BEBR

FACULTY WORKING
PAPER NO. 975

Sources of Productivity Growth in a Medium Term Macroeconomic Model with Human Capital

Walter W. McMahon

College of Commerce and Business Administration
Bureau of Economic and Business Research
University of Illinois, Urbana-Champaign

BEBR

FACULTY WORKING PAPER NO. 975

College of Commerce and Business Administration

University of Illinois at Urbana-Champaign

September 1983

Sources of Productivity Growth in a Medium Term Macroeconomic Model with Human Capital

Walter W. McMahon, Professor
Department of Economics

Abstract

This paper considers the relation of education and of scientific knowledge developed through R&D to productivity growth within a medium time macroeconomic model that includes private and public physical, human, and knowledge capital formation. It is unique in developing a medium term model for determining productivity growth, and hence the relative competitiveness of states and nations, that includes both demand side and supply side effects, as well in incorporating total investment.

Empirical results for the US and 14 other major OECD nations for 5 year time periods from 1950 through 1980 find stable growth of total capital formation to be critical. Education as measured separately by average educational attainment of the labor force, bachelors and more advanced level graduates in the physical, life, and social sciences that embody the new scientific developments bringing them to bear on production more quickly are both found to be highly significant determinants of productivity growth. Investment in physical capital is also highly significant, but the R&D effort is less so, although R&D may be effective largely as it is embodied through this investment in human and physical capital. High utilization rates, as measured by full employment, and lower relative initial productivity levels permitting transfer of technology, are found to be the other highly significant sources of labor productivity growth.

Sources of Productivity Growth in a Medium Term Macroeconomic Model with Human Capital

Walter W. McMahon

This paper considers the relation of education and R&D to labor productivity growth in the U.S. and other OECD nations within the context of a macroeconomic model that includes both human capital and stocks of knowledge.

Supply side policies have tended to emphasize physical capital formation by private business firms, with less attention to investment in education or to investment in new knowledge such as which that occurs via non-defense R&D. Both include public investment, and education also includes private investment by households as they save and invest their time and other resources. These sources of investment also affect productivity growth.

A macroeconomic model that incorporates the concept of total capital as defined and measured for the U.S. by Kendrick (1976) will be developed in this paper. The model is unique in including human capital formation and knowledge capital formation through public and private investment in education and in R&D within a medium term IS-LM structural framework, as well as in relating these to the growth of output on the supply side. Blinder and Solow (1973) were the first to incorporate physical capital formation into a medium term macroeconomic model. But neither their work nor the extension of it by Turnovsky (1977, pp. 127-158) to incorporate inflation and expectations allows the capital accumulation that does occur as part of Turnovsky's "intrinsic dynamics" to have any effect through a production function on output from the supply side.

The significance of incorporating total capital and productivity growth in a medium term model is to extend and improve the consistency of the concept of intrinsic dynamics by allowing capital stock accumulation to affect output from the supply side rather than limiting it to wealth effects on demand. The implication of too narrow a view of saving and of capital deepening, if used to determine supply side policies, could include actually reducing saving and investment in education and R&D below what it would otherwise be.

If the rates of return to education and to R&D are high relative to the alternatives as they are found to be by Psacharopoulos (1981), McMahon (1982), and Griliches (1983) respectively, reduced investment in education and in R&D would be expected to contribute to reductions in productivity growth in the future. Finally, the significance of the concept of total capital is also apparent in the new science-technology-information revolution and the structural shift away from smokestack industries. Both Japan and Germany, for example, have invested a larger percent of their GNP in non-defense R&D since 1960, and Japan has maintained a higher rate of increase in its stock of human capital than have almost all of the other OECD countries.

Part I of this paper develops a structural macroeconomic model that incorporates the effects of education and R&D on productivity growth. It focuses on a production function that contains physical capital, human capital, and knowledge capital, all differentiated with respect to time, and that attempts to control for demand side influences by including unemployment as a measure of the influence of slack demand and underutilization. This is necessary because underutilization, and particularly underutilization of human capital in the form of labor hoarding by firms, contributes to lower productivity for each person on the average that remains employed in the medium term. Other components of the demand-side are not estimated empirically here. The model does provide for the fact that productivity growth in the medium term can arise from demand pull forces, so that the recovery of productivity growth need not necessarily be supply-led.

Part II considers the empirical significance of these sources of productivity growth using data for each five year period from 1955 through 1980 for the U.S. and 14 other OECD nations. Since a slowdown in productivity growth occurred in all of these nations beginning in 1973, a somewhat broader perspective is offered on the sources of the slowdown. But the primary focus is on the contribution of education, R&D, and demand pull forces to productivity growth in the medium term.

I. The Medium Term Macroeconomic Model Incorporating Total Capital

To consider the supply side and the capital deepening process as distinguished from long run steady state solutions, the production function will be the starting point. It will be followed by investment functions for human, physical, and knowledge capital, and this by abbreviated reference to other components of an IS-LM type system.

The production function as well as the rest of the model with which it is consistent will be expressed in terms of percentage rates of change, all of which are represented by lower case notation, with capital letters referring to the level of each variable. The reason is that the productivity growth and capital deepening, (as well as inflation rates, rates of change in the money supply, and rates of change in demand) which are the focus are all percentage rates of change with respect to time. The underlying model is specified in terms of levels, as is more customary. Most of the derivations that then convert it to percentage rates of change are shown in the Appendix.

The model also incorporates simplifying assumptions which are essential in order to consider the interactions within the system. All economic theory simplifies reality, but the simplifying assumptions seek to avoid doing violence to the essence of the phenomena simplified.

