A Relationship between the Rate of Economic Growth and the Rate, Allocation, and Efficiency of Investment

Dennis Anderson

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ABSTRACT

The paper derives the relationship described in the title and then discusses how the methods and results of micro-economics might be brought to bear on the analysis of growth. The approach is compared with those of several long-standing studies on the subject. It is shown that the "residual", i.e. the technical progress parameter in these studies turns out not to be a parameter but a function of the rate of investment, the allocation of investment among economic activities, the rates of return to investment in these activities, and variables representing the influence of investment on labor's share in economic output. The weighted average returns to investment implied by the approach are estimated for several countries and, it is suggested, are not inconsistent with project experience and with their observed growth rates. As the argument is developed, an attempt is made to discuss the relevance of the approach for the analysis of economic policy.
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I. INTRODUCTION

Purpose of Paper

In the analysis of economic growth, in the developing as in the industrialized countries, the methods of micro-economic analysis for appraising the efficiency of investments are rarely (if ever) used. One reason for this, perhaps, is that a large number of studies have estimated investment's contribution to growth to be comparatively minor. Typically only about one quarter of economic growth in the industrialized countries is attributed to material investment, perhaps another quarter or third to investment in the education, or the "quality" of the labor force, and a large measure of the remainder to exogenous technical progress, brought about by comparatively small investments in research and development.1/ In the earlier studies, before allowances were made for improvements in the quality of labor force, over 80% of the measured increases in growth were attributed to technical progress.2/

The purpose of this paper is to derive and discuss a relationship between the rate of economic growth and variables representing the rate, allocation and efficiency of investment. Following Maurice Scott's lead, 3/ there is no "residual" or trend term in the relationship to account for technical progress.4/ It is not that technical progress is held not to occur, or that it is held to be possible without investment in research and development, but rather that it is reflected in people's abilities, including the abilities of those working in R and D, to find new forms of investment offering positive rates of return once the previous investments have become economically obsolete - for example, because of a rise in the costs of labor. Drawing on standard methods of investment analysis, the rate of economic growth is related directly to economists' measures of the rate and allocative efficiency of investment decisions. Further, it is shown that the technical progress "parameter" that appears in both the economists' models of growth, and their procedures for accounting for it, turns out not to be a parameter but a simple function of the variables noted in the title. The

1/ The literature of the subject is huge, and one necessarily must start with the papers of those who have reviewed it: e.g., Nelson (1981),Binswanger and Ruttan (1978), Kennedy and Thirlwall (1972), the long-standing survey of Hahn and Matthews (1967), and the readings in Sen (1970) and Stiglitz and Uzawa (1969). For historical and cross-country comparisons see Kuznets (1966); for a review of material and a study on Japan see Nishimizu and Hulten (1978),also Nishimizu and Jorgenson (1978) and Denison and Chung (1978); on US estimates, Denison (1962 and 1974); on US and Europe, Denison (1967); and on education, see Griliches (1970). A review is also provided in Maurice Scott's forthcoming book on growth. The preceding list is unavoidably selective, since the present paper is not a review; but the references cited in the papers of these authors together provide a comprehensive bibliography. E.g., Solow (1957).

2/ E.g., Solow (1957).


4/ As in any analysis, there may be a residual due to "errors and omissions" or random factors. But in the above analysis, the errors and omissions appear in the estimates of the rates of return, the rate of investment, or both.
The economic rate of return to investment is taken to be a measure of economic efficiency, and can be estimated by the familiar methods of micro-economic analysis; it is not difficult to reformulate the relationship in terms of the more general measure, the net present value of investment, and the choice of the former in this paper is a matter of convenience.

The analysis below departs in several respects from the types of analysis followed in a number of influential studies on the subject. But I am encouraged in the endeavor by the recent work of Maurice Scott, and by the proposals of others for an approach towards the analysis of growth according to the principles followed below. A further stimulus was provided by the recent critique of research on productivity growth by Nelson (1981), who called attention to the surprising fact that the role of efficient resource allocation, and of the numerous economic, social, institutional and political influences that bear on it, has been given little weight by economists in their theoretical and empirical work on growth over the past 25 years. He proposed that "the reallocation of resources ought to be seen as a key process in productivity growth which governs the pace at which potentialities opened up by new technology can be exploited" (op. cit., p. 1054). At the risk of lengthening the introduction, it is worth considering what other economists have proposed in a similar vein.

Relation to Other Methods of Studying Growth

Nearly twenty years ago, Johnson suggested that the influence of efficient resource allocation on growth would best be studied through "a generalized capital accumulation approach towards economic development," observing that:1/

The growth of income that defines economic development is necessarily the result of the accumulation of capital, or of "investment"; but "investment" in this context must be defined to include such diverse activities as adding to material capital, increasing the health, discipline, skill and education of the human population, moving labor into more productive occupations and locations, and applying existing knowledge or discovering and applying processes. All such activities involve incurring costs, in the form of use of current resources, and investment in them is worth while if the rate of return over cost exceeds the general rate of interest, or the capital value of the additional income they yield exceeds the cost of obtaining it. From the different perspective of planning, efficient development involves allocation of investment resources according to priorities set by the relative rates of return on alternative investments.

Similarly, Schultz (1970, pp. 301-2), who refers to Johnson and seemed to hope "that we have disposed of the residual", remarked that "the growth problem, thinking in terms of economic decisions, requires an investment approach to determine the allocation of investment resources in

1/ Johnson (1964, p. 221).
accordance with the priorities set by the relative rates of return on alternative investment opportunities. It is applicable not only to private decisions but, also, to public decisions ... for example, the investment in research where the fruits of it do not accrue to the individual researcher or his financial sponsor but are captured by many producers and consumers ... For particular investments, and there are many areas in the domain of human capital, the value of the resources added (services rendered) is exceedingly hard to come by. It is all too convenient to leave the hard ones out, yet each and every omission falsifies the true picture of the full range of investment opportunities."

In these remarks Johnson and Schultz are explicit about the crucial importance of a proper classification and enumeration of investment and consumption activities, a task taken up by Scott in the references cited. A large number (if not all?) of previous studies and the accounts data they use are shown to be faulty in this respect. Many expenditures commonly classified as consumption, including (but not only) so-called capital consumption or depreciation expenditures, turn out, on a closer inspection, to be a sacrifice of consumption intended to raise economic output; that is, they would be better classified as investments. As Scott remarks (op. cit., 1981, pp. 212-213):

"In a static economic all output would be consumed and investment would be zero. There would, of course, be expenditure on maintenance, but that should be regarded as part of the current costs of production. If output is to grow, the static economy must be changed. It seems to me that this will involve incurring expenditures which need not be incurred in a static economy, for the building of new buildings, roads, vehicles, machines, etc., and the improvement of existing ones, for moving labor from places where its marginal product is low to where it is high, for improving labor quality through better health, education and skills, for developing new products, processes, markets and sources of supply, and so on. All these changes are costly, and so involve a present sacrifice of consumption in the hope of subsequent gain."

While some of these expenditures, such as those on new buildings and machines, might be thought to be counted as investment in most studies, in practice they are often unwittingly netted out of the analysis by imprecise distinctions between maintenance and depreciation; and the frequent use of the latter as an estimate of the former again leads to underestimations of the proportion of gross investment that is, on closer inspection, devoted to introducing economic change and growth. It is true that some studies are more careful in this respect, but Scott's review shows that the issues remain important nevertheless.

