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The Contribution of Higher Education to R & D and Productivity Growth

Walter McMahon
The Contribution of Higher Education to R & D and Productivity Growth

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Abstract

The Contribution of Higher Education to R&D and Productivity Growth

This paper defines an overall conceptual framework for starting to measure the contribution not only of the human capital formed through investment in higher education but also of investment in academic research to (labor) productivity growth.

After considering various problems of measurement (e.g., of low frequency effects, where there are lags, and where output measures understate quality improvement), as well as the trends in the character and relative importance by field of academic research, a vintage model is presented that considers the embodiment of the new technology created by basic research in human capital through education and embodiment in physical capital through patenting. Estimates of the partial derivatives defining the impact of higher education and R&D for the 11 largest OECD nations offer a C-D first approximation that suggests a substantial contribution. A progress report on estimates using a nested-CES production function suggests a contribution that is somewhat smaller.
The Contribution of Higher Education to R&D and Productivity Growth

Walter W. McMahon

The contribution of higher education to basic and applied research both at the universities and after university graduates enter industry, as well as the contribution of the outcomes including patenting and technical change to productivity growth is well recognized and not disputed by economists. The problems come in measuring the value of these contributions of R&D to productivity growth in any precise way, and in relating them to the costs, much less in isolating that portion attributable to basic research conducted at higher educational institutions.

It is illuminating, however, to consider the nature of these measurement problems, and then to go on to attempt to define or specify the theoretical framework for what it is that needs to be measured. There is a great deal of descriptive material about the academic research establishment and some of its impacts, some of which is merely anecdotal, but it nevertheless helps to define the framework within which academic research is conducted and the nature of some of the outcomes. A notable recent study on the "real effects of academic research" by Adam Jaffe (1989) does undertake a systematic empirical analysis of the effects of geographical proximity. It finds significant effects of academic research on corporate patents in Drugs, Medical Technology, Electronics, Optics, and Nuclear Technology, but it does not undertake to analyze the further steps or to measure overall impacts on productivity growth. Other investigations are also
underway on the relation of investment in research to patenting, and on the relation of technical change to productivity. (See, for example, Griliches and Berndt (1989), as well as the recent issues of the National Science Foundation's Science Indicators.)

After considering briefly some of the problems in measuring the marginal productivity of the academic resources invested in basic research, and the conceptual framework, this paper will turn to several situations in which efforts have been made to isolate and measure these impacts. Although each shed some light on the problem from different perspectives, there still are many things that are not known, and effects that are hard to trace. So a high degree of precision in the measurement of impacts on productivity growth should not be expected.

I. Basic Problems

There are five basic problems involved in tracing and measuring the contribution of higher education to R&D and hence to productivity growth.

The first problem is that there are very long lags before basic research and development conducted by universities and colleges affects economic productivity, lags of perhaps from 7 to 40 years or longer. The results of basic research conducted by universities must first be translated into the more highly applied development of products and processes which is a much larger enterprise conducted largely by private industry. Also the research workers trained in universities must graduate and carry their skills into industry or
government. But even after the development of workable products or processes, the dissemination of these to a broader market takes time before there is any economic impact.

The second problem is that from the point of view of the econometrician, these long lags and the inherent nature of productivity change result in low frequency effects. Time series data over short time periods such as from 1960 onwards when relatively good R&D data first become available for most of the O.E.C.D. nations are too short to adequately test for these low frequency effects. Using non-linear estimation with the long lags that are necessary results in wide error margins. It is therefore usually necessary to use international comparisons for the period since 1960, for although there are problems of data comparability and other problems, these comparisons do reveal low frequency effects.

A third problem is that new technology created by R&D is relatively meaningless in terms of its effect on productivity unless it is embodied. This means it must either be embodied in machines as the new machines (or replacement machines) are produced, or embodied in persons through education. Higher education in fact is the major institution embodying this new technology, not only in the research workers trained as new Ph.D.s, but also in undergraduates who will become the support staff in industry for the new technologies. This creates "vintage human capital," and "cohort effects" to be discussed at some length below. The trouble is that it is difficult to sort out the direct contribution of the education of new workers (human capital production) from the indirect contribution made by the R&D as the new
technology is embodied in those new workers. The latter contributes an additional increment to their productivity, and gives them an earnings-advantage in the labor market. (See the most recent research results on this point by Bartel and Lichtenberg 1985, 1988).

A fourth problem is that higher educational institutions do only a very small percentage of the R&D. They do only 8.9 percent of the total R&D, according to the National Science Board of the NSF (1987, p. 13). However the research universities do over 50 percent of the basic research, whereas industry accounts for 80 percent of all development work. If R&D does affect productivity growth, to sort out what portion of this affect is attributable to the basic research mainly done in universities versus the development mostly done in industry is difficult. Furthermore, universities train virtually all of the research scientists who do the research and development work in industry and government. But then if these research workers are paid something approximating their marginal products, that contribution to productivity is included as part of higher education's direct contribution to growth through human capital formation.