The Production Function

Starting, therefore, with a Cobb-Douglas production function that includes human capital and both embodied and disembodied stocks of knowledge, taking the natural logs, and differentiating with respect to time gives the growth rate of real Gross Domestic Product (y) as a function of the rate of growth of the various inputs. The rate of growth of the number of persons employed (n) may then be subtracted from both sides under the simplifying assumption of constant returns to scale to determine the rate of growth of output per worker: (The production function from which it can be derived is shown in the Appendix.)

$$(1) \qquad (y-n) = \gamma_1 U_H + \gamma_2 (Y/N)_{-1} + \gamma_3 (k+a-n) + \gamma_4 (h+a-n) + \gamma_5 (he+a-n) + \gamma_6 a + \gamma_7 (e-n)$$

Here:

$(y-n)$ = labor productivity growth per worker, (rather than per hour, for consistency with the rest of the model, is also close to Denison's (1979, 1983) NIPPE),

U_H = percent underutilization of human capital,

$(Y/N)_{-1}$ = the initial level of output per worker reflecting the costs of technological leadership that deters those in the lead and the advantages of backwardness for those adapting the technology developed by others,

$(k+a-n)$ = the rate of physical capital formation (k) per worker (n),

$(h+a-n)$ = the rate of human capital formation per worker,

$(he+a-n)$= the rate of increase in higher educational attainment (he) per worker (n), a mechanism for embodiment and dissemination of the new technology,

a = the rate of increase in technical knowledge generated by R&D, and

$(e-n)$ = the rate of change in petroleum-energy use per worker.

Total Capital Deepening. Human capital deepening includes the increased average educational attainment of the labor force per person which would include the embodiment of new knowledge (h+a) that occurs as the result of investment in education. It facilitates adaptability to change and, when the education emphasizes creativity, also facilitates innovation, e.g., OECD (1982). Increased higher education also embodies the new technology (he+a) but at more advanced levels. It is measured here as the number of graduates in the physical sciences, life sciences, social sciences, engineering, medicine, agriculture, and business administration as a percent of the labor force. It brings the new technology to bear on production as the new graduates enter the labor force, while also strengthening the research capability of firms (e.g., Mansfield, 1983), all of which strengthens the effect of education on productivity growth. This effect from technology, and the increased completion of two year degree programs at the Associate and Masters' level, especially by women, are the main reasons for postulating that some effects of human capital formation on productivity should be detectable within medium term 5-10 year periods. The increase in the explanatory power of human capital formation as the result of embodiment of the technology is directly analogous to the stronger effects from the growth of physical capital formation as the more recent vintages included in Gross Private Domestic Investment embody the new technology, (k+a above), a well known affect previously found for physical capital by Robert Solow (1960).

The measurement of each of these variables, anticipating the empirical tests for the effects from each of these components of total capital formation in Part II requires some further comments. The general education component, increases in the average educational attainment, measures an increased number of years of schooling primarily at the primary and secondary levels. But it also indirectly measures human capital formation on the job, which is included conceptually in human capital formation, because of the close correlation between the number of years of schooling and the amount of human capital formation that occurs through experience and training on the job.

Technical higher education, just as with physical capital investment, is a gross investment concept in that new graduates include replacement of persons who retire and this replacement investment also brings the new technologies to bear on production. As stressed by Eliasson (1981), new technologies are defined more broadly here to include the more recent production management, marketing, and business administration efficiencies as well as improvements in economic and social organization, all of which can contribute to less private and social waste and hence greater social efficiency. The embodiment of the new technology occurs in part as the result of government and industry supported research, especially that conducted at universities, since in the latter case there is a joint product of the new knowledge as well as the embodiment of it in a constant flow of new students.

The more rapid dissemination of the new technologies, broadly defined, among firms and countries is a separate important means by which both general education and higher technical education increments can contribute with lags to productivity growth. For example, Mansfield (1983, p. 3) finds in a sample of 104 firms that a 10 percent increase in the number of years of schooling of the company's president is associated, after controlling for other factors, with a significant increase in the probability that new innovations are adapted by the firm. The importance of dissemination is also illustrated by the fact that the productivity in best practice plants within each industry far exceeds the productivity in the worst practice plants, e.g., Carlsson (1980, pp. 15-30). So significant increases in productivity can occur merely through dissemination among firms, facilitated by the presence of more highly trained people. It can also occur across nations--to measure this, the initial productivity level variable $(Y/N)_{-1}$ is used above to measure Maddison's (1982) "advantages of backwardness."

To measure disembodied technical progress, a in Eq. (1) above, research and development investment is used as a more explicit index of additions to the stock of knowledge. The measure is confined to non-defense R&D, not because defense research does not have spillover effects, but because research and development effort designed specifically to contribute to efficiency in the non-defense parts of the economy is more likely to have effects on productivity growth than research not so designed. The effects of disembodied R&D on productivity are much debated, e.g., National Science Foundation (1981, pp. 13-16). But they are likely to operate with longer lags, to be related to patenting activity, e.g., Griliches (1983), and to be important to sustaining the technological leadership in the leading firms and leading countries. Less developed nations may be able to adopt existing technologies with smaller R&D efforts, and yet to enjoy significant productivity gains. So the expected direction of this effect is not clear, as it is with all of the other effects, when the regression includes the follower-countries (or follower-firms). A positive relation would be expected between R&D effort and productivity growth in the U.S. taken alone, but there could even be a negative relation between the smaller R&D efforts in the follower countries and their faster productivity growth as they embody in human and physical capital the fruits of the R&D efforts of others.

The effect of physical capital formation (k+a) on productivity growth is well known, and included in Eq. (1). Since the objective is to focus on the net effects from education and R&D on productivity, this serves to control for the simultaneous effects from physical capital formation. But to measure both physical capital investment and investment in R&D in international data as the percentage change in the respective stocks of capital goods and of knowledge however is impossible. Kendrick's (1976) measures of the latter are available for the U.S. but not the other OECD countries. A useful solution, which also turns out to have a logical relation to the linear additivity of the levels of investment on the demand side, is to scale the data for investment in physical capital and in R&D by expressing them as a percentage of the Gross Domestic Product of each country.

Underutilization. As aggregate demand falls off, raw labor becomes unemployed. But the most skilled workers and management personnel essential to the survival of the firm tend to be retained. As the volume of output falls far below capacity, this human capital tends to be underutilized. Hence the productivity per person employed, since these workers are still counted as employed, tends to fall sharply in most recession periods. The workers retained are likely to be those with more human capital who are the more productive workers--but the underutilization of all of the overhead human capital results in lower output per worker for all of those who remain employed. The result of this effect, which is also a result of having introduced human capital into the model, is that rising productivity in the medium term is partially due to reduced underutilization and hence to demand-pull forces.

With respect to measurement, there is no direct measure of the lack of full human capital capacity utilization within firms. But the unemployment rate of all labor as adjusted by the OECD to allow for some international differences in measurement should be a good proxy, since both phenomena are largely the result of slack demand.