Aside from the misclassification and underenumeration of investment activities, further errors arise from the neglect of changes in the occupations of the labor force brought about by material investment. Most studies attempt to allow for such changes, but only for broadly defined
occupations—e.g., for the movement of workers from agriculture to industry, defined at the one-digit level. The practice is broadly as follows.1/ The labor force is grouped according to the occupations, educations and ages of its male and female members. The contribution of labor to the growth of income is then taken to be a weighted average of the rates of change of the proportions of the labor force in each group, the weights being the average incomes of labor in each group divided by national income per worker. Then (i) if there is a net movement of workers from, say, agriculture to industry, with wages being higher in industry, there is a rise in income attributable to the redeployment of labor; (ii) if there is an increase in the proportion of workers in the higher paid, higher educated groups, there is a rise in income attributable to investment in education; (iii) if there is an increase in the average age, such that a greater proportion is in the higher paid age groups, there is a further rise attributable to the increased experience of the labor force; and (iv) if there is an increase in the proportion of women in the labor force, the average contribution of labor to the growth of income may be estimated to fall, since women, within any particular education-age-occupation group, are paid less than men.2/

It is apparent that a greater disaggregation of occupational or industrial groupings would show the rate of redeployment of the labor force, and the increases in income derived from redeployment, to be significantly greater than the analyses following the above approach have so far concluded. Take manufacturing activities for example, which are treated as a homogenous group in most studies. In the course of economic growth both the size distribution and the composition of activities change appreciably over time—e.g., from a concentration of employment in small scale cottage industries and workshops in food processing, textiles, wearing apparel and light engineering, towards a greater concentration on heavy engineering.3/ The earnings differentials between these activities for workers of a given age and education are often large, e.g., over a 2 or 3 to one range as between large and small firms in a given industry,4/ and it follows that an application of the above method of analysis would attribute some, if not a large share of the observed increases of incomes of labor in manufacturing to redeployment within manufacturing. Similar remarks can be made about changes in the scale and composition of activities within agriculture (arising, e.g., from changes in produce over time), commerce (arising from changes in the types and scales of retailing, wholesaling and banking activities for example), transport and construction. Furthermore, each generation of the labor force is continually redeploying itself through introducing new "high technology" industries and products in the industrialized countries, or

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1/ For a recent study see Nishimizu and Hulten (1978), and for an earlier one, see Denison (1967).

2/ Schultz has questioned this last view of women's contribution to the growth of economic output drawing attention to the "troublesome omission" of investment in females and by them in the upbringing of children (op. cit. pp. 297-306).

3/ On the structural changes see e.g., Chenery (1979), Staley and Morse (1965), Hoselitz (1959), Banerji (1978) and Anderson (1982).

4/ See e.g., Shinohara (1966) on wage differentials between large and small firms in Japan.
diversifying the industrial base in the developing countries. Insofar as the new industries are associated with higher earnings levels for workers in a given age and education group, a redeployment of the labor force towards them will again account for some of the observed increases of both labor’s income and value added.

It is unlikely, however, that a greater disaggregation of industries or occupations, say to the 4 or 5 digit level, would provide a satisfactory estimate of the rate of redeployment that takes place in a growing economy, even assuming the formidable difficulties of data compilation could be solved. The reason is that workers of a given age and education may be redeployed by material investment without changing their industry or occupation—or even their place of employment. In agriculture, for example, changes from rainfed to irrigation crops, from traditional to high yield seed-fertilizer varieties, from the use of bullocks to tractors, all bring about a redeployment of agricultural labor, often without changing the crop variety. It is not difficult to think of examples in other industries, each being associated with a change in the nature of work, economic output and ultimately labor’s income.

If further disaggregation will not provide the necessary information it is evidently desirable to consider another approach. As discussed later, the increases in labor’s income brought about by redeployment of the labor force within the principal economic sectors may be comparable to those brought about by redeployment between the sectors, and possibly greater. This is a conclusion of some practical importance, and has been recognized in the literature on development policy for some time (e.g., in the arguments for rural-led industrial growth). But it has yet to be reflected in growth theory as the subject has developed over the past 25 years, or in the methods used in growth accounting.

The approach proposed in this paper is based on the net present value of labor’s share in the value added by investments. This quantity provides a measure of the changes in labor’s income brought about by the redeployment of labor on the investments. It can be estimated from the series on value added and wages and salaries for each sector of interest; evidence from "samples" of investments in each sector would provide another source if project studies are available. As will be seen, it also fits quite simply into the resource allocation framework for the study of growth and development policies.

Organization of the Paper

To begin, Part II derives an aggregate form of the relationship drawing on Solow’s vintage model of growth, as expounded in his book on growth theory in 1970. This book contains a discussion of redeployment and wage determination in the presence of technical change, and which it will be helpful to lean on in Part III. The question is raised, what is the rate of return to investment implied by the vintage model? In striving to answer it, I arrive at an aggregate form of the relationship derived in Part III.

Part III shows that the rate of economic growth can be related to the following product: the rate of investment times a weighted average of the economic rates of return to investment taken over all economic sectors. The
weights are each sector's share in total investment times a factor representing the present value of labor's share in the output of the investment. The rates of return and the weights indicate the allocative efficiency with which capital and labor resources are deployed. Part IV, which discusses the applicability of the methods of micro economics to the analysis of growth, argues that the relevant rate of return is the social rather than the private return where the two differ.

Part V first compares the analysis with those of a number of influential and long-standing growth accounting studies, such as those of Kuznets and Denison. It then considers data on investment and growth for some industrialized and developing countries, and asks if the economic rates of return implied by the relationship are implausibly high, as Denison and others have suggested they would be. In this I am again following Maurice Scott's lead, and reach the same conclusion. Part VI considers the question, does the absence of a residual (since there is none in the accounting definitions used in this paper) imply no technical progress? and, by reference to Solow's vintage and non-vintage models, concludes that it does not. Part VII presents the conclusions.

II - AN AGGREGATE FORM OF THE RELATIONSHIP
BASED ON SOLOW'S VINTAGE MODEL OF GROWTH 1/

In this model, technical progress is assumed to be labor augmenting, increasing output per worker at a given rate denoted by 100 b percent per year. The output per worker for an investment introduced in year v would then be $b_0(1 + b)^v$, where $b_0$ is the output in the base year. (I have changed Solow's notation slightly, and am working with discrete, one year time intervals instead of continuous time.) The output per worker in the oldest vintage of investments (age n) in the economy would then be $b_0(1 + b)^{v-n}$ while that of some intermediate vintage would be somewhere in between this and $b_0(1 + b)^v$. This is illustrated in figure 1, which shows the output per worker for different vintages from ($v-n$) to $v$, arranged in ascending order of their outputs per worker. The labor force in $v$, denoted by $L_v$, is deployed on these various vintages of plant as indicated on the horizontal axis; the total output in the economy is represented by the area under the (stepped) curve, and the quasi-rent on any given vintage of plant is, by definition, the difference between the total output on that vintage and the wage bill, again as indicated.

To continue the analysis, if a new vintage of investments is introduced in the following year with outputs of $b_0(1 + b)^{v+1}$, they would, on these assumptions, have higher quasi-rents. If the labor force were either fully employed, or alternatively if the labor requirements of the new vintages exceeded unemployment levels plus the number of new entrants to the labor force, then labor would have to be redeployed from existing investments. As Solow explains, in any competitive economy, or in any planned economy maximizing output per worker, they would become redeployed from the oldest investments, which would be duly retired. Further, in a competitive economy, wages would be bid up to the point where the quasi-rents of the oldest (marginal) investments remaining in operation were zero (or close to zero). That is, the output per worker on the oldest investments determines the wage rate, which rises whenever those investments are displaced by, and labor is redeployed on, new investments. In explaining this, Solow considers the case history of a single factory as follows:2/

"when it is new it earns profits equal to the difference between its productive capacity and its wage bill. As it ages, its productive capacity is unimpaired and its output per man is unchanged. But if, as is normal, the real wage rises through time because of technological progress and the competition of newer and more efficient factories, its bill will rise and its profits will diminish. Eventually the wage rises as high as the output per man in this factory and it has become the marginal no-rent factory. Let the wage go a touch higher, and this factory goes out of business; it has become obsolete, not because of any reduction in its efficiency, but because the rising real wage has rendered it incapable of covering its own variable costs of production."

1/ As presented in Chapter III of his book in 1970. A note on his earlier non-vintage model is provided in Part VI of this paper.

2/ op. cit., p. 47.
Figure 1:
Solow's Vintage Model: Employment, Productivity, Wages and Quasi-Rents for Successive Vintages of Investments

Value added (net of maintenance) per worker

bV(1 + b)\textsuperscript{t}

bV(1 + b)\textsuperscript{t-n}

Quasi-Rents

Wage Bill

\( L_v \) (no. workers employed in \( v \))

\( \Delta E_v \) (no. deployed on new vintage)

Figure 2:
As above, but with low rates of redeployment of the labor force on new investments (Large shares of labor force on "old" vintages)

Value added (net of maintenance) per worker

\( L_v \) (no. workers employed in \( v \))

\( \Delta E_v \) (no. deployed on new vintage)
The only point one might add to this is that "old" factories may continue to operate in these circumstances by introducing the new methods of production, i.e., new vintages, themselves—that is, by redeploying their own workers. As noted in the introduction, it is these changes that growth accounting studies commonly neglect.