The fifth problem is that there are major externalities related especially to basic research that even those who question the existence of external benefit spillovers from education do not deny. These externalities mean that the earnings of scientists engaged in basic research do not include rewards for many widely disseminated and long delayed effects from their discoveries on the economy, some of which may not occur for generations. It is not only famous artists who often die poor; it is also famous mathematicians. In light of
these externalities, it is not possible to use the earnings of scientific research workers, especially in academia, as a measure of their contribution to national income growth and hence to output-related productivity. Production functions therefore are more appropriate in addressing this problem than are earnings functions.

There are various other problems that arise, but most are less unique to R&D. There is the "simultaneity problem," for example. Investment in R&D contributes to growth, but a feedback effect occurs in that growth of income and output in a county in turn contributes to larger investment expenditures on both higher education and on R&D. (These effects are developed for higher education and for R&D in McMahon (1974, Chs. 4 and 6).) There is a recursive nature of this relationship in time series data for a single county, given the long lags that are involved, but the simultaneity involved in longer-period inter-county data will be considered further below.

II. A Brief Description of the Patterns

Most of the basic research done in the United States is done by higher education as shown in Figure 1, largely in the major research universities. Most of the rest is done by government, and very little by industry. Applied research and development however is overwhelmingly done by industry. About 15 percent of the applied research and development is done by government, although if the research and development tax credits given by government are taken into account, the portion supported either directly by government or through these tax subsidies is much larger.
Billions of Dollars

![Bar Chart]

**Figure 1**

Types of Research Performed by Universities, Government, and Industry

Source: National Science Board (1987, p. 13)

Billions of Dollars

![Line Graph]

**Figure 2**

University Research by Field

Source: National Science Board (1987, p. 14)
Since development expenditures loom so large, academic research focusing on basic research (the small 8.9 percent of the total) can be divided among fields as shown in Figure 2. The largest amount by far is supported in the life sciences, for research on various diseases and health problems. Research in physics, chemistry, and the computer sciences at $2 billion a year currently is less than half that in the life sciences, but considerably more than the amount spent on R&D in engineering and in the social sciences.

The United States has fallen far behind Japan and Germany since 1971 in the percent of GNP spent on non-defense R&D, as can be seen in Figure 3. If defense is included, the United States spends more. But although there is some spin-off of defense research into civilian applications, there is also a drain of talented scientists away from focusing their energies on civilian production problems in order to produce weapons. On balance it is doubtful that defense research contributes as much to productivity growth per dollar spent as does R&D that is focused more explicitly on non-defense product and process innovation, or on other sources of productivity growth such as education, health, and the design of effective social programs that bear more directly on improvement in living standards. Data relevant to this issue will be presented later (in Table 3). But in any event, there is continuing concern about the slow productivity growth in the U.S. and U.K. since 1973 in relation to the higher growth in Japan, Germany, and other fast growing countries such as South Korea, Singapore, Hong Kong, and Taiwan. All have invested larger
Figure 3
Non-Defense Research and Development as a Percent of GNP

Source: National Science Board (1987, p. 3)
percentages of their GNP in education and in non-defense R&D since 1960 than has either the U.S. or the U.K.

III. The Conceptual Framework

In light of these conceptual problems, and this factual background, a production function within which contributions of higher education and of R&D to productivity and to output can be measured directly is more appropriate than is a focus on proxies for their contributions to productivity such as the earnings of graduates and the earnings of research scientists. The latter do not accommodate the long lags or the externalities from R&D.

The Production Function. The production function that seems most appropriate expresses potential output, \( Y \), as a function of both the quantity and the quality of each input. It allows for increases in the quantity of both capital goods, \( K \), and raw unimproved labor, \( N \), but also for improvement in the quality of labor through investment in human capital, \( H \) and \( HE \), at both basic and higher education levels. It also allows for investment in R&D, leading to both disembodied technical progress and embodiment in both human capital (\( HE \)) and physical capital (\( K \)) as investment in the education of each new generation and in each new vintage of capital goods occurs. That is:

\[
(1) \quad Y = Y(N, H, HE, K, A, \mu),
\]

where:

\( Y \) = real output (e.g., real GDP);

\( N \) = employment, the quantity of raw unimproved labor;
\( H \) = human capital, formed through basic education, which raises the productivity of the labor force, measured by accumulated depreciated past real investment in primary and secondary education;

\( HE \) = human capital created by higher education. The new technology created by R&D embodied in each succeeding vintage (or cohort) is embodied as gross new investment occurs, as indicated by the overbar.

\( K \) = physical capital, with the new technology embodied in each new vintage;

\( A \) = knowledge-capital created endogenously by investment in R&D, i.e., \( A = A_{-1} + I_A - \delta_A A_{-1} \), where \( \delta_A \) is the rate of obsolescence of knowledge, and

\( \mu \) = disturbance to productivity growth due to wars, oil price shocks, weather, or other external shocks.