The final term in Eq. (1) provides for the energy shocks occurring in 1973 and in 1979 as crude oil prices, and all the energy sources that depend on them, rose dramatically. The variable measuring the rate of change in the availability of cheap energy per worker, (e-n), is measured as the percentage change in net oil imports plus domestically produced and consumed oil per person employed.

Total Investment

Total investment, including investment in education and in R&D, is stimulated in turn by more rapid growth of income per person employed. The investment demand functions incorporating this feed-back effect are shown below for gross investment in physical capital (k+a), investment in general education (h+a), investment in technical higher education (he+a), and investment to increase the stock of knowledge via R&D, (a):

$$(2) \qquad (k+a-n) = \Theta_1(y-n) + \Theta_2(\dot{r-p}) + \Theta_3 U_H + \Theta_0$$

$$(3) \qquad (h+a-n) = \delta_1(y-n) + \delta_2(g_H^*-n) + \delta_0$$

$$(4) \qquad (he+a-n) = \varepsilon_1(y-n) + \varepsilon_2(g_{HE}^*-n) + \varepsilon_0$$

$$(5) \qquad a = \nu_1(y-n) + \nu_2(\dot{r-p}) + \nu_3 g_A^* + \nu_0$$

Variables not already defined under Eq. (1) above are:

$(\dot{r-p})$ = the rate of change in the real rate of interest,

g_H^* = government expenditure on education as a percent of GDP, a policy variable,

g_{HE}^* = government expenditure on higher education as a percent of GDP, a policy variable,

g_A^* = government expenditure on research and development done by universities and firms, also a policy variable.

In the last analysis, final decisions to invest or not invest in human capital formation are made primarily by households who invest their time and other resources, but with "price" incentives provided by government subsidies as in Eqs. (3) and (4) through low public school tuition and other types of financial help. Analysis of microeconomic data reveals that the amount of schooling planned and undertaken by those from middle and lower income families depends heavily on family disposable income per person (e.g., (y-n) above), given imperfect capital markets, but also on public financial support of education, including that for tuition at all levels and for student loans and grants, (i.e., g_H^* and g_{HE}^* above); see McMahon (1983)). The latter are policy variables that influence the effective price of education to households, and hence the private rates of return. The result of these public loan, subsidy, and grant programs is broader access to education and more schooling undertaken by the economically marginal groups, plus a stimulus to additional household saving from student time and family foregone earnings to support the investment that otherwise would not occur.

Structural improvements in the educational system, if any, (e.g., strengthened high school requirements in science, social science, mathematics, and English, higher pay for these teachers, a longer school day, and a longer school year as called for in the 1983 Presidential Commission Report entitled _A Nation At Risk_) are likely to require more public and more private resources if they are to occur. But the analysis does not depend on any structural reform occurring. It focuses instead the relation of family and public sources of financial support to the number of years of education attained. Once this is determined by equations (3) and (4) above, (based on McMahon (1983)) it then is related directly to productivity and income growth in equation (1).

Joint Determination with the Demand-Side

The focus of the empirical estimation in Part II is on the parts of the model already presented above--i.e., the relation of total investment to productivity growth, plus the equilibrium condition with aggregate demand. Table 1 presents the demand side, Eq. (6), and flow equilibrium condition, Eq. (7), in order to explain the underutilization and reduced investment which are also part of the medium term. Table 1 also suggests how the productivity and investment demand components (Eqs. 1-6) can be viewed as part of a consistent overall model.

The linearity in percentage rates of change with respect to time is straightforward on the supply side because the underlying production function and the wage and price equations can best be regarded as linear in the logs. But on the demand side problems arise, because the aggregate demand components, given GNP definitions, must be regarded as additive in terms of levels, and not in terms of their logs. The solution however, turns out to also be convenient for our purposes. It is to first define Consumption as net of household investment in education, and Gross Private Domestic Investment as net of Investment in R&D, then to subtract aggregate demand expressed in terms of levels and lagged one period from itself. Finally divide by Y_{-1} to obtain:

$$\text{(6a)} \quad \frac{Y-Y_{-1}}{Y_{-1}} = \frac{C-C_{-1}}{Y_{-1}} + \frac{I-I_{-1}}{Y_{-1}} + \frac{I_H-I_{H-1}}{Y_{-1}} + \frac{I_{HE}-I_{HE-1}}{Y_{-1}} + \frac{G^*-G^*_{-1}}{Y_{-1}} + \frac{F-F_{-1}}{Y_{-1}}$$

Collecting the lagged terms like C_{-1}/Y_{-1} on the right yields:

$$\text{(6b)} \quad \frac{Y-Y_{-1}}{Y_{-1}} = C/Y_{-1} + I/Y_{-1} + I_H/Y_{-1} + I_{HE}/Y_{-1} + G^*/Y_{-1} + F/Y_{-1} - Y_{d-1}/Y_{d-1}$$

This is identical to Equation 6 in Table 1 when re-expressed in the lower case notation defined there. G^*, T^*, and $\overline{F}$ are treated as exogenous (they do not appear in Eq. (1) directly), and n has been subtracted form both sides to get Eq. (6). The investment/income ratios are not exactly rates of change over time in each capital stock, but they are rates of capital formation relative to a base income level. This is convenient because it is what is required for a logically consistent solution to the macroeconomic model and because it scales the investment components for each of the 15 countries considered in Part II by the Gross Domestic Product of that country. The data on GDP are available for all countries, whereas the data on these capital stocks are not.