It is of course possible that the technological characteristics of new investments may be such that they redeploy very little labor (the new "blocks" in figure 1 becoming increasingly narrow and tall). In this case the wage rate would barely increase. If in addition the labor force is expanding quickly, the majority of its members may be working with exceedingly old methods of production with low levels of labor productivity, as illustrated in figure 2. This is indeed the situation of many developing countries today, as one might gather from the extensive literature concerning the choice of "appropriate" technologies and the case for more labor demanding investment incentives in industry and agriculture. For the moment, however, let us proceed with the conditions where real wages are rising and labor is being redeployed from the older, lower productivity investments, which are being displaced.

We now consider the question, what is the rate of return to investment implied by Solow's vintage model? To answer this it is necessary to compare the present worth of the quasi-rents with the investment costs. To simplify algebra, the lead time of investment is ignored. For investments introduced in year \( v \), the present worth of quasi-rents per worker employed on them at a discount rate of \( r \) per year, is given by:

\[
\frac{b_0(1+b)^v}{(1+r)^v} \sum_{t=1}^{n} \left( \frac{(l+b)^t}{(1+r)^t} \right) \sum_{t=1}^{n} w_t (1+r)^{-t}
\]

From the above explanation of wage determination in the vintage model, the wage level in any period is causally related to the rate of investment. In the present case:

\[
w_{t+v} = b_0(1+b)^v (1+r)^{-n}
\]

that is \( w_{t+v} \) is determined by the output per worker of investments about to be retired as a result of the new investments. On substituting for \( w_{t+v} \) in the previous expression, it becomes apparent that the ratio of the second term to the first term, that is to say, the PW of labor's share in the value added by the investment taken over the lifetime of the investment, depends only on \( b \), and under conditions of steady growth is constant. Let us denote this ratio by \( \lambda' \).

Inclusion of lead times in the analysis is discussed in Part III.

It is apparent that there is a close relation between \( \lambda' \) and the more commonly used quantity, labor's share in current output which is denoted in this paper by \( \lambda' \). After substituting for \( w_{t+v} \) and simplifying (the \( \Sigma \)'s are over 1 to n):

\[
\frac{\sum_{t=1}^{n} \sum_{t=1}^{n} \frac{(1+b)^t}{(1+r)^t}}{[\sum_{t=1}^{n} (1+r)^{-t}][1+b]^n}
\]

For relatively slow rates of growth of the labor force, labor's share in current output turns out to be (the \( \Sigma \)'s are again over 1 to n):

\[
\lambda' = \frac{nb_0(1+b)^v}{\sum_{t=1}^{n} \sum_{t=1}^{n} (1+b)^v} = \frac{n}{[\sum_{t=1}^{n} (1+b)^v]}[1+b]^n
\]

For given \( r \) and \( b \), the ratio of \( \lambda' \) to \( \lambda \) is constant. A more precise expression is given in the following footnote.
(Note that even if growth is not steady, there is still a causal relationship between the two terms on account of investment's influence on wages and thus on labor's share in value added; in Parts III and V further use is made of this relationship.) Hence the expression becomes:

\[(1-\lambda) b_0 (1+b)^V \sum_{t=1}^{n} (1+r)^{-t} \]

To obtain the total investment per worker in \(v\), it is first necessary to determine the total output per worker and multiply this by the rate of investment, denoted here by \(i\). In turn, this requires some assumptions about how the labor force employed in \(v\), denoted here by \(L_v\), is deployed on the various vintages of investments. Let \(c\) be the rate of growth of the employed labor force and \(E_v\) the number employed on the vintages introduced in \(v\). Then

\[
L_v = \sum_{t=1}^{n} E_{v-t}
\]

If we take the case where the rate of redeployment \(E_v/L_v\) is constant, we can write \(E_{v-t}\) in the form \(E_v(1+c)^{-t}\). Substituting into the above expression and summating the series gives:

\[
E_v = cL_v/(1 - (1+c)^{-n})
\]

\[
\approx (1/n)L_v, \text{ if } c \text{ is small.}
\]

The total output in \(v\) is equal to the total output per worker on each vintage of plant in use in \(v\), namely \(b_0(1+b)^{-t}\), multiplied by the number of workers on each vintage, namely \(E_{v-t}\), added up over all vintages \(t = 1,...,n\). The total investment in \(v\) is then the resulting expression multiplied by \(i\), namely:

\[
i \sum_{t=1}^{n} b_0(1+b)^{-t} E_{v-t}(1+c)^{-t}
\]

1/ This expression is consistent with one of the "stylized facts" of growth with which Solow is concerned, namely the approximate constancy of labors' share over time. At time \(v\), the wage bill is given by:

\[
b_0(1+b)^{-n} \sum_{t=1}^{n} E_v(1+c)^{-t}
\]

while total output is given by:

\[
\sum_{t=1}^{n} E_v(1+c)^{-t} b_0(1+b)^{-t}
\]

Taking the ratio and simplifying leads to the following expression for labor's share:

\[
= (1+b)^{-n}(1-(1+c)^{-n})(b+c)/c(1-(1+b+c)^{-n})
\]

which reduces to the expression in the previous footnote for small \(c\).

As discussed in Part I, the rate of redeployment \(E_v/L_v \approx (1/n)\) may significantly exceed the rate of growth of the labor force, \(c\), in regions of economic growth. E.g. in high growth economies, the average lifetime of investments may be in the range 10 to 15 years, from which the rate of redeployment of the labor force (under the conditions assumed) would be around 7 to 10% per year.

2/
The present worth of total output from the investment, on the other hand, is \((1)\) multiplied by the number of workers engaged on it, \(E_y\). If we now choose the discount rate such that it is the same as the rate of return on the investments, then by definition of this quantity we can set \((2)\) equal to \((1)\) times \(E_y\); that is, we choose \(r\) such that the present worth of the quasi-rents from the investments equals the costs of the investments. Doing this, using the approximation \((1+b)^{-t}\) \((1+r)^{-t}\) \((1+b+r)^{-t}\), and rearranging leads to

\[
(b+c) = g = \sigma r / (1 - \lambda) \tag{3}
\]

where \(\sigma = (1-(1+g)^{-n})/(1-(1+r)^{-n})\)

and \(g\) is the rate of economic growth. (The term in the numerator of \(\sigma\) represents the loss of output from the retirement of old investments, and the denominator the "end correction", familiar from project analysis, which allows for the discounting of the output of investments over a finite lifetime. To a good approximation \(\sigma\) is likely to be a constant even when \(r\) and \(g\) change slowly \(1_/\), and we will refer to it, perhaps imprecisely, as a parameter.)

Hence we have an accounting identity in which the rate of economic growth is related to the rate of investment, the present worth of labor's share in the value added by investment, and the economist's commonly used measure of economic efficiency, the rate of return to investment. In earlier growth accounting studies, the "contribution" of investment was taken to be given by the product \(ir\), but as will be discussed in Part \(V\), this significantly understates investment's contribution to growth because a cross-derivative, namely the change in labor's income brought about by investment, is neglected. In other words, the product \(ir\) is based on the partial derivative of the increase in output with respect to investment, holding labor's income constant, while \((3)\) is based on the total derivative, in which the change in labor's income induced by investment is included. This is the reason why the term \((1-\lambda)\) appears in the denominator above.

The preceding relationship is obviously too aggregative to apply to examine the influence of resource allocation on growth. The lead times of investments have also been neglected. Consider now how these limitations might be addressed.

\(1_/\) \(r\) and \(g\) also move in the same directions.
III DERIVATION OF THE RELATIONSHIP

The Relationship Based on Some Simplifying Assumptions

In the following analysis, the level and change in economic output (value added) is considered to be the aggregate of the levels and changes in the output of all investments in use in an economy. Throughout, the analysis allows for changes in relative prices but ignores inflation or deflation; that is, it is couched in terms of "real" prices. To begin, it is also convenient to introduce the following simplifying assumptions:

- the case where the cost and revenue streams of an investment provide a satisfactory basis for estimating its contribution to economic output. That is, consumers' surplus, externalities, and distortions in the pricing system are at first ignored and discussed later (in Part IV);
- the revenue and cost streams have a fairly simple form;
- departures between ex post and ex ante returns are ignored, and the analysis at first concentrates on ex post returns only.