All inputs and potential output are treated as at full capacity, with no underutilization. The demand-side (not specified here) jointly determines inflation rates, and output, including underutilization.

The most crucial point has to do with the embodiment of the new technology by means of new investment in human capital as each new generation of college and university students learn the latest techniques.

Thus the R&D done at universities augments their earnings power as they enter the labor force (Bartel and Lichtenberg, 1988, 1988), and makes it difficult to separate the contribution of university-based
R&D to productivity growth from the contribution of higher education alone, without the benefit of the embodiment of the new discoveries.

Similarly, new investment in physical capital incorporates the more recent advances made as the result of R&D. But in this case not all of the R&D is university-based, and the portion that is may have been basic research performed many years back.

Both of these stocks of human capital formed through investment in higher education and of physical capital therefore must be measured in "efficiency units," as shown in Equations (2) and (3) below (with an overbar). They embody the new technology by means of gross investment (i.e., both net new and replacement investment) at rates $a_{HE}$ and $a_K$, respectively:

\[(2) \quad \bar{HE} = \bar{HE}_{-1} + e^{a_{HE}^t}I_{HE} = \delta_{HE} \bar{HE}_{-1}\]

\[(3) \quad \bar{K} = \bar{K}_{-1} + e^{a_K^t}I_{K} - \delta_{K}^{\bar{K}}_{-1}.\]

These rates of embodiment, $a_{HE}$ and $a_K$, are endogenous in the sense that they depend upon the rate of investment in R&D, i.e.,

\[(4) \quad a_{HE} = \frac{A_{HE} - A_{HE-1}}{A_{HE-1}} = \frac{I_{AHE} - \delta A_{HE-1}}{A_{HE-1}}\]

But they are also endogenous in the sense that the rate at which this disembodied technical progress, $a$, gets embodied in either human capital or physical capital, or both, $a_H$ and $a_K$, depends upon the rates of investment in human and physical capital, respectively. If there is
no investment in higher education, there is no embodiment of the technology created by the newest basic research.

The Contribution of Higher Education to R&D and Productivity Growth

The contribution of higher education to R&D and to productivity growth can now be defined more precisely with the help of this conceptual framework and measured in terms of the partial and cross partial derivatives of the production function shown above. Defining productivity growth as labor productivity growth (rather than total factor productivity), one can get this out of the production function by first taking the total differential with respect to time, then dividing through by Y (to get percentage rate of growth of output on the left), and then subtracting the percent rate of growth of employment from both sides (to get productivity growth on the left).

Assuming that the variables have each been transformed in this way, the elements can be analyzed as follows:

Direct Contributions of Higher Education:

1) From teaching, including the effects on productivity growth from the embodiment of technology: \( \partial Y/\partial HE \)

2) From research done at universities: \( \partial Y/\partial A (\partial A/\partial HE) \)

Indirect Contribution to Productivity Growth via Embodiment of R&D Done at Universities:

3) Of new technology in physical capital: \( \partial Y/\partial K (\partial K/\partial A) (\partial A/\partial HE) \)

4) Training researchers, no externalities: Zero (included in 1)

Total Contribution of Higher Education and of R&D Conducted by Higher Education to Productivity Growth:

5) \( \partial Y/\partial HE + \partial Y/\partial A (\partial A/\partial HE) + \partial Y/\partial K (\partial K/\partial A) (\partial A/\partial HE) \)
If the production function given by Eq. (1) could be estimated accurately, then with one simplifying assumption (i.e., that \( \frac{\partial A}{\partial A_{HE}} = \frac{A_{HE}}{A} \)) it would be a relatively straightforward matter to calculate these partial derivatives, and to compute the social rates of return to both the education and the academic R&D components that they imply.

IV. Empirical Estimates

For the 11 OECD nations for which total investment by government, universities, and industry is available for the 1960-1980 period, a production function of the type described above was estimated. The dependent variable is labor productivity growth, measured as the 5-year percent rate of change over time within each country in real GDP per person employed. All explanatory variables are also for comparable 5-year time spans. This inter-country dimension, and the 5-year time spans within each country, are both quite advantageous in that they allow for changes in productivity as the result of the effects from the supply side of rates of investment in higher education and in R&D as is necessary when testing for low frequency phenomena.