The Wage-Price and Monetary Sectors

The inflation rate is determined by relatively standard Phillips-type wage and price equations. They contain demand-pull, core inflation rate, and supply-shock elements. They represent something short of the long run rational expectations polar case where $\pi = \dot{p}$, full pass-through of expectations into wages and prices, forecast errors and shocks with means of zero, and hence a Phillips curve that is vertical. Instead, the model focuses on the medium term within which

Table 1

A Structural Interpretation of Sources of Medium-Term Productivity Growth

Productivity Growth:

$$(1)\quad (y-n) = \gamma_1 U_H + \gamma_2 (Y/N)_{-1} + \gamma_3 (k+a-n) + \gamma_4 (h+a-n) + \gamma_5 (he+a-n) + \gamma_6 a + \gamma_7 (e-n) \qquad \gamma_1 < 0,\ \gamma_2 < 0$$

Total Investment:

$$(2)\quad (k+a-n) = \Theta_1 (y-n) - \Theta_2 (r-\dot{p}) + \Theta_3 U_H + \Theta_0, \qquad (k+a) = I/Y_{-1}$$

$$(3)\quad (h+a-n) = \delta_1 (y-n) + \delta_2 (g_H^* - n) + \delta_0, \qquad (h+a) = I_H/Y_{-1},\ g_H^* = G_H^*/Y_{-1}$$

$$(4)\quad (he+a-n) = \varepsilon_1 (y-n) + \varepsilon_2 (g_{HE}^* - n) + \varepsilon_0, \qquad (he+a) = I_{HE}/Y_{-1},\ g_{HE}^* = G_{HE}^*/Y$$

$$(5)\quad a = \nu_1 (y-n) + \nu_2 (r-\dot{p}) + \nu_3 (g_A^* - n) + \nu_0 \qquad a = I_A/Y_{-1},\ g_A^* = G_A/Y_{-1}$$

Aggregate Demand (Flow Equilibrium) and Fiscal Policy:

$$(6)\quad (y-n) = (c+a) + (k+a-n) + (h+a-n) + (he+a-n) + a + g^* + \overline{f} - 1+2n$$

$$c+a = C/Y_{-1},\ g^* = (G_H^* + G_{HE}^* + G_A^* + G_K^* + G_C^*)/Y_{-1},\ f = \overline{F}/Y_{-1}$$

$$(7)\quad c+a = \lambda_0 + \lambda_1 y_D$$

$$(8)\quad y_D = (1+y)(Y_{-1}/Y_{D-1}) - \overline{T}^*/Y_{D-1} + \overline{R}^*/Y_{D-1}$$

Inflation Rate:

$$(9)\quad p = \beta_1 U_H + \beta_2 w + \beta_3 (y-n) + \beta_4 p_e \qquad \beta_1 > 0,\ \beta_2 > 0,\ \beta_3 < 0,\ \beta_4 > 0$$

$$(10)\quad w = \alpha_1 U_H + \alpha_2 \pi + \alpha_3 (y-n) \qquad \alpha_1 > 0,\ \alpha_2 > 0,\ \alpha_3 > 0,\ \beta_3 \neq -\beta_2 \alpha_3$$

(11) $\pi = \psi_1 p + \psi_2 p_{-1}$

(12) $U_H = U_K = U = N/N_P = \gamma_0 (1+y) Y_{-1}$

(13) $y = (y-n) + (1/N_{-1}) N_{-1}$

Monetary Sector: (Restrictive Demand Management in Reaction to Inflation):

(14) $\dot{m}_s = \kappa_1^* y_p + \kappa_2 p + \kappa_3^* U$ $\qquad \kappa_2 < 1,\ \kappa_3 > 0$

(15) $\dot{m}_d = \mu_1 y + \mu_2 (\dot{r} - p) + \mu_3 \dot{\pi}$ $\qquad \mu_2 < 0$

(16) $m = m_s = m_d$

Variables are defined in the text except for:

Asterisk (*) symbolizes policy determined expenditure (g^*) and tax (t^*) rates.

p = the inflation rate.

w = the rate of increase in money wages.

U = percent underutilization of raw labor (one minus the percent unemployed), of human capital (some of which is hoarded by firms, U_H), and of physical capital (U_K = one minus the percent excess capacity), assumed to be equal as a simplifying assumption

G = government investment in human capital (G_H), in higher education (G_{HE}), in R&D performed by universities and firms (G_A), in physical capital (G_K), and government support of consumption (G_c).

I_H = household investment in education, which is netted from Personal Consumption Expenditure (C) and is assumed to be positively related to (h+a) as a simplifying assumption,

I_A = investment in R&D which affects a.

y = percent rate of change in real Gross Domestic Product during the medium term, (5-10 year period), with $y = (Y-Y_{-1})/Y_{-1}$.

n = percent rate of change in employment.

y_D = percent rate of change in real disposable income.

r = the nominal rate of interest.

$\dot{\pi}$ = the rate of change in the expected inflation rate.

T = total tax receipts, $\overline{R}$ = transfer payments.

prices and wages may not be able to fully adapt (i.e., α_2 and β_2 are not necessarily equal to unity, and not all markets clear). In this medium term, expectations adapt partially to changes in the inflation rate (Eq. 11).

The monetary sector consists of an expectation augmented demand for money function of a type that has been used by Friedman, plus a money supply reaction function. On the demand side, additional uncertainty in interest rate outcomes has arisen as structural changes have created larger money market fund balances and other forms of near money--but rather than add an additional term (e.g., σ) we have chosen to leave this with the residuals. On the supply side, Black (1981) has estimated reaction functions of this type for ten OECD countries, after controlling for foreign exchange reserves. With the discount rate as the dependent variable, for example, he finds both an expected restrictive monetary policy reaction to higher inflation rates in these countries, and easier money and credit terms following higher unemployment rates in the period 1963 to 1980 in Belgium, France, Germany, Italy, Japan, Netherlands, Sweden, and the U.S. (ibid, pp. 35-37). In the U.S. the tightening in mid-1980 when the inflation rate was high and the abandonment of the 2½%-5½% monetarist rule in August 1982 as it fell and unemployment rose are perhaps other examples of this.

One Period Equilibrium Solutions to the Model

Since the model as a whole is linear in the rates of change as defined above, it can be solved for a one period equilibrium relevant to the approximately five year time span in which the model is expressed. That is, the solution produces a value for each of the 15 endogenous rates of change and for average utilization. For this purpose the lagged endogenous variables are treated as predetermined, and hence as parameters.

The solution produces a steady state rate of growth of productivity (at fixed values of the exogenous variables and lagged endogenous variables) that is non-zero within any given 5 to 10 year period. It is an equilibrium rate in the sense that the flow equilibrium and monetary equlibrium conditions are enforced (Eqs. 6 and 16). Utilization rates can remain below full capacity on the average for any given 5 to 10 year period, so that a failure to reach full recovery can adversely affect both productivity growth directly and investment (Eqs. 1 and 2). In contrast to the Blinder-Solow (1973) long run steady state solution however, net saving and capital deepening continue to occur. This is also an extension of Turnovsky's (1977) intrinsic dynamics, since human as well as physical capital deepening in the medium term contributes through the production function both to embodiment of the new technology and to productivity growth.