Let $X_{tv}$ denote the gross output of an investment in year $v$, and $a_{tv}$ the sum of material inputs and maintenance costs per unit of output. Alternatively, $X_{tv}$ can denote a group of comparable investments within a narrowly defined sector, with $v$ again being the year in which they are brought into service. Later we shall identify such a sector by introducing an additional subscript, $j$; but to economize on notation, the subscript is not introduced until needed. Then the contribution of the investment to value added in year $t$, denoted by $Y_{tv}$, is given by:

$$Y_{tv} = (1 - a_{tv}) X_{tv}$$

Similarly, let $E_v$ be the number of people employed to produce output from the investment. They may include one or more of the following:

- new entrants to the labor force and employed for the first time as a consequence of the investment;
- people who have been redeployed within their present places of work to use the investment; e.g., those previously making products, providing services or using technologies and methods of organizing their work that have been changed by the investment;
- people redeployed from other occupations or places of employment and who may or may not have been unemployed during the transition.

In any economy in which the productivity of a large proportion of its labor force is rising it is likely that the rate of redeployment would be far greater than the rate of increase in the labor force, since even quite minor investments may introduce changes in the nature of the work and in the productivity of people already
employed, as noted in the introduction.

If then \( w_{tv} \) represents the average annual earnings per person employed on the investment, the net revenues (quasi-rents) in each year are given by:

\[
(Y_{tv} - E_v w_{tv})
\]

For fixed assets, the investment expenditures are often incurred over several years, or over what is sometimes called the lead time or gestation period of the investments. Let the total investment over this period be denoted by \( I_v \). Most series on investment expenditures do not include what in physical investment is often termed "interest during construction", or perhaps more simply as the costs of financing the investment expenditures during this period. These costs are simple to estimate however from a knowledge of the profile of investment expenditures over time. Expressing them in per unit terms by dividing by \( I_v \), and denoting the resulting ratio by \( f \), then by definition the discounted value of the investment expenditures, referred to the time when the investment is brought into service, is given by \((1 + f)I_v\)

Denoting the rate of return to the investment by \( r \), then by definition of this quantity:

\[
(l + f)I_v = \sum_{t=v+1}^{v+n} Y_{tv} (1+r)^{-(t-v)} - \sum_{t=v+1}^{v+n} E_v w_{tv} (1+r)^{-(t-v)}
\]

where \( n \) is the economic life of the investment, and is determined by the time at which the quasi-rents have declined to zero. Note that since \( Y_{tv} \) is net of maintenance costs the relevant measure of \( I_v \) to be used in the above relation is gross investment. \( \text{I/} \)

To put the equation into a form where it can be manipulated for use in the analysis of growth it is helpful to introduce some approximations with respect to the variations over time of revenues and costs. There are obviously a large number of possibilities, but the profiles shown in figure 3 capture the main elements of most, which are the lead time (or construction or gestation period), the rise and then the decline of value added and quasi-rents, and finally the retirement of the investments. If the data were available for samples of actual investments from each economic sector, it would be possible to work with the actual profiles in equations of the above form, and use the methods of numerical analysis to estimate the contribution of the investments to the growth of output. But in the absence of this, it is easier to work with the stylized version shown in the lower of the two diagrams. In this version, \( Y_{tv} \) is constant over the period \( v+1 \) to \( v+n \) and is now denoted by \( Y_v \); it is the value added by the investments after they have been fully brought into service.

In figure 3, the wage bill is also taken to be rising over time such that, eventually, the quasi rent declines to zero and the investment is retired. The quasi rents may of course decline for other reasons - changes in the relative prices of material inputs, for example, or due to changes in demand. But for the moment, let us concentrate on wages. The basic assumption is that, as in Part II, new investments are being introduced in times \( t>v \), labor is being redeployed on them

---

\( \text{I/} \) In this I am following Maurice Scott (1981, and in his forthcoming book).
Figure 3:
Variations Over Time of Costs, Gross Output, Intermediate Inputs, Value Added, Wage Bill and Quasi-Rents of an Investment

ACTUAL VARIATIONS:

STYLISTED FORM OF ABOVE:
from old investments, whose quasi rents have declined to zero, and the wage levels are related to the output per worker on these old investments.

As noted in the introduction, this process of redeployment has two components. The first is redeployment within sectors, as labor moves from the use of old to new vintages of investments; the second is redeployment across sectors as a consequence, for example, of the emergence and growth of new kinds of economic activities and products and the displacement of old ones. Both may be associated with changing shares of the labor force in the various sectors of an economy. Thus the number of workers deployed on a new investment in a particular sector, denoted above by $E_v$, will generally differ, except by chance, from the number of workers deployed on investments in the same sector $n$ years earlier, $E_{v-n}$, and which are about to be retired. A lot will depend, of course, on the nature and extent of structural changes taking place in an economy. Thus $(E_{v-n} - E_v)$ would be redeployed elsewhere if $E_{v-n}$ exceeds $E_v$, as happens for example in agriculture as industrialization proceeds in developing countries; while $(E_v - E_{v-n})$ would be redeployed from elsewhere if the sector is expanding relative to others. But for our present purposes, the important point is that, as a consequence of this process of redeployment, the wage bill is taken to rise over time on any particular vintage of investment (in regions of economic growth) and the quasi rent to decline as indicated.

As in Part II, let $\lambda$ denote the present value of labor's share in the value added by the investment, using $r$ as the discount rate. It is the second term divided by the first on the RHS of the above equation. The above expression then becomes (after substituting for $Y_v$ and simplifying):-

$$ (1+f) I_v = (1-\lambda) Y_v \frac{(1-(1+r)^{-n})}{r} \tag{4} $$

As the quantity has been defined above, $Y_v$ is strictly the gross increase in value added, net of maintenance costs, in year $v$. To arrive at the net increase in value added (net of maintenance costs) it is necessary to deduct from this the value added by the investments that are to be taken out of service in $v$ as a consequence of new investment. For such investments, the quasi-rents would have declined to zero, and their total value added (net of maintenance) would just be sufficient to cover labor costs, as indicated in the lower diagram of figure 3. In practice few investments are retired so abruptly but rather are "run down" towards the end of their economic lifetime, with the labor working on them being gradually redeployed to other, generally newer investments. Hence just before retirement they may be generating little or no output and providing little or no employment at all, as indicated in the upper diagram. However, in the years preceding retirement both the value added and net revenues would be declining, and it is necessary to make some allowance for this. The required allowance depends on the nature of the economic changes taking place in the sector over the period of interest.

If for instance there has been a period of steady growth in the industry or sector in question, at a rate of 100g % per year, then the output of investments introduced $n$ years earlier, and which are about to be retired, would have been $(1+g)^{-n}$ times that of current investments. Hence the net increase in value added in year $v$, denoted by $Y_v^*$ would be:

$$ Y_v^* = (1 - (1+g)^{-n}) Y_v $$

This is the same term that appeared in the elementary manipulation in Part II of
Solow's vintage model of growth; for convenience it is used in the analysis of this paper, but with the following qualification.

This is that, if the growth rate and the economic lifetimes of investments are changing in a particular sector - as of course they do in conditions of rapid structural change - the above term is at best an approximation. Moreover, and particularly in developing regions, net increases in value added may be discontinuous and not simple to formulate algebraically: e.g. the transition from traditional seed varieties and methods of cultivation in rural areas, in which \( g \) may have been zero and \( n \) large over a long period, to high yield seed-fertilizer varieties, irrigation and more mechanized methods of cultivation, in which \( g \) is positive and \( n \) relatively short. If we are concerned with the analysis of growth over relatively short periods, say of about 20 years, then it may be possible to take \( g \) and \( n \) to be approximately constant over those periods. If not, however, or if changes have been more abrupt, then there would seem no alternative than to examine the rate of retirement of investments directly, along with the influence of this on the net increase economic output.

Substituting for \( Y_v^* \) and rearranging (4) we then have:

\[
Y_v^* = I_v \cdot \sigma/(1-\lambda) \tag{5}
\]

where \( \sigma = (1+f)(1-(1+g)^{-n})/(1-(1+r)^{-n}) \), and is similar to the term defined in Part II, differing only because it now allows for the financing costs associated with the gestation period of the investment.