The Functional Form

Assuming a Cobb-Douglas form as a first approximation, it is also possible to start with Eq. (1) above, take the logs (in contrast to the procedure described above), differentiate with respect to time, and to convert to per-worker terms by subtracting the rate of growth of employment of total labor from both sides. (For the mathematics of this derivation, see McMahon, 1984, Appendix A). The result is a
production function that explains productivity growth per person employed in terms of physical capital deepening, human capital deepening, and the rate of investment in research and development, plus some variables necessary to control for demand-side influences and for other disturbances. Specifically (and corresponding to the empirical results to be shown in Table 1), the production function estimated for the 11 OECD nations, and then for the five largest nations for which data on investment in R&D is available is as follows (the lower case letters represent proportional rates of change over time in the corresponding upper case variables shown in Eq. (1)):

\[
(5) \quad y - n = \alpha_0 (Y/N)_0 + \alpha_2 (h-n) + \alpha_3 (he-n) + \alpha_4 (k-n) + \alpha_5 a
\]

+ \alpha_6 e + \alpha_7 u + d,

where:

\( y - n \) = labor productivity growth, measured as the 5-year percent rate of change in real GDP per person employed;

\( (Y/N)_0 \) = a constant term, different for each of the 11 countries, measured as the initial (1960) output or real GDP per person employed;

\( h - n \) = increase in human capital, measured as the average educational attainment of the labor force per person employed;

\( he - n \) = increase in the higher educational attainment of the labor force, including embodied technical change, measured as the increase in the number of persons with advanced training in the sciences, social sciences, life sciences,
business administrative, medicine, and agriculture per person employed;

\[ k - n = \text{increased physical capital per worker, including the effects of R&D embodied in the new physical capital stocks. This is measured as gross private domestic investment as a percent of GDP (the latter used as an approximation for the size of the physical capital stock for which data is not available) less the percent growth in the number of workers,} \]

\[ a = \text{investment in R&D as a percent of GDP, taken as an endogenous index of the rate of technical change;} \]

\[ e = \text{energy shock dummy, zero before the first energy price shock in 1973 and one thereafter;} \]

\[ u = \text{percent rate of change in the unemployment rate, a control for demand-side influences on labor (and other factor) utilization rates which would otherwise affect shorter term movements in labor productivity; and} \]

\[ d = \text{a disturbance term. Disturbances affecting labor productivity growth such as changes in the hours of work, changes in the compensation of the labor force, and changes in product quality due to product innovation which are not the focus of this study are collected in this disturbance term.} \]
The Empirical Results

The results of estimates of this production function for the 11 OECD nations for which R&D data is available, and for the sub-set of the largest five nations is shown in Table 1 below.

A larger investment in higher education in this cross section of industrialized nations is associated with higher productivity growth after controlling for other influences or growth. This may be seen in line 3 of Table 1, where the coefficient of .02 for higher education is positive, although only at the 87 percent confidence level \((t = 1.49, \text{DF} = 36)\). However, when higher education and basic education are combined for the five largest countries, the coefficient of 3.2 is much larger, suggesting strong complementarity. Its \(t\)-statistic \((t = 6.41, \text{DF} = 9)\) indicates very high significance at the 99.99 percent confidence level, for the five largest O.E.C.D. nations, which includes the U.S. So the direct contribution of higher education to labor productivity growth, \(\frac{\partial Y}{\partial HE}\) (where the variables have been transformed into percentage rates of change over time per worker) by this estimate lies somewhere between .02 and below .32 since the latter includes the complementarity in production between workers with a college education and the human capital involving a high school education or less.

The other component of the direct contribution of higher education is its contribution through basic R&D to disembodied technical change (and hence to productivity). The coefficient of "a" is insignificant, but in the regression for 11 industrialized nations the constant term of .25 is highly significant \((t = 3.38)\), which will pick up much of
Table 1  

The Contribution of Higher Education and R&D to Productivity Growth  
(t-statistics are shown below coefficient in parentheses)

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Initial Productivity Level (Y/N)₀</td>
<td>-18.3 (-3.7)</td>
<td>-6.8 (-1.3)</td>
</tr>
<tr>
<td>Human Capital Deepening (Basic Ed.)</td>
<td>.02 (1.91)</td>
<td></td>
</tr>
<tr>
<td>Higher Ed. Deepening (Tech. embodied)</td>
<td>.02 (1.49)</td>
<td>.32 (6.41)</td>
</tr>
<tr>
<td>Physical Capital Deepening (Tech. embodied)</td>
<td>.59 (2.83)</td>
<td>1.01 (3.45)</td>
</tr>
<tr>
<td>Disembodied Technical Change (a)</td>
<td>.01 (.49)</td>
<td>-.05 (-1.23)</td>
</tr>
<tr>
<td>Energy Shocks (e:60-80) or Underutilization (U:55-70)</td>
<td>-.15 (-4.57)</td>
<td>-3.21 (-1.70)</td>
</tr>
<tr>
<td>Control for Underutilization (u)</td>
<td>.41 (.51)</td>
<td>-3.67 (-3.68)</td>
</tr>
<tr>
<td>Constant Term</td>
<td>.25 (3.38)</td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>.76</td>
<td>.97</td>
</tr>
<tr>
<td>D-W</td>
<td>1.74</td>
<td>2.30</td>
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<tr>
<td>Number of Observations</td>
<td>44</td>
<td>15</td>
</tr>
</tbody>
</table>
the effects of technical change since the dependent variable is a
growth rate. Keeping in mind that only about 8.9 percent of the R&D
is done at universities, only a small fraction of this .25 contri-
bution to the growth rate can reasonably be attributable to higher
education. For the five largest OECD nations the constant term is
deliberately suppressed. Then disembodied technical change related to
investment in R&D is insignificant, but the portion explained by human
capital and physical capital investment is much larger as diminishing
returns to both investment in physical capital and to human capital
are offset by the new technologies (see Bartel and Lichtenberg, 1985,
1988).