II. Empirical Estimates of the Productivity Growth and Investment Functions

To offer an intuitive illustration of the operation of the model, following higher inflation rates in 1973-74 and 1979-80 that occurred at the time of the oil price shocks p^e in Eq. (9) which were initially accommodated by the money supply, restrictive monetary policies were employed by most of the 15 major OECD countries, (i.e., $\kappa_2 < 1$ in Eq. 14). The result was higher interest rates (Eqs. 14-16), reduced investment (Eq. 2), and reduced aggregate demand (Eq. 6). The effect of this on productivity growth in threefold. First, the underutilization that accompanies reduced aggregate demand slows productivity growth directly as some human capital remains employed but underutilized. Second, slowed physical capital formation lowers productivity growth because of its supply-side effects (Eq. 1). Third, slower income growth reduces human capital and knowledge capital formation (Eqs. 3-5), with delayed effects on productivity growth (via Eq. 1). As recovery begins, the reverse process occurs.

The regressions shown in Table 2 are one-stage least squares estimates of Equation (1). They are a first approximation to explaining the sources of productivity growth in the period from 1955 through 1980 in the major OECD nations, including the U.S.

For the 15 nations in the regression at the top, 5 year periods from 1955 through 1980 for each nation yield 75 observations, which drops back to 45 when the more stable growth period from 1955-70 is considered, eliminating the energy shocks and productivity slowdown that characterized the more unstable 1971-1980 period (e.g., McMahon (1981)). At the bottom of Table 2, a measure of total public and private R&D effort is available for only the 5 largest nations, so the number of available observations drops back to 15 for 1955-70 or to 25 for the 1955-80 period as a whole.

Human Capital Formation

The significance of human capital formation to productivity growth revealed here is somewhat similar to that found by Denison (1983), Schultz (1983), and Kendrick (1980).

When human capital formation per worker as measured by increased average educational attainment of the working age population (h+a-n) is introduced as shown in Table 2, it always turns out to have the expected positive sign. It is a more significant factor explaining productivity growth in the relatively stable period from 1955 to 1970 for both the 15 nations (at the top of Table 1) and the 5 largest nations (at the bottom), although it continues to have a positive relation to productivity growth when the 1970-1980 period is included.

When this measure of schooling which reflects basic literacy in mathematics, language, and science is augmented with a measure of the number of newly trained physical scientists, social scientists, engineers, management personnel, and agricultural specialists as a percent of the labor force in each country, (he+a-n), this higher technical education variable has the expected positive sign and is also significant at the .05 level.

However, Higher Technical Education (he+a-n) also allows the follower country to capitalize on the "advantages of backwardness" by adapting and using the new technologies. So it is picked up indirectly by the initial productivity level term (Y/N) as a proxy as "backwardness" is capitalized on. There are many LDC's that have not equaled the growth record of Japan and Israel, for example. In these two countries, large initial stocks of human capital and higher rates of growth in education and health levels have undoubtedly made it easier for them to adopt and adapt western technology. The level of educational attainment in Japan was not only high initially, but the rate of increase at all levels, and especially in advanced technical areas, has been considerably higher than that in the U.S. or the UK since 1950. Importing high technology capital goods undoubtedly transmits some kinds of new technology, (e.g., Maddison, 1979), but there are still significant steps requiring trained people before most of these capital goods and especially the more intangible kinds of scientific findings (e.g., uses of hybrids in agriculture) can be adapted by development efforts within firms and brought to bear on production.

This combined effect of general education, technical education, and the advantages of backwardness is consistent with what is being found in an increasing number of studies of productivity growth in the less developed countries as well. To cite only one example, there is an interesting recent study by Yamada and Ruttan (1980, p. 559) of the sources of productivity growth in agriculture in 41 developed and developing countries. They find that the number of graduates of agricultural colleges per person employed in agriculture (which helps to facilitate the dissemination of new technology but also the mobility out of lower productivity agriculture into agribusiness), supplemented by the average educational attainment of persons in agriculture, accounts for 30-32 percent of the productivity differences in agriculture within both developed and less developed countries.

This is not to suggest that reduced human capital formation has as yet been more than a minor source of the slowdown since 1973 in growth per capita. The slowdown has been experienced by all of the major OECD nations, as can be seen at the top of Table 2. This is largely because investment in education is not as sensitive to restrictive monetary policies as is physical capital investment.

Table 2

Growth in Labor Productivity

Dependent Variable: Productivity Change Over 5 Year Period (y-n) for Each Country: (y-n)

FIFTEEN OECD NATIONS:

Independent Variables:	1955-1970 Coef.	1955-1970 t-stat.	1955-1980 Coef.	1955-1980 t-stat.	1955-1970 Coef.	1955-1970 t-stat.
Underutilization (Av. U)	-1.23	-1.52	-1.50	-2.60	-.91	-1.27
Initial Productivity $(Y/N)_{-1}$	-11.23	-2.62	-10.70	-3.10	-10.59	-3.22
Physical Capital Deepening (Av. I/Y_{-1}-n)	.81	3.38	.67	3.63	1.08	7.92
Human Capital Deepening (h-n)	.05	2.02	.02	1.22	.07	2.91
Higher Technical Education (he+a-n)					.03	2.75
Energy Change per Worker (e-n)	.00	.38	.01	1.17	.002	.74
Constant (eg., a)	.14	1.70	.16	2.32		
Number of Observations =	45		75		45	
R^2 =	.57		.54		.61	

FIVE LARGEST OECD NATIONS:

Independent Variables:	1955-1970 Coef.	1955-1970 t-statistic	1970-1980 Coef.	1970-1980 t-statistic
Underutilization (Av. U)	-3.21	-1.70	-4.48	-11.56
Change in Underutilization (μ)	-3.67	-3.68		
Initial Productivity $(Y/N)_{-1}$	-6.76	-1.35	12.74	5.82
Physical Capital Deepening (k-n) = (Av. I/Y_{-1} -n)	1.01	3.45	.21	.81
Human Capital Deepening (h-n)	.32	6.41	.08	3.71
R&D Knowledge Formation a = $(R\&D)_{-1}/Y_{-1}$	-.05	-1.23	.04	1.42
Energy Change per Worker (e-n)	.002	.46	.001	.03
Number of Observations =	15		10	
R^2 =	.97		.99	
Simple Correlation, (y-n) with $(R\&D)_{-1}/Y_{-1}$	.16		.51	