To proceed from (5) to the relationship we are seeking, it is necessary to consider how the total expenditures, \( I_v \), on investments brought into service in \( v \), are related to the annual rate of investment. The reason is essentially an operational one in that series are usually published on the latter but not on the former quantity; otherwise, we could proceed with the analysis using \( I_v \) as defined above. Using the annual rate of investment unavoidably introduces some approximations into the analysis. Where it might be felt that the approximations discussed are unreliable, the right approach would be to reclassify annual investment expenditures for the industry or sector in question according to the vintages of the investments with which they are associated. Since this evidently would be an arduous task, it seems appropriate to search for some procedure that would permit the use of existing series while making clear the nature of the approximations involved.

The difficulty arises from the point that in any year \( t \), and for any particular sector, investments will be in progress whose first year of output will be \( t+1 \) for those nearing completion, \( t+2 \) years later for those just being started, and \( t+2 \) to \( t+2-1 \) years later for those at some intermediate stage. Suppose the investment expenditures, \( I_v \), are distributed over the gestation period according to the shares \( a_1, a_2, \ldots, a_k \), with \( a_1 + a_2 + \ldots + a_k = 1 \), so that \( a_1 I_v \) are the expenditures (excluding financing costs) in the first year, \( a_2 I_v \) are the expenditures in the second year, and so forth. (In the stylized form of figure 3, all the \( a \)'s are equal; but this approximation is not used below.) If the \( a \)'s are similar for investments brought into service over the years \( v-k+1, \ldots, v, \ldots, v+k-1 \), then the following are the annual investment expenditures, denoted by \( I_v^* \), over the period \( (v-k+1) \) to \( v \):-
The RHS of each of these expressions is of the order of $I_v$, since the a's add up to unity, the first being somewhat greater than $I_v$ if investment in the sector or industry is expanding, the last being correspondingly less; and conversely if it is contracting. This suggests the approximation, after adding the expressions together and dividing by $\ell$:

$$I_v \approx \frac{1}{\ell} (I_{v+1}^* + I_{v}^* - \cdots - I_{v-\ell+1}^*)$$

That is, $I_v$ corresponds approximately to the average annual level of investment in the sector over the period spanned by the lead time of the investment. We denote this quantity by $I_v^*$. 

Substituting for $I_v$ in (5) we now have

$$Y_v^* \approx I_v^* r \sigma/(1-\lambda)$$

The sum of $Y_v^*$ over all sectors of economic activity represents the net increase in economic output in the economy in year $v$, while the sum of $I_v^*$ over all sectors represents total investment. Introducing the subscript $j$ to denote sector $j$, noting that $r, \sigma, \lambda$ and $I_v^*$ all may differ between sectors, and adding over $j$:

$$\sum_j Y_v^* = (\sum_j I_v^*) \sum_j \{I_v^*/\sum_j I_v^*\} r_j \sigma_j/(1-\lambda_j)$$

The first term within the summation is evidently the share of the sector in total investment over the period ($v-\ell+1$) to $v$, which we denote by $s_j$. Dividing through by the total value added in the economy in $v$ gives:

$$g = \frac{1}{\sum_j r_j s_j \sigma_j/(1-\lambda_j)}$$

where $g$ is the rate of economic growth and $i$ is a measure of the average rate of gross investment.

This is the relationship noted in the introduction. Before relaxing the simplifying assumptions stated earlier, to arrive at a more general form of (6), it might be helpful to comment on the behaviour of the relationship when the variables on RHS are changing over time. In growing economies the variables that perhaps change most noticeably are the sectoral shares and the relative rates of return to investment, so we confine our attention to these.

**Structural Change in the Relationship**

The term structural change is commonly associated with changes in the shares of output, employment and investment in the various sectors of economic...
activity 1/, for example the rise in industry's shares with growth and the fall in agriculture's shares. It may also occur within sectors such as with the growth of 'heavy' relative to 'light' industry as industrialization proceeds, and with the emergence of new industries and products that had not existed previously.2/ With sufficient disaggregation, many of these changes within sectors would be re-classified as cross-sector changes and would become apparent, in the above relationship, in the relative values of the $s_j$'s.

Two types of structural change are illustrated respectively in figures 4 and 5. The first is one in which one kind of economic activity or method of production is contracting and being displaced by another, which is expanding. Examples might be the replacement of steam by electric power in factories, of draft-animals by tractors in agriculture, and of sea-passenger by air-passenger transport. In the second, one industry is maturing and is either constant in size or expanding only slowly relative to a newly emerging high growth industry.

In the first example, the variations in gross output over time in the two industries are shown in figure 4a, and the schedules of new investments in years $v$ and $v+1$ are shown below it in 4b. These schedules represent the rates of return to investments introduced in years $v$ and $v+1$, ranked in descending order of their rates of return. Since figure 4b is for a contracting industry, the schedule for year $v+1$ is shown below that for year $v$; the opposite applies to the schedules shown in figure 4c for the expanding industry. Note that in the former case, new investment possibilities are taken to exist for a period even though the industry is contracting; that is, the investment schedule is assumed to decline steadily rather than to vanish or fall abruptly below the opportunity cost of capital.3/

What happens to the rates of return to investment in the two industries? If capital markets are functioning efficiently and investors make decisions according to the expected rates of return to investment, the ex ante returns on the marginal projects in the two industries would be the same and equal to the opportunity cost of capital (shown as $r$ in the figures). Ex post returns will generally differ from these, however, for the obvious reason that perfect forecasts are impossible; but if the forecasts on which the investment decisions were based are unbiased, then over a period one might expect the ex post returns on the marginal projects in the two industries to be equal on average.

The above relationship, however, is concerned with the returns to all investments in each industry in the years in question rather than with the marginal returns. In other words it is better to think of the $r_j$'s as being average values. This variable may of course differ appreciably between sectors even when marginal values are comparable, but in a way that is difficult to determine theoretically. Intuitively, in a rapidly expanding industry one would generally expect the average returns to be higher, that is, for the investment schedules shown in figure 4c to be steeper. If in addition there are uncertainties and difficulties in transferring finance to the new industries, there may be a rental element, which would tend to raise further the average rates of return in the expanding industry relative to those in the contracting industry.

1/ See e.g. Chenery (1979) and Kuznets, op.cit. 1966.
3/ This again seems to be a matter of experience. Ibid.
Figure 4

(a) Gross Output

(b) Investment Schedules of Contracting Industry

Rate of Return to Investment

Year v

Year v + 1

Opportunity Cost of Capital

(c) Investment Schedules of Expanding Industry

Rate of Return to Investment

Year v + 1

Year v

Opportunity Cost of Capital

Figure 5

(a) New "High Growth" Industry

"Maturing" Industry

(b) Investment Schedules of "Maturing" Industry

Rate of Return to Investment

Year v

Year v + 1

Opportunity Cost of Capital

(c) Investment Schedules of New Industry

Rate of Return to Investment

Year v + 1

Year v

Opportunity Cost of Capital

World Bank—24713
Turning to the second case, in which one industry is "maturing", the difference is that innovation continues in this industry and, with it, the possibilities remain for new investment with rates of return greater than the opportunity costs of capital. That is, the investment schedule may not contract significantly; it may even move outwards, as in figure 5b. The associated changes in the investment shares are obviously less than in the first case. The points to be made about relative rates of return are similar.

A More General Form

So far the cost and revenue streams of investments have been taken to have a simple form, with the yearly value added by each investment being constant over its economic lifetime once it has been brought into service. Furthermore, the only changes in relative prices that were considered were those between labor and all other inputs and outputs. These obviously restrictive assumptions need to be removed:

- the value added each year by any investment may change appreciably over economic cycles, and also exhibit some randomness (e.g. on account of the weather's influence on crop and energy prices); it may also change over time with "learning by doing" and with the experience of the labor force working on the new vintages of investments;

- changes in the terms of trade affect the relative prices of inputs and outputs for many commodities and services;

- scarcities may develop in the supply of certain factors;

- innovation may change the relative prices of several inputs and outputs.

