The Granger causality concept is used to test the hypotheses drawn from the existing literature in the field. The results show positive effects of changes in R&D expenditure on three different

Table 4
Dynamic Multipliers for R&D Expenditure

Period	National Income	National Income/ Person Employed	National Income/ Hour of Work
1	0.18	0.19	0.12
2	0.26	0.24	0.28
3	0.12	0.19	0.11
4	0.04	0.06	0.07

measures of productivity growth. Data for this study cover the period 1956-83 which includes cycles of growth and decline in R&D expenditure and productivity.

The study shows that changes in R&D expenditure affects the growth rate of three different measures of productivity with varying degrees of intensity. National Income per hour of work shows a much higher R^2 than National Income or National Income per person employed. This suggests that R&D expenditure may have induced an expansion in productive employment. A further analysis of data reveals that a positive growth rate in the R&D expenditure caused different lag effects, intensity, as well as growth cycle effects on various productivity indices. Growth in R&D expenditure has an instantaneous positive effect on all productivity measures. However, the intensity of the contribution and the growth cycle effect vary greatly between the measures. National Income per hour of work shows the highest growth rate, with the peak effect occurring in the second year and maintaining a high growth rate through the fourth year. National Income shows the second highest growth rate in response to a positive shock to changes in R&D expenditure. The peak effect again occurs in the second year. National Income per person employed also peaks in the second year. The growth rate of all three measures decreases significantly in the fourth year. These results provide support to the observation that R&D expenditure causes expansion in the employment sector of the economy. It can be concluded from the findings of this study that productivity and economic growth is a function of R&D expenditure, which supports the popular belief. In order to achieve a higher employment goal, the policy makers should consider the vital role of R&D expenditure in the expansion of employment opportunity.

The findings of this study will be of interest to the planners and policy makers in different ways. The results indicate that using only the trend analysis of the productivity variables may not be the best way to project economic growth. Along with other variables, the projected levels of investment in R&D should also be taken into account. Furthermore, the lag and cycle effect shown here indicate that the impact of R&D expenditure on productivity has a time lag of one year; reaches its peak within 2 years and then falls. This suggests that productivity in different sectors will be better maintained if a time lagged continuous plan of R&D investment is adopted, instead of one based on the need for and availability of resources.

Finally, it also suggests some implications for accounting policy decisions. FASB 2 requires companies to show R&D expenditures in the year in which they are incurred.[24] This policy does not support the 'matching revenues with expenses' principle in accounting. As the contribution of R&D investment is felt after a time lag of one year and as its effects continue for some subsequent time period, results from this study provide an argument for capitalizing R&D expenditure and amortizing it over its productive life.

It should be noted that this study did not investigate the question: How do R&D expenditures cause increases in productivity growth. However, it can be argued that R&D expenditures contribute to productivity through advances in the knowledge base that controls the pace of development of new products, processes, and technological innovations. These enhance the productive efficiency of factors of production, and make more resources available for new investments. This, in turn, expands employment opportunities and results in increases in per capita National Income.

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[1]Foster M. Scherer, "Inter-Industry Technology Flows and Productivity Growth," *Review of Economics And Business,* 64, November 1982, 627-634; and Edward Denison, *Trends in American Economic Growth,* 1929-1982, National Bureau of Economic Research, 1985.

[2]Edward Denison, *Accounting for United States Economic Growth,* 1929-1969, National Bureau of Economic Research, 1974.

[3]In addition to Denison and Scherer, see Zvi Griliches, "Productivity and Technical Change," *National Bureau of Economic Research Reporter*, Spring 1983; Barry P. Bosworth, "Tax Incentives and Economic Growth," Brookings Institute, 1984.

[4]John W. Kendrick, "Productivity Trends and the recent Slowdown: Historical Perspective, Causal Factors, and Policy Options," *Contemporary Economic Problems*, (Washington, D.C.: American Enterprise Institute for Public Policy Research), 1979; and Edwin Mansfield, A. Romeo, M. Schwartz, D. Tecce, S. Wagner and P. Brach, *Technology Transfer, Productivity, and Economic Policy*, (Norton), 1982.