Relatively less human capital is financed with credit, or sensitive to changes in credit terms. Nevertheless, there is some evidence that there may be a greater reduction in the rate of effective human capital formation than is revealed by the figures. For example, the quality of education has fallen in the U.S. in some respects since the late 1960's as evidenced by the reduced high school requirements mentioned earlier for courses in math, science, and social science, and the falling math, science, and verbal scores on college admission and graduate record examinations. A weakening in college curricular requirements occurred also in the U.S. as well as in Japan and elsewhere at the time of the campus unrest of the late 1960's that has not been fully reversed. Furthermore, human capital formation in the form of on-the-job training has been reduced for those unemployed during the 1975 and 1982 recessions. Public support per pupil for education has been cut in real terms by Federal and state governments in the U.S. in the period from 1979 through 1983. This is likely to have adverse effects on productivity growth in 1985 and beyond.

The obsolescence of energy-intensive physical capital investment (the Baily effect) slowing productivity growth since 1973 is not strictly reversible in that the same kinds of energy-intensive investment cannot merely be resumed. More attention needs to be paid to the less energy-intensive sources of productivity growth such as human and knowledge capital formation, as well as to adaptation of technology developed by others.

Advances in Knowledge Through R&D

A larger civilian total public and private R&D effort in the U.S. might be expected to lead to some productivity growth directly. But such an effect proves difficult to detect. The lags are likely to be somewhat longer than for human capital deepening which aids dissemination. The contribution of R&D efforts is also limited somewhat by the fact that scientific discoveries are communicated among the leading countries (externalities) and by the Rosenberg (1976) effect which causes many of the costs of failed research and innovation, and hence of diminishing returns to R&D, to be borne by the leading countries.

In Table 2, the R&D effort appears explicitly only in the regressions for the five largest OECD nations. This is because data is available on total public and private non-defense R&D only for these nations, and not for the other 11. (Source N.S.F., 1981). However, data on public support for non-defense R&D were obtained from the science policy branch at NSF for 11 of these nations. But when included in regressions the results were not much different than those for the public plus private civilian R&D efforts of the five largest nations that are shown at the bottom of Table 2. Above and beyond the technology embodied in human and physical capital formation, the additional statistical contribution of R&D prior to 1970 was negative but not significant. After 1970, those countries that had engaged in larger R&D efforts earlier (R&D effort is lagged 5 years) did much better in sustaining their productivity growth after the slowdown began.

Some additional insight is offered by the new data in Table 3 on Government R&D by Major Objective which has recently been collected and made available by Rolf Piekarz and Eleanor Thomas (1983). This is so since some types of R&D may reasonably be viewed as more relevant to productivity growth than other types. For example, Japan's much larger investment as a percent of its GDP for adaptation of western technology relevant to agricultural productivity, industrial productivity, and energy shown in Table 3, as well as its much smaller total public defense R&D effort relative to that in the U.S. and U.K., could help to partially explain slower growth in the U.S. and U.K. as well as the shift of technological leadership to Japan in an increasing number of product lines. The Rosenberg (1976) effect has the potential of helping to explain the slower growth in the U.S., but not the shift of technological leadership in some lines to Japan. The explanation therefore needs to be augmented with the effects of investment in new advances in knowledge, a part of total capital. Germany's non-defense R&D effort has been even more dramatic than that in Japan, both of which have considerably exceeded that in the U.S. and the U.K. since 1965 (see Table 3). It may well be fruitful to extend the NSF data to measure those types of R&D expected to be more relevant to productivity growth over the entire 1955-1980 period so that the effect of the composition of the R&D effort could be tested more systematically in regressions.

Some will argue that new weapons systems and space exploration have spillover effects on productivity growth--and here the U.S.

Table 3

Growth Rates and Composition of R&D Expenditure
Countries Ranked from Fastest (left) to Slowest (right)
Pre-Energy-Shock Growth

	JAPAN	GERMANY	FRANCE	SWEDEN	U.S.	U.K.
Growth Rate Per Capita:						
1966-1973	9.5%	3.9%	4.9%	3.2%	2.9%	2.5%
1974-1980	1.9	2.1	2.3	.9	1.3	.7
Non-Defense Govt. R&D Plus Pvt. R&D As a Percent of GDP:						
1965	1.53%	1.53%	2.01%	n.a.	1.33%	1.49%
1975	1.89	2.19	1.80	n.a.	1.50	1.39
Government R&D by Major Objective:						
Defense	5%	19%	36%	33%	49%	61%
Industrial Productivity	13	15	14	3	.4	10
Agricultural Productivity	30	3	4	3	2	5
Energy	19	21	9	12	10	8
Health	7	6	5	11	12	3
Advancement of Knowledge	0	9	15	5	4	4
Other (e.g., Space, Telecommunication, Environment)	25	27	17	26	23	9.2

Sources: Non-Defense R&D from Science Indicators, N.S.F., p. 212
Government R&D by Objective is net of general university funding, and from Piekarz et al. (1983, Table 10).

clearly leads. But it is a reasonable hypothesis that those components of R&D directly oriented to improving economic efficiency and productivity or to expanding basic knowledge are likely to have a larger impact on productivity growth than those that are not--see Gilpin (1975) and NSF (1981, p. 9). Defense research also competes for scarce scientific research personnel. But in addition to defense, the United States devotes a larger fraction of its research dollars to health than anywhere else. There are monetary returns to health research in the form of less illness that improves productivity and non-monetary returns that yield a longer and better quality of life. But no imputations are made for the latter in the measures of GNP, and hence no contribution to productivity growth for much health research is revealed.