In addition, the analysis was concerned with the rate of growth of output at a particular time. Studies of growth however are usually concerned with the underlying rate of growth of economies over long periods, in which \( r, s, \lambda, i \) might vary appreciably. Hence it is necessary to reformulate the relationship in more general terms.

To begin, the accounting identity given in (4) can be rewritten in the form:

\[
(1 + f_v) I_v = (1 - \lambda_v) \sum_{t=v+1}^{v+n} Y_{tv} (1 + r_v)^{-(t-v)}
\]

where, to be general, subscripts \( v \) have been attached to those quantities that may vary between vintages of investments. The possibility of variations over time in the output of an investment of vintage \( v \) are acknowledged by reintroducing the subscript \( t \) in the variable \( Y_{tv} \). As before, the subscript \( j \) is omitted until needed.

To simplify the term on the RHS, we can define a weighted average value of \( Y_{tv} \), denoted by \( \hat{Y}_v \), as follows, in which the discount factors are the weights:

\[
\hat{Y}_v = \sum_{t=v+1}^{v+n} \frac{Y_{tv}}{(1+r_v)^{-(t-v)}} = \sum_{t=v+1}^{v+n} Y_{tv} (1+r_v)^{-(t-v)}
\]

where, to be general, subscripts \( v \) have been attached to those quantities that may vary between vintages of investments. The possibility of variations over time in the output of an investment of vintage \( v \) are acknowledged by reintroducing the subscript \( t \) in the variable \( Y_{tv} \). As before, the subscript \( j \) is omitted until needed.
Note that $\hat{Y}_v$ is approximately equal to the average output of the investments over their lifetime, which is denoted here by $\bar{Y}_v$. Using this approximation in (7) and simplifying gives:

$$r_v(1 + f_v)I_v \equiv (1 - \lambda_v)\bar{Y}_v (1 - (1+r_v)^{-\lambda_v})$$

Previously it was also shown that $I_v$ might be approximated by the average rate of investment over the years $v-\lambda_v+1$ to $v$, denoted by $I_v^\star$. An adjustment was also made in the relationship to allow for the output no longer provided by those investments displaced by the new vintages. The adjusted value of $Y_v$ was denoted by an asterisk. Making the same adjustment to $\bar{Y}_v$ gives:

$$\bar{Y}_v^\star \equiv \bar{I}_v^\star r_v c_v/(1-\lambda_v)$$

Re-introducing the subscript $j$, and adding over all sectors:

$$\sum_j \bar{Y}_v^\star \equiv \sum_j \bar{I}_v^\star \sum_j \bar{I}_v^\star r_j c_j^{jv} (1-\lambda_j^{jv})$$

Dividing through by current output in year $v$, the LHS gives the proportionate increase in average value added associated with investments introduced in year $v$. It follows that if we summate over a long interval, say $v = 1 \ldots T$ years, this is the same as the average annual rate of growth over the interval times $T$; denoting this by $g$ gives:

$$g = (1/T)\sum_{v=1}^{T} i_v \sum_j c_j^{jv} s_j^{jv} r_j^{jv} (1-\lambda_j^{jv})$$

where $i_v$ is the rate of investment in $v$.

In this relataionship, changes in relative prices (e.g. those arising from changes in the terms of trade, factor scarcities or innovation) should become apparent in changes in the rates of return to investment. Depending on their incidence, changes in sector shares in total investment and in labor's share in output may also occur. Changes induced by economic cycles and, particularly in LDCs, by yearly variations in agricultural output, would probably be associated with changes in both the rate of investment and the rates of return to investment.

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1/ To show this, write

$$Y_{tv} = \bar{Y}_v + \Delta Y_{tv}$$

where $\Delta Y_{tv}$ is the deviation of $Y_{tv}$ from its average value. By definition:

$$\sum \Delta Y_{tv} = 0$$

which suggests the approximation:

$$\sum \Delta Y_{tv} (1+r_v)^{-(t-v)} = 0$$

from which it follows $\hat{Y}_v \approx \bar{Y}_v$. 
IV MICRO-ECONOMIC ANALYSIS AND
THE ANALYSIS OF GROWTH

The following discussion first considers the methods of marginal
analysis, and then the procedures for dealing with non-marginal changes.

Marginal Analysis

As a starting point for discussion, we might note Nelson's 1/ recent
objections to the application of marginal analysis to the analysis of growth:

"When the changes in question are large, marginal analysis may be
misleading. Thus, factor prices measure the contribution of a factor
at the margin. However, growth accounting usually has been concerned
with changes over a considerable interval of time. The fact that the
yearly percentage increases in labor, capital and gross national
product are typically quite small should not obscure the fact that,
even over a period as short as a decade, the percentage changes are
substantial.....

"If factors are complements, growth is super-additive in the sense
that the increase in output from growth of inputs is greater than the
sum of increases in output attributable to input growth, calculated
one by one, holding other inputs constant at their base level in each
sub-calculation. The growth of one input augments the marginal
contribution of others. Where complementarity is important, it makes
little sense to try to divide up the credit for growth, treating the
factors as if they were not complements."

Scott makes a similar observation with respect to the complementarities
between physical investment and R & D: 2/ "If R & D is just an element in a
total package, all of which is essential, then it is the total package and not
just R & D to which growth must be attributed."

There seem to be three problems here. First, many investments are
in fact large when accumulated over a long period; this question is discussed
in the next section. Second, marginal analysis does not seem to deal
satisfactorily with complementarities. Third, and partly on account of this,
estimating the changes in output associated with the change in each input in
an economy, and summing over inputs may not give a correct estimate of the
total change in economic output. Nelson refers to this third problem as "the
adding-up problem" and, since the summation procedures in Part III appear to
be at variance with Nelson's argument, this problem ought to be addressed.

One answer to Nelson's difficulties with marginal analysis is that
marginal analysis does not necessarily have to rest on the assumptions of
partial analysis. That is, it is possible to take the total rather than the

partial derivative when estimating the effects of investment on output. This was essentially the procedure followed in Part III, in which the accounting identities used included two terms, one being the present worth of quasi-rents generated by the investments, and which are the returns that would be estimated by an analysis of partial effects, the second being the change in labor's income brought about by the redeployment of labor to new vintages of investments in the same or other sectors. As will be seen in Part V, a similar result emerges when we take the total derivative of output with respect to change in capital stock, assuming that the labor's income is not independent of the change in capital stock.

Marginal analysis is similarly adaptable to the study of the effects of investments in complementary activities on the output of the activity in question. Further, it turns out that it is sometimes more difficult to analyse investments holding other inputs constant since the analyst may be faced with the tasks of estimating the scarcity prices arising from any bottlenecks that might have developed. Consider, for example, the analysis of the returns to investment in agriculture. If for some reason there had been significant underinvestment in crop processing services, or alternatively in the provision of fertilizers and farm equipment, then there would be a rationing element in the prices of such services and inputs, and the returns to investments in agriculture would be lower than otherwise. If on the other hand the complementary investments were made, it would be sufficient to allow for them by valuing inputs at marginal cost, including their long-run elements, the marginal cost of the investments.

It follows that, except for large investments, it is not incorrect first to consider each investment's contribution to output on its own account, and then to summate over all investments to obtain their total contribution, as was done in Part III. So long as we are concerned with their total and not their partial effects, this aspect of the "adding up" problem, as Nelson subtitled the passages from which the above remarks were taken, seems to be answered. For the case where prices reflect marginal costs among the investments under analysis, including prices of the outputs of any upstream or downstream investments, the answer is to be found in the cost-benefit literature regarding the treatment of secondary effects. Prest and Turvey 1/ consider an example in which several investments are indubitably complementary, being those of farmers, millers and bakers to produce bread. In this example they were also concerned with the treatment of one non-marketed input (irrigation water). But here it is sufficient to concentrate on the other aspect of their analysis, which is whether, in examining the returns to the farmers' investments it is necessary to include the returns to those of the millers and bakers on the grounds that these "stem" from the farmers' investments. Do estimates of the private returns to the farmers' investments (assuming prices everywhere = marginal cost), understate their overall contribution to output and, if so, should we compare the value of the final product (bread) with the combined costs of all three activities? Or can we first estimate the returns to each separately, and add up later to determine their total contribution to output?