The indirect contribution of R&D conducted by higher educational
institutions comes through the embodiment of design improvements in
the newly constructed producer capital and consumer capital goods.
The coefficients in line 4 of Table 1 of .59 for the 11 OECD nations
and 1.01 for the five largest nations are both highly significant. To
estimate as a first approximation the portion of these contributions
of new physical capital that are made possible by basic research done
in higher education:

\[
\text{Contribution to Productivity Growth of R&D at Universities} = \frac{\partial Y}{\partial K} \quad \frac{\partial K}{\partial A} \quad \frac{\partial A}{\partial A_{HE}}
\]

Relative Significance of Basic Research

For 11 OECD Nations: \( = .59 (.33) (8.9\%) (3) = .05 \)
For 5 largest: \( = 1.01 (.33) (8.9\%) (3) = .089 \)

The above involves multiplying the coefficients that estimate the
impact of physical capital deepening on productivity growth (.59 and
by the proportion due to design improvements (.33 as desired below). This in turn is multiplied by the 8.9 percent estimate of higher education R&D as a percent of the total, and by the estimated three-fold significance of each "dollar" spent on basic research relative to development expenditures.

The relative significance of basic research has been addressed in recent work by Griliches (1986, pp. 141-54). His estimates use a relatively similar production function to that in Eq. (1) and Table 1 but at the firm level. Based on four data sets containing between 396 and 1105 firms each, he concludes that "R&D contributed positively to productivity growth and seems to have earned a relatively high rate of return." Furthermore "basic research seems to be more important as a productivity determinant than other types of R&D." In fact, based on the coefficients from his microeconomic data regressions, basic research has an effect in relation to development expenditures that is in a 3.2 to 1 ratio when disembodied technical change that spills over and diffuses throughout the industry is not included, but in a 7 to 1 ratio in favor of basic research when these externalities (to the firm) are included. It is for this reason that we have multiplied the 8.9 percent of all R&D that is done by universities times three above, since almost all of the university-based research is basic research rather than development.

The contribution of R&D to design improvements is addressed by other research underway at the National Bureau of Economic Research. The correlation between investment in R&D and patenting activity which leads to embodiment has been found by Griliches to be very high, with
a correlation coefficient close to 1.0 (see Griliches and Berndt, 1989, pp. 1-5). The work on embodiment of technical change through patenting is summarized in Griliches, Pakes, and Hall (1986), and Griliches is currently writing a more general survey paper in this field.

There are also problems in the correct measurement of output (as in Table 1) because prices do not fully incorporate the positive effect of product quality improvements. Further research on the measurement of price indices by regression methods (i.e., hedonic price indices) of the type summarized by Griliches and Berndt (1989) but adapted to GDP as an output measure in OECD countries is needed to address this.

The estimate of .33 for the contribution of technology as a portion of the impact of net new and replacement capital is suggested by the work on multifactor productivity (MFP). This isolates the effects of increases in quantities of capital and labor from the effects of improvements in their quality. Multi-factor productivity has grown .77 percent per year in industry from 1950 through 1989 (see Griliches, 1988, p. 10-11), and faster than that in agriculture. This is about one-third of the 2.4 percent annual total (labor) productivity growth in the U.S. during that period.

Controls are imposed in the regressions shown in Table 1 for a number of other factors that also influence productivity growth. These include the initial productivity level (line 1) for each nation in the base year. This negative coefficient is consistent with the widely discussed hypothesis that the follower notions have an advantage
and tend to grow faster as they adopt and adapt existing technology which has been the product of more costly experiments, many of which fail, in the lead nations. Controls also are introduced for energy shocks in 1973 and 1979 in line 6, and for underutilization in line 7, which together accounted for a substantial portion of the productivity growth slowdown since 1973 in oil consuming nations. (For further development of this point see McMahon (1984b, 1987a) and Griliches (1988).)

The Relative Contribution of Human and Physical Capital

The contribution of human capital to productivity growth compared to that of physical capital, each with the new technology embodied, can be compared for these OECD nations. Each coefficient must be weighted by the mean of its corresponding explanatory variable. When this is done

For the 11 OECD countries:

Human Capital: \( \frac{\partial Y}{\partial H} + \frac{\partial Y}{\partial HE} (\overline{HE}) = 0.02 (1.05) + 0.02 (3.25) = 0.09 \)

Physical Capital: \( \frac{\partial Y}{\partial K} = 0.59 (.207) = 0.12 \)

For the 5 largest:

All Human Capital: \( \frac{\partial Y}{\partial (H+HE)} (H+HE) = 0.32 (.71) = 0.22 \)

Physical Capital: \( \frac{\partial Y}{\partial K} (K) = 1.01 (.21) = 0.21 \)

This suggests that the relative contributions of human capital, including both basic and higher education, is about three-fourths \((0.09/0.12)\) that of physical capital in the 11 OECD nations, and
essentially equal contributions are made by each in the five larger nations.