There is other empirical evidence of shifts in technological leadership away from the U.S. The increasing number of U.S. patents secured by foreign inventors, for example, and the decline since about 1967 in the number of patents secured by American inventors (NSF, 1981, p. 110) may also be related to the smaller nondefense R&D effort in the U.S., one implication of Griliches' (1983) findings that R&D effort and potenting activity are closely related. This smaller total public plus private R&D effort has been due largely to the decline in Federal support for non-defense R&D. This is because R&D by private industry continued to grow slowly in real terms, in spite of the lower profits during the 1975 and 1982 recessions (NSF, 1981, p. 75).

Utilization and Demand-Led Sources of Productivity Growth

It is necessary to control for underutilization since slack demand, reduced output, and the resulting excess capacity in the human capital stock retained by firms contributes to demand-induced slowdown in productivity growth. The consistently negative signs in Table 2 for the 1955-80 period as a whole, as well as for sub-periods, for the underutilization created by slack demand as measured by the average level of unemployment during the 5-year period (Av. U by Okun's law, and after adjustment of unemployment rates by the OECD for differences in measurement among countries) is consistent with this hypothesis. The result is an implication of having introduced human capital into the model, but is also consistent with Oi's (1962) earlier work on labor as a fixed factor.

Beyond this however, the change in productivity which is our dependent variable starts to become positive right after the trough of each recession even though the level of output per man remains low--witness the recovery of productivity growth in 1975-II and in late 1982 for example. So the change in underutilization has been introduced in one of the regressions to test for, and control for, this effect. The result shown in Table 2 is a negative sign for a coefficient that is highly significant. This result for both the changes in and level of underutilization is consistent with the hypothesis that a significant portion of the recovery in medium term productivity growth in the major OECD nations is demand-led.

Physical capital formation per worker has a consistently positive and significant relation to productivity growth in Table 2, as expected. It had a weaker effect in the 1970-80 period, in part perhaps because of the Baily effect from the 1973 and 1979 energy shocks causing obsolescence of existing capital so that replacement investment was substituted for investment that might otherwise have added to productivity growth. A second factor must be mentioned since it affects the analysis. It is that in the U.S. a much larger wave of new workers was entering the labor force from 1970-1980 due to the wave of post WWII births which was not matched by comparable increases in France, Germany, Japan or the U.K. where total employment remained stable in this period. For any given rate of investment in physical or human capital, this growth in the labor force contributed to lower capital formation per worker, thereby limiting capital deepening in the U.S. with adverse effects on productivity growth. The future effect of this demographic factor as college enrollments and labor force growth rates decline from 1984-94 should be adverse for aggregate growth rates, but positive for productivity growth per worker, since it is easier for any given level of capital formation to achieve greater capital deepening per person employed.

A Structural Interpretation of Productivity Growth

Although this paper is limited in its empirical aspects to the productivity growth equation (it is already too long), the theoretical contribution in Part I make it clear that productivity growth is being interpreted as part of a structural process that interacts with the rest of the system. Preliminary two stage least squares simultaneous equation estimates of equations (1-8) in Table 1 which will not be reported in detail here reveal that the signs of all of the coefficients in the productivity growth equation remain identical to those shown for the 15 OECD nations for 1955-70 in the last column of Table 2 above. The absolute size of the coefficients also remain approximately the same. The t-statistic for the "higher technical education" variable drops below the .05 level, but the remaining t-statistics remain apparently the same. The per capita income growth is very significantly related to all components of investment-demand in the demand equations (1-5 in Table 1). The relative price terms remain insignificant in these preliminary runs, but there is some question as to whether or not they should be measured in per-capita terms as shown in Table 1.

Larger GDP per person employed clearly feeds back and leads to increased total capital formation in the medium term (the modified accelerator effect in Eqs. 2-5 in Table 1), as well as some growth of demand Eq. 6). The estimation of Equations 1-8 by simultaneous equation methods now underway will be followed by dynamic solutions by simulation techniques that include the moderating effect of productivity on inflation (assuming $\beta_3 < -\beta_2\alpha_3$ in Eqs. 9 and 10) and that go beyond the one-period (5 year) solution considered in Part I.

Conclusion

In conclusion, to summarize the sources of labor productivity growth in the medium term they are first, the demand-led higher utilization rates and higher physical capital investment associated with recovery from recessions. Second, an important source of labor productivity growth, (but not of the 1973-82 slowdown), is human capital formation. Its effects are revealed in three ways--through increased overall average educational attainment, among other things increasing the "ability to deal with disequilibria" (Schultz, 1975), through advanced technical education that brings the new technology and research to bear on production, and through the ability it conveys to capitalize on the "advantages of backwardness" (Maddison 1982).

This analysis has attempted to control for the effects of energy shocks, both by integrating them into the logic of the analysis and by introducing the rate of growth of energy use per worker as a variable in the productivity growth equation. What is normally thought to be another major source of productivity growth--disembodied technical progress, as measured here by public and private investment in R&D as a percent of GDP--did not stand alone as an independent and significant influence in the analysis of data for the 15 OECD nations. Perhaps this is because its effect is already picked up by the new human capital formation and new and replacement investment in physical capital that together embody the technology and bring it to bear on production--plus the fact that the lags are longer than the lags in the permitted by the data, especially for the disembodied components of total capital formation.

As an issue in supply side economics, the debate is likely to continue for the foreseeable future on what is the appropriate mix between a mere quantitative expansion of the educational system and improvements in the quality of the services which it provides. But productivity growth could suffer if such a debate were allowed to obscure the contribution of both--quantity and quality--and the resources required for each. Similarly, the most recent Economic Report of the President (1983, p. 77) mentions that "another major source of productivity growth in investment in education and training that promotes the accumulation of valuable human capital." It then goes on to "... focus on non-residential plant and equipment investment," which is also relevant, but not the whole story.

References

Black, Stanley (1981) "The Use of Monetary Policy for Internal and External Balance in Ten Industrial Countries," paper for the conference on "The Political Economy of Monetary Policy in Western Europe," University of Illinois, Urbana-Champaign, Nov. 18-20, 1981.

Blinder, Alan S. and Robert M. Solow (1973) "Does Fiscal Policy Matter?", Journal of Public Economics.

Carlsson, Bo (1980) "Technical Change and Productivity in Swedish Industry in the Postwar Period," Research Report #8, Industrial Institute for Economic and Social Research, Grevgaton 34 Stockholm.

Denison, Edward F. (1983) "Accouting for Slower Growth: An Update," in John Kendrick, ed., International Comparisons of Productivity and Causes of the Slowdown, AEI, Washington, DC.