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1/ In their survey in 1966, p. 161-162. See also Turvey (1974).
The answer is that, with a properly functioning price mechanism, the result would be the same. In this circumstance, the mechanism is performing the job of imputing values to the final and various intermediate inputs, and regulating the final demand and the derived demands at each stage of production such that prices = marginal values = marginal costs. If we were estimating the contribution of investment to output at each stage of production, and adding up later, we would be using these prices, while if we were working with the consolidated account, we would be using marginal costs. It is then a tautological exercise to show that the result is the same in both cases.

The question arises, what if prices do not equal marginal costs, for example because of monopolistic practices in certain industries, the structure of taxes and tariffs in an economy, or because the currency is overvalued? Further, what if there are external costs to an investment? Or, to turn to a different example, what if its output is not marketable, such as happens with public goods and certain types of R&D? It would be beyond the scope of this paper to present a satisfactory discussion of these questions, on which guidance should be sought in the literature on cost-benefit analysis. Although this literature is for the most part concerned with ex ante analysis, there seems no objection in principle to applying the methods recommended to ex post analysis. For the present purposes of this paper it is sufficient to make two points. First, and perhaps most obviously, these commonly discussed shortcomings of pricing systems do not invalidate the principle of applying marginal analysis to estimate investment's contribution to output; in fact, cost-benefit procedures are essentially an extension of marginal analysis to deal with the kinds of questions just raised.

Second, in most cases, the actual contribution of investments to output are better measured through estimates of their social rather than their private returns since the former are intended to include net contributions to output not included in the latter. Thus if investments in a particular sector are subsidized or otherwise benefit through various devices at the expense of others, then estimates of their private returns would be misleading as to their net contribution to output whereas those of their social returns would not. Exceptions might arise, if one attempts to apply the recommended procedures religiously, with investments having elements in their social costs and returns that may not appear in the national accounts - the value of public goods and environmental costs are two common examples and another related to consumers' surplus will be discussed below. The recommended procedures in such instances are helpful for assessing the desirability of an investment, but take us beyond the more limited task of assessing investment's contribution to economic output, as it appears in national accounts. The postulates of applied welfare economics on which cost benefit analysis is based, as Professor Harberger (1971) remarked, "incorporate a greater degree of subtlety of economic analysis than does national income methodology". Provided one is aware of this, however, and concentrates on those elements of the social rates of return that do appear in the accounts, the social rates of return provide a better guide as to the contribution of investment to output

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than do private rates of return; at the same time, if used in conjunction with relationships of the form derived in Part III, they would also serve to indicate the costs of various distortions in an economy, as measured in terms of growth sacrificed.

**Non-Marginal Investments and Structural Change**

The micro-economic analysis of non-marginal investments in an economy is most frequently associated with indivisibilities, or more generally with large changes at a given point in time. But in the analysis of growth the more common case is one in which large changes take place over a long period. As Nelson remarks, while the changes in any year might be small in relative or absolute terms, when accumulated over a decade or more they are often substantial. An example is one in which electric power and motors are introduced to replace steam power and engines on railways or in factories. Over periods of time that are not long, the returns to investments in the user industries may have risen appreciably either because of reductions in costs, a greater volume of output from their investments, or both; a new group of supplier industries may have emerged (electric power and motors) and which did not exist before; while the old ones may have declined (steam engines) or had found new outlets (coal). Numerous other examples could be cited. Hence it is necessary to consider how to address this problem; again, guidance is to be found in the literature on cost benefit analysis, in the present case in that part of it concerning the concept and measurement of consumers' surplus.

The distinguishing feature of the present case, when contrasted with those discussed under marginal analysis, is that a change in prices is involved. The examples discussed in the section on marginal analysis were essentially simple expansions of the activities with prices = marginal costs. In the present case, however, there may be significant reductions in prices (of power and energy), and also an outward shift of the derived demand curve for the input if the new inputs lead to a productivity shift in the user industry. The prices paid by the users will thus not reflect the total contribution of the investments in the supplier industry to economic output. There are then two procedures that might be followed.

The first is to estimate the consumers' surplus (in the user industries, to continue the example) associated with the changes described, and attribute these to the investments in the new supplier industries. If this were done then to avoid double counting it would be necessary to deduct the consumers' surplus from the net revenue streams of the user industry. This procedure, however, aside from the empirical difficulties involved, runs into the problem mentioned above regarding the differences between what cost-benefit analysis counts as the net returns and the net returns that are included in the national accounts. In this context Harberger 1/ has shown that the change in national welfare, as the concept is often used in cost-benefit analysis, associated with changes in economic inputs, is equal to the change in national income plus the change in consumers' surplus. Actually, Harberger's approach may have overstated the difference between the two measures of welfare since the point that some consumers' surplus benefits may

enter the national accounts is not allowed for in his analysis; the cost savings to industries previously using the old inputs provide one example. Nevertheless, the point remains that if the consumers' surplus benefits are counted as part of the returns to investments, inconsistencies may arise when comparing the aggregate results with national income data.

Hence it might be simpler to acknowledge that those consumers' surplus benefits eventually appearing in the national accounts do so in the accounts of the beneficiaries and not (by definition) in the accounts of those industries whose investments have generated them. In this case, the pitfall to avoid would be to attribute too much of the causation of the changes in the users' contribution to output to their own investments. Given the extent of the interdependence of investments in present day economies, however, this is an obvious pitfall to be aware of.

Conclusion

To sum up, the methods of micro-economics seem readily applicable to the analysis of growth, over long or short periods. The practical relevance of this conclusion arises from the point that an exceedingly large number of micro-economic studies are now available, in both the developing and the industrialized countries, regarding the effects of policies, and often of political and institutional reforms, on the rate and yield of investment. Further, for the developing countries, various studies have identified policies that would raise the demand for labor and, by implication, labor's share in output, while not reducing—and possibly increasing—the rate and yield of investment. Even where the empirical results are not available, there are now well-developed and robust methods within the discipline that would enable the economist to examine the effects of economic decisions on the micro-economic variables we have been examining in this paper.

Suppose then that a country has been observed to raise the PW of labor’s share in output and the rate and weighted average yield of investment in the amounts \( \Delta \lambda \), \( \Delta i \) and \( \Delta i \) respectively. These quantities may of course change over time for reasons unconnected with internal policies—such as with changes in the terms of trade or, to take a different example, through chance discoveries of high yielding resources. But let us concentrate on those increases that can be attributed to changes in policies. They may have been achieved in one or more of several ways:

- through raising the incentives to save and invest in general,
- through encouraging more investment in high yielding (and possibly

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\[1\] Three sections of the development literature arrive at this conclusion: the industry and trade literature, e.g. Little, Scitovsky and Scott (1970), Myint (1971) and Ranis (1973); the technology literature, e.g. Stewart (1977), Sen (1974) and Bhalla (1975); and the rural development literature, e.g. Johnston and Kilby (1975) and Mellow (1976). For more comprehensive reviews incorporating a large volume of new evidence and country studies, see the IBRD's World Development Reports, I to V, 1978 to 1982.
also more labor demanding) and less in low yielding activities,
- through the choice and management of its public investment programs,
- through its ability to address sources of market failure (e.g. with respect to the distribution of educational opportunities),
- through raising the returns to investment in general (e.g. through appropriate macro and exchange rate policies),

and so forth. Then from the aggregate form of the relationship derived in Part III, the proportional change in the rate of growth would be given by:

\[ \Delta g/g = \Delta r/r + \Delta i/i + d\lambda/(1-\lambda) + \text{---------} \]

plus higher order terms if the changes are large and if there are significant inter-relationships between \( r, i \) and \( \lambda \). In other words it is possible to appeal to the micro-economic explanation of the observed changes in \( r, i \) and \( \lambda \) to explain changes in \( g \).

---

1/ As e.g. the financial intermediation literature argues there is between \( r \) and \( i \). See Shaw (1973) and McKinnon (1973 and 1976).
Kuznets (1966) and Later Growth Accounting Studies

Kuznets estimated the relative contributions of capital, labor (measured in man-hours) and technical progress to the growth of output in the industrialized countries in the following way:1/

"By relating property income from assets to the total capital that yields it, we can ascertain the relevant rate of input. Income from assets, excluding the part implicitly contained in the incomes of individual entrepreneurs (i.e. return on capital excluding entrepreneurial equity) averages about 20 percent of total income... Returns on entrepreneurial equity differ widely.. [But] since entrepreneurial capital in developed countries is at most 25% of total income - the contribution of capital input to total product - is about a quarter of the latter...