**Direct and Indirect Contributions**

From this data base of OECD nations, which does allow very long run low frequency phenomenon to be revealed (in a way that the U.S. data even from 1946-90 does not), the first approximation estimates developed above can be briefly summarized in Table 2.

The mean rate of productivity growth for each five-year period was 19% in the 11 OECD countries (roughly 3.7%/year) and 27% in the five largest countries (approximately 5.3% per year) during the 1955-1980 period. It has slowed since that time. But in the 11 OECD nations, this suggests that higher education and academic R&D alone account for about 13 percentage points of the 19 percent five-year productivity growth rate, even though oil shocks, and (in the case of the U.S.) the higher initial productivity level were a disadvantage and may have meant a negative (or negligible) initial contribution.

**Interaction Between Higher Education, R&D and Other Forms of Investment**

A relatively simple log-linear Cobb-Douglas production function may be suitable for a first approximation (as above). But it does not take into account the higher elasticity of substitution between physical capital and raw labor, leading to some displacement of raw labor when investment in physical capital occurs. In addition, the preceding analysis has suggested that there is complementarity between higher education and basic education. (In Table 1 above, the coefficients
<table>
<thead>
<tr>
<th></th>
<th>11 OECD Nations</th>
<th>5 Largest</th>
</tr>
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<tbody>
<tr>
<td><strong>Direct</strong> (via Graduates and Disembodied Technical Progress):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) $\partial Y/\partial \text{HE} \ (\text{HE})$</td>
<td>.065</td>
<td></td>
</tr>
<tr>
<td>(2) $\partial Y/\partial \text{H} \ (\text{H})$</td>
<td>--</td>
<td>.22</td>
</tr>
<tr>
<td>(3) $\partial Y/\partial A \ 3A/3A^\text{HE}$</td>
<td>.022</td>
<td>included above</td>
</tr>
<tr>
<td><strong>Indirect</strong> (via Embodiment of R&amp;D in $\bar{K}$):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4) $\partial Y/\partial \bar{K} \ (\bar{K}/\partial A) \ (3A/3A^\text{HE})(3)$</td>
<td>.05</td>
<td>.089</td>
</tr>
<tr>
<td><strong>Total Direct and Indirect Contribution</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of Higher Education and R&amp;D to Productivity Growth:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>.13</td>
<td>.309</td>
</tr>
</tbody>
</table>
suggest this as does prior work by P. R. Fallon (1987).) These differing elasticities of substitution can best be accommodated in a nested-CES production function of the following form. The estimates of the coefficients use U.S. annual data for 1947 through 1988:

\[ Y_p = [0.97 Z^{(8.4)} + 0.03 e^{at_{NS}}]^{(8.4)} \]
\[ Z = [0.91 K^{(6.71)} + 0.09 H^{(6.71)} + 0.01 HE^{(6.71)}]^{(6.71)} \]

\[ R^2 = 0.998; \quad DW = 1.92, \quad Rho = 0.57 \]

where:
- \( Y_p \) = real potential GNP,
- \( Z \) = the combined factor,
- \( \bar{K} \) = physical capital, with embodiment of the technology,
- \( \bar{H} \) = human capital (primary and secondary), with embodiment,
- \( \bar{HE} \) = human capital (higher education), with embodiment,
- \( NS \) = labor supply, the number of workers, and
- \( a \) = rate of growth of the R&D stock.

Technical change is regarded here as embodied as the result of past investment in both physical (\( \bar{K} \)) and human capital (\( \bar{H} \) and \( \bar{HE} \)). But there is also a disembodied component that is raw-labor-augmenting via \( e^{at_{NS}} \).

The elasticity of substitution calculated from the estimates above is higher (\( \sigma = 0.43 \)) for the substitution of total capital (\( Z \)) for
raw labor (NS) than it is for substitution among the different forms of human and physical capital ($\sigma = .22$).

The real rates of return derived as shown in Appendix A and calculated from the estimates of Eq. (6) are:

\[(7) \quad r^*_K = .04, \quad r^*_H = .06, \quad r^*_HE = .07\]

These real rates of return are somewhat lower than those obtained using microeconomic data for the U.S., the averages of which for the 1967-87 period are:

\[(8) \quad \text{Basic education: } r^*_H = 10.7\%\]
\[(9) \quad \text{Higher education: } r^*_HE = 9.7\%\]
\[(10) \quad \text{Housing capital: } r^*_K1 = 4.0\%\]
\[(11) \quad \text{Non-housing Fixed Capital: } r^*_K2 = 15\%\]

So, although the nested-CES production function is a very promising approach, the estimates given by Eqs. (6) and (7) above cannot be regarded as final. Two problems in particular remain:

1. The way in which technical change is introduced makes considerable difference. In Eq. (6) it is treated as embodied in $K$, $H$, and $HE$ (all of the components of $Z$), and disembodied technical change is treated as raw labor augmenting, rather than as a separate term in $Z$.