[5]The non-residential business sector includes business firms involved in the production process.

[6]Clive W. J. Granger, "Investigating Causal Relations by Econometric Models and Cross-Spectral Methods," *Econometrica*, July 1969, 424-38.

[7]William D. McMillin, "Federal Deficits, Macrostabilization Goals, and Federal Reserve Behavior," *Economic Inquiry*, 24, April 1986, 257-269.

[8]The effect of alternative funding methods are not statistically analyzed in this study.

[9]Zvi Griliches, "Returns to Research and Development Expenditures in the Private Sector," in John Kendrick and B. Vaccara (eds.) *New Developments in Productivity Measurement and Analysis*, The University of Chicago Press, Chicago, 1980.

[10]Scherer (1982, pp. 215).

[11]Kendrick (1979).

[12]Mansfield et al. (1982).

[13]For a more detailed discussion of this issue, see Griliches (1983). See also N. E. Terleckyj, "Direct and Indirect Effects of Industrial Research and Development on the Productivity Growth of Industries," in John Kendrick and B. Vaccara (eds.) *New Developments in Productivity Measurement and Analysis*, The University of Chicago Press, Chicago, 1980; and A. N. Link, *Research and Development Activity in U.S. Manufacturing*, Praeger Publishers, New York, 1981.

[14]Mansfield et al. (1982).

[15]The Granger test is simple, straightforward and saves degrees of freedom. The limited number of observations available is an important consideration in using this test. To economize space, the estimation procedure for causality testing is not discussed here. Interested readers are referred to McMillin (1986) and the references therein. The Granger test is used with the usual misgivings, see, for example, R.K. Conway, P.A.V.B. Swamy, J.F. Yanagida, and P. Muehlen, "The Impossibility of Causality Testing," *Agricultural Economics Research*, Summer 1984, 1-19.

[16]For a detailed discussion of the rationale for using the FPE criterion, see, McMillin (1986) and Dan Thornton and Dallas S. Batten, "Lag Length Selection and tests of Granger Causality between Money and Income," *Journal of Money, Credit and Banking* 17, 1985, 164-78.

[17]The time series data on various productivity measures are taken from Edward Denison: *Trends in American Economic Growth*, 1929-1982, Tables 2-1 and 2-2. The data on R&D expenditure is taken from the Statistical Abstract of the United States 1985 published by the U.S. Department of Commerce (pp. 577-580).

[18]It has been argued that the bivariate Granger-causality test may be biased due to omitted variables. See, for example, McMillin (1986). However, Yamada have shown that it is very costly in terms of degrees of freedom to include more variables and/or more lags in the system when only a small number of observations are available to test the Granger causality. See, Tadashi Yamada, "Causal Relationships Between Infant Mortality and Fertility in Developed and Less Developed Countries," *Southern Economic Journal*, 52, October 1985, 364-370.

[19]Since the lagged values of the dependent variable are used as regressors, the Durbin-Watson Statistic becomes meaningless and, hence, is not reported here.

[20]To economize space, these results are not reported here but are available from the authors upon request.

[21]Kendrick (1979) and Man field et al. (1982); for an opposing view, see, Scherer (1982), Griliches (1983), Bosworth (1984), and Denison (1985).

[22]Dynamic multipliers have also been calculated by reducing the growth rate of R&D expenditure by one percent below its historical value. The results are very similar to those shown in Table 3. Hence they are not reported separately.

[23]A positive shock to R&D spending implies a 1 percent increase in the growth rate of R&D above its historical value.

[24]'Financial Accounting Standard Board' (FASB) Statement of Financial Accounting Standards No. 2, *Accounting for Research and Development Costs* (Stanford, FASB 1974. Two of the reasons cited by the FASB for arriving at its decision to expense the R&D is, first, lack of causal relationship between the expenditures and benefits and, second, matching of revenues and expenses.