Denison, Edward F. (1979) Accounting for Slower Growth, The Brookings Institution, Washington, DC.

Eisner, Robert, and David Nebhut (1982) "An Extended Measure of Government Product: Preliminary Results for the United States, 1946-1976."

Eliasson, Gunnar (1981) "Electronics, Economic Growth, and Employment: Revolution or Evolution?" in Herbert Giersch, Emerging Technologies, Institut für Weltwirtschaft an der Universität Kiel, J.C.B. Mohr, Tübingen, West Germany, 1982.

Gilpin, Robert (1975) Technology, Economic Growth, and International Competitiveness, Joint Economic Committee of the Congress, Supt. of Documents, Washington, DC.

Griliches, Zvi (1983) "Productivity and Technical Change," Program Report in NBER Reporter, Spring 1983, 1-4.

Kendrick, John (1976) The Formation and Stocks of Total Capital, NBER, Columbia University Press.

Kendrick, John W. (1979) "Expanding Imputed Values in the National Income and Product Accounts," Review of Income & Wealth, Dec., 349-363.

Maddison, Angus (1982) Phases of Capitalist Development, Oxford University Press, Oxford and New York.

Maddison, Angus (1979) "Long Run Dynamics of Productivity Growth," Banca Nazionale del Lavoro Quarterly Review, No. 128, March 1979, 3-43.

Maddison, Angus (1964) Economic Growth in the West, W. W. Norton & Co., New York.

Mansfield, Edwin (1983) "Engineering Employment, Federal Funding, and Company Financial R&D Expenditures," Working Paper, University of Pennsylvania, May 1983.

McMahon, Walter W. (1981) "The Slowdown in Productivity Growth: A Macroeconomic Model of Investment in Human and Physical Capital With Energy Shocks," Faculty Working Paper #752, BEBR, University of Illinois, Urbana, 1-43.

McMahon, Walter W. (1982) "The Monetary Returns to Education as Partial Social Efficiency Criteria," in W. W. McMahon and T. G. Geske, eds., Financing Education: Overcoming Inefficiency and Inequity, University of Illinois Press, Champaign-Urbana.

McMahon, Walter W. (1983) "Why Families Invest in Education," in Seymour Sudman, ed., The Collection and Analysis of Economic and Consumer Behavior Data: Essays in Honor of Robert H. Ferber, University of Illinois Press, forthcoming, 1983.

National Science Foundation (1981) Science Indicators, Report of the National Science Board, 1981, U.S. Govt. Printing Office, Washington, DC.

O.E.C.D. (1982) Innovation in Small and Medium Firms. A Report of the Committee for Science and Technology Policy, Paris, 1982.

Oi, Walter (1962) "Labor as a Quasi-Fixed Factor," Journal of Political Economics, Oct. 1962.

Piekarz, Rolf, Eleanor Thomas and Ronna Jennings (1983) "International Comparisons of R&D and Government Policies," in John Kendricks, ed., International Comparisons of Productivity and Causes of the Slowdown, AEI, Washington, DC.

Psacharopoulos, George (1981) "Returns to Education: An Updated International Comparison," Comparative Education, Vol. 17, No. 3, pp. 321-41.

Rosenberg, N. (1976) Perspectives on Technology, Chapter 15, Cambridge University Press, Cambridge.

Schultz, T. W. (1975) "The Value of the Ability to Deal with Disequilibria," Jour. Econ. Lit., Vol. 13, No. 3 (Sept.).

Solow, Robert M. (1960) "Investment and Technical Progress," in Mathematical Methods in the Social Sciences, Arrow, Karlin, and Suppes, eds., Stanford University Press, Stanford, CA, 1960.

Turnovsky, Stephen J. (1977) "An Intermediate Run Macroeconomic Model," Macroeconomic Analysis, Cambridge University Press, pp. 129-158 adapted from Pyle and Turnovsky, Journal of Money Credit and Banking, 8, 1976.

Yamada, Saburo and Vernon W. Ruttan (1980) "International Comparisons of Productivity in Agriculture," in John W. Kendrick and B. Vaccara, New Developments in Productivity Measurement and Analysis, NBER Studies in Income and Wealth, Vol. 44, pp. 509-94. University of Chicago Press, Chicago.

Appendix

The sources of productivity growth given by equation (1) in the text may be derived from the following production function:

$$(1a)\quad Y = e^{\gamma_1 U_H t} e^{\gamma_2 (Y/N)t} N\gamma (A_K K)^{\gamma_3} (A_H H)^{\gamma_4} (A_H HE)^{\gamma_5} A^{\gamma_6} E^{\gamma_7}$$

Terms not already defined above under equation (1) are:

Y = real GDP, e = base of natural logs,

N = employment of raw labor,

A = the stock of knowledge, embodied in physical capital through replacement (and net new) investment (A_K), in human capital through education and on-the-job training (A_H), and disembodied new research discoveries (A).

E = petroleum-energy inputs

Taking the logs:

$$(1b)\quad \ell nY = \gamma_1 U_H t + \gamma_2 (Y/N)t + \gamma \ell nN + \gamma_3(\ell nA_K + \ell nK) +$$

$$\gamma_4(\ell nA_H + \ell nH) + \gamma_5(\ell nA_H + \ell nHE)\ \gamma_6 \ell nA + \gamma_7 \ell nE$$

Differentiating with respect to time, and using simpler lower case notation for percentage rates of change gives:

$$(1c)\quad y = \gamma_1 U_H + \gamma_2 (Y/N) + \gamma n + \gamma_3(a+k) + \gamma_4(a+h) + \gamma_5(a+he) + \gamma_6 a + \gamma_7 e$$

Assuming constant returns to scale among the inputs,

(1d) $\gamma = 1 - \gamma_3 - \gamma_4 - \gamma_5 - \gamma_6 - \gamma_7$, n can be subtracted from both sides.

$$(1) \qquad (y-n) = \gamma_1 U_H + \gamma_2 (Y/N) + \gamma_3 (kta-n) + \gamma_4 (hta-n) + \gamma_5 (he+a-n) + \gamma_6 a + \gamma_7 (e-n),$$

the same determinants of the rate of growth in labor productivity shown in equation (1) in the text.