2. Highly nonlinear estimates are sensitive to changes in the initial guesses. This is a typical problem faced by non-linear dynamics
in all disciplines. One of the major remedies is to start with very good initial guesses, perhaps using those obtained from microeconomic data as in Eqs. (8-11) above.

The Significance of Non-Defense R&D

It is very difficult to isolate analytically and measure the precise contribution of basic research to productivity growth, although a first approximation has been offered in Table 2 above. However, as the tensions with the USSR and Eastern Europe continue to recede, it is useful to contemplate some of the implications of the shift from defense to non-defense investment in R&D.

The U.S. and the U.K. have been the slowest growing of the five largest OECD nations prior to the major oil shocks of 1980, as shown in Table 3 below. It can also be seen that they have spent the largest percent of their R&D budgets on defense R&D (49% in the U.S. and 61% in the U.K.). Their non-defense R&D as a percent of their respective GDP's has also been the lowest. In contrast, Japan and Germany have focussed their R&D budgets much more heavily on trying to solve the energy problem and on matters relevant to industrial productivity and agricultural productivity. Although a reduced defense burden, and greater emphasis on non-defense R&D should not be interpreted as a necessary and sufficient condition for faster growth, it nevertheless is suggestive. It also has implications for the structure of academic research budgets.
Table 3
Growth Rates of Real GDP Compared to the Composition of R&D Expenditure
Countries Ranked from Fastest (left) to Slowest (right) Growth Rates

<table>
<thead>
<tr>
<th>Growth Rate of Real GDP Per Capita:</th>
<th>JAPAN</th>
<th>GERMANY</th>
<th>FRANCE</th>
<th>U.S.</th>
<th>U.K.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966-1973</td>
<td>9.5%</td>
<td>3.9%</td>
<td>4.9%</td>
<td>2.9%</td>
<td>2.5%</td>
</tr>
<tr>
<td>1974-1980</td>
<td>1.9</td>
<td>2.1</td>
<td>2.3</td>
<td>1.3</td>
<td>.7</td>
</tr>
<tr>
<td>Average</td>
<td>5.7</td>
<td>3.0</td>
<td>3.6</td>
<td>2.1</td>
<td>1.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Non-Defense Govt. R&amp;D Plus Pvt. R&amp;D as a Percent of GDP:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965</td>
</tr>
<tr>
<td>1975</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Government R&amp;D by Major Objective:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defense</td>
</tr>
<tr>
<td>Industrial Productivity</td>
</tr>
<tr>
<td>Agricultural Productivity</td>
</tr>
<tr>
<td>Energy</td>
</tr>
<tr>
<td>Health</td>
</tr>
<tr>
<td>Advancement of Knowledge</td>
</tr>
<tr>
<td>Other (e.g., Space, Telecommunication, Environment)</td>
</tr>
</tbody>
</table>

Sources:  
b. Government R&D by Objective is net of general university funding. See Piekacz (1983).
V. Conclusion

Higher education, and the predominantly basic research conducted by higher educational institutions, makes a major contribution to productivity growth. Although the conceptual nature of the basic and indirect contribution involving embodiment of the new technology in both human and physical capital appears to be reasonably clear in its major dimension, a precise measure of its contribution in what is characteristically low frequency data over time is difficult to obtain.

A first approximation for the 11 OECD nations where higher education and university-based R&D together appear to contribute about 13 percentage points or about 60% of the five-year growth rate seems high, but is what is offered by the OECD data. The real rates of return to investment in higher education, calculated at 9.7% from U.S. microeconomic data, do not include the full contribution of the investment made in R&D. Comparable real rates of return to higher education calculated from a nested-CES production function average 7% in the U.S., which perhaps sets a lower bound. The 7% to 9.7% real rates of return to human capital formed by higher education are quite respectable when it is realized that these must be augmented by the contributions of academic R&D (as well as increased by the inflation rate if they are to be compared to other nominal rates of return). There are also suggestions in the data of complementarity with the other factors of production, so that to avoid diminishing returns, \textit{balanced} investment in each is needed.
References


Appendix A

Derivation of the Rates of Return from a Nested CES Production Function

Without the error terms, a nested CES production function is specified by the following two equations:

\[
YP = [\alpha_1 Z^{-\rho} + \alpha_2 N^{-\rho}]^{-\frac{1}{\rho}}, \quad \alpha_1 + \alpha_2 = 1 \tag{1}
\]

\[
Z = e^a[\beta_1 K^{-\rho_1} + \beta_2 H^{-\rho_1} + \beta_3 HE^{-\rho_1}]^{-\frac{1}{\rho_1}}, \quad \beta_1 + \beta_2 + \beta_3 = 1 \tag{2}
\]

Substituting (2) into (1), we have

\[
YP = [\alpha_1 e^{-a \rho} \{\beta_1 K^{-\rho_1} + \beta_2 H^{-\rho_1} + \beta_3 HE^{-\rho_1}\}^{\frac{\rho}{\rho_1}} + \alpha_2 N^{-\rho}]^{-\frac{1}{\rho}} \tag{3}
\]

Let

\[
P = \alpha_1 e^{-a \rho} \{\beta_1 K^{-\rho_1} + \beta_2 H^{-\rho_1} + \beta_3 HE^{-\rho_1}\}^{\frac{\rho}{\rho_1}} + \alpha_2 N^{-\rho} = YP^{-\rho}
\]

and

\[
Q = \{\beta_1 K^{-\rho_1} + \beta_2 H^{-\rho_1} + \beta_3 HE^{-\rho_1}\} = \left(\frac{Z}{e^a}\right)^{-\rho_1}
\]

Then, taking the total derivative of (3) with respect to time \(t\), we have

\[
\frac{dYP}{dt} = \frac{\partial YP}{\partial K} \frac{dK}{dt} + \frac{\partial YP}{\partial H} \frac{dH}{dt} + \frac{\partial YP}{\partial HE} \frac{dHE}{dt} + \frac{\partial YP}{\partial N} \frac{dN}{dt}
\]

\[
= P^{-\frac{1+\rho}{\rho}} \left[\alpha_1 e^{-a \rho} Q^{\frac{\rho}{\rho_1}} \beta_1 K^{-(\rho_1+1)} \frac{\partial K}{\partial t} + \alpha_1 e^{-a \rho} Q^{\frac{\rho}{\rho_1}} \beta_2 H^{-(\rho_1+1)} \frac{\partial H}{\partial t}
\]

\[
+ \alpha_1 e^{-a \rho} Q^{\frac{\rho}{\rho_1}} \beta_3 HE^{-(\rho_1+1)} \frac{\partial HE}{\partial t} + \alpha_2 N^{-(\rho+1)} \frac{\partial N}{\partial t}\right]
\]
Appendix A (continued)

\[ \frac{dYP}{dt} = YP^{\rho+1} \left[ \alpha_1 \beta_1 e^{-\alpha \rho \pi} Z^{\rho \pi - \rho} K^{-(\rho+1)} \frac{\partial K}{\partial t} + \alpha_1 \beta_2 e^{-\alpha \rho \pi} Z^{\rho \pi - \rho} H^{-(\rho+1)} \frac{\partial H}{\partial t} \right. \]

\[ + \alpha_1 \beta_3 e^{-\alpha \rho \pi} Z^{\rho \pi - \rho} HE^{-(\rho+1)} \frac{\partial HE}{\partial t} + \alpha_2 N^{-(\rho+1)} \frac{\partial N}{\partial t} \left. \right] \quad (4) \]

Since

\[ Z^{\rho \pi - \rho} = \frac{Z^{\rho+1}}{Z_{\rho+1}} \]

(4) becomes

\[ \frac{dYP}{dt} = \alpha_1 \beta_1 e^{-\alpha \rho \pi} \left( \frac{YP}{Z} \right)^{\rho+1} \left( \frac{Z}{K} \right)^{\rho+1} \frac{\partial K}{\partial t} + \alpha_1 \beta_2 e^{-\alpha \rho \pi} \left( \frac{YP}{Z} \right)^{\rho+1} \left( \frac{Z}{H} \right)^{\rho+1} \frac{\partial H}{\partial t} \]

\[ + \alpha_1 \beta_3 e^{-\alpha \rho \pi} \left( \frac{YP}{Z} \right)^{\rho+1} \left( \frac{Z}{HE} \right)^{\rho+1} \frac{\partial HE}{\partial t} + \alpha_2 \left( \frac{YN}{N} \right)^{\rho+1} \frac{\partial N}{\partial t} \quad (5) \]

Therefore, the rate of return to physical capital,

\[ r_K = \alpha_1 \beta_1 e^{-\alpha \rho \pi} \left( \frac{YP}{Z} \right)^{\rho+1} \left( \frac{Z}{K} \right)^{\rho+1} \]

the rate of return to basic education,

\[ r_H = \alpha_1 \beta_2 e^{-\alpha \rho \pi} \left( \frac{YP}{Z} \right)^{\rho+1} \left( \frac{Z}{H} \right)^{\rho+1} \]

the rate of return to higher education,

\[ r_{HE} = \alpha_1 \beta_3 e^{-\alpha \rho \pi} \left( \frac{YP}{Z} \right)^{\rho+1} \left( \frac{Z}{HE} \right)^{\rho+1} \]