"The combined inputs of man-hours and capital would account for an even smaller fraction of the growth in product per capita. Since man-hours per capita are found to decline 2 to 3 per cent per decade and their weight in total product is 0.75 (since income from assets is assumed to account for 0.25), the direct contribution would be a reduction in the rate of growth of per capita product of 1.5 to 2.25 percentage points. If the rate of growth of per capita product is, say, 15 percent per decade, the reduction amounts to a tenth of the rate or more... the inescapable conclusion is that the direct contribution of manhours and capital accumulation would hardly account for more than a tenth of the rate of growth in per capita product - and probably less. The large remainder must be assigned to an increase in efficiency of productive resources - a rise in output per unit of input, due either to the improved quality of the resources, or to the effects of changing arrangements, or to the impact of technological change, or to all three."

Kuznets subsequently qualifies this conclusion by emphasizing that "the low proportions of growth in per capita product allocated to increased input of man-hours and capital do not mean that the absence of such an input would have resulted in only a small proportionate loss... The lines of the relationship between absolute increases in population, labor force and capital on the one hand, and growth in the per capita product on the other are numerous and far reaching... in ways that make it difficult, if not impossible, to establish the correct partial effects of increases in inputs of man hours and capital on growth of per capita product."2/ Furthermore, the link between structural changes and investment is clearly established in his subsequent analysis.

These passages raise an issue that continues to afflict, though to a


2/ Ibid., p. 85. The emphasis on partial effects is mine.
lesser degree, the more recent growth accounting studies cited in the introduction. This is that only the partial effects of investments on output are considered when the intention of the large majority of investments is to raise the productivity of other inputs—principally, though of course not exclusively, by redeploying labor. Consequently it is more useful to consider the total effects together. 1/

To make the point formally, consider the commonly used national accounting identity:

\[ Y = rK + wL \]

where \( Y \) is net national income, \( K \) is the net capital stock, \( L \) the labor force, \( w \) wages and \( r \) the returns to capital. 2/ Now consider a change in \( K \). Taking the total derivative gives:

\[ \frac{1}{Y} \frac{dY}{dK} = r \frac{dK}{Y} + \frac{1}{Y} \frac{\partial (wL)}{\partial K} \frac{dK}{Y} \]

It is apparent from this expression that what is omitted in the above estimates of Kuznets is the second term on the right hand side, which measures the change in labor's income, in relation to national income, with respect to a change in capital stock. If for instance we assume this term is zero and take \( rK/Y = 0.25 \), then the increase in output attributed to the increase in capital stock is only 0.25 \( dK/K \), as he estimated. As discussed in Part I, later studies continue to make the same omission with respect to material investment, though not with respect to investment in education. It is true that the effects of material investment on labor's income—accomplished by redeploying labor towards occupations or industries in which wages are higher—are partly recognized, but only for redeployment across broadly defined occupations or industries, e.g., from agriculture to industry. Changes in labor's income brought about by redeployment within industry or agriculture for example, and also within given places of employment, for example on farms or in firms, are necessarily overlooked by a aggregative an analysis. Thus the effects of material investment on labor's income through the redeployment of labor are significantly underestimated.

It was also noted in the introduction that even a highly disaggregated analysis of occupations could not be relied upon (assuming it

1/ This also seems to be one of Nelson's points when discussing the "adding up" problem in growth accounting, in which he observes "two evident kinds of interaction among the three sources of economic growth—technological advance, capital growth and rising educational attainment. First, they appear to be complementary in the sense that an increase of any one raises the marginal contributions of the others. Second, because of this, forces that lead to the augmentation of any one are likely to stimulate an increase in the others", op.cit., 1981, p. 1050.

2/ In this identity, \( r \) is not of course the same as the internal rate of return to investment, used in Parts II and III.
were practical) to address the issue. What is needed in practice is a means of estimating \( \partial (wK)/\partial K \) reliably for each sector at whatever level of aggregation is thought appropriate for analysis. The simplest procedure is to appeal to the relationships discussed variously above, between the change in labor's income and investment. First apply the above accounting relationship to each sector such that

\[
Y_j = r_j K_j + (wL)_j
\]

and then consider a change in total net capital stock, given by \( dK = d(\sum K_j) \). Then the total change in \( Y_j \) is given by:

\[
dY_j = r_j \frac{\partial K_j}{\partial K} dK + \frac{\partial (wL)_j}{\partial K} dK
\]

(Note that the wage bill in sector \( j \) is more influenced by the total change in net capital stock than by the change in the net capital stock in sector \( j \), on account of the greater influence of the former on the demand for labor.) As in Parts II and III, now define a variable relating the change in labor's income in sector \( j \) to the change in value added in sector \( j \), as follows

\[
\lambda''_j = \frac{\partial (wL)_j}{\partial K} \frac{dK}{dY_j}
\]

\( \lambda''_j \) would equal labor's share in current output, denoted in Part III by \( \lambda'_j \), if the latter quantity were constant over time. However, there is no need to make this assumption.

The first term on the RHS of (9) can be written as \( r_j s_j \), where as before \( s_j \) is sector \( j \)'s share in investment. Adding (9) over all \( j \), substituting for \( \lambda''_j \) and rearranging we obtain:

\[
g = \sum s_j r_j / (1 - \lambda''_j)
\]

This expression differs from the one derived in Part III because lead times have been ignored and it is based on a different accounting identity, the identity in Part III, it will be recalled, being based on the internal rate of return to investment. The two expressions are similar however.

Taking an average growth rate over the period \( v=0 \ldots T \), we can also obtain an expression similar to the more general relationship, (8), derived in Part III:

\[
g = \frac{1}{T} \int_0^T \left( \sum s_j r_j / (1 - \lambda''_j) \right) dv
\]

where \( i, s_j, r, \) and \( \lambda''_j \) may vary with \( v \), as before.

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1/ Given the definitions of \( K, Y \) and \( r \), we are currently talking in terms of labor's share in net valued added.
Methods Using Incremental Capital-Output Ratios

Rewriting (10) in the form:

\[ \frac{dY}{dt} = \left\{ \sum_{j} s_{j} r_{j} / (1 - \lambda_{j}) \right\} \frac{dK}{dt} \]

the incremental output-capital ratio, denoted here by \( \beta \), can be seen to be given by:

\[ \beta = \sum_{j} s_{j} r_{j} / (1 - \lambda_{j}) \]  \[\text{(12)}\]

There are therefore some similarities between the commonly used INCOR methods of analyzing growth, the early Harrod-Domar accelerator models, and the generalized capital accumulation approach followed in this paper. All of these approaches place the rate and the yield of investment in a central position in the explanation of economic growth.

There would seem to be two advantages to decomposing the capital-output ratio in the manner implied by equation (12). First, the RHS of (12) uses a standard measure of comparing the efficiency of investments between sectors. Thus if the rate of return to investment in one sector is, say 15\%, and in another 5\%, while the opportunity cost of capital is 10\%, the economist is led to inquire as to the circumstances that are leading to what is, at first sight, a misallocation of resources. In contrast, capital-output ratios may vary appreciably between sectors and over time whether or not resources are being allocated efficiently, making it difficult to interpret them unambiguously. Second, the returns to labor resulting from investment are distinguished from the returns to capital and, as discussed variously above, attention is then focussed on the importance of a proper and efficient deployment of labor (as well as of capital) in the process of growth.

Rates of Return and Growth: Estimates for Some Countries

Since there is no "residual" in the approach suggested above (apart from errors and omissions in estimating \( i \) and \( r \)) does this imply that the rates of return to investment would have to be implausibly high, as Denison argued, for the approach to be reconciled with observed growth rates?  \[1/\] Scott reconsidered this question based on a more careful analysis of the definitions and measurement of investment, and finds that they would not, averaging around 13.2\% for 10 OECD countries.  \[2/\]

If anything, Scott's estimates may be on the high side, since with minor adjustments he takes Denison's figures for the quality adjusted labor force, and (rightly) adds to these Denison's estimates of the increases in labor's income arising from the contraction of self-employment and employment in agriculture, that is to say, from the redeployment of labor towards higher income wage and salary work in industry and commerce. The sum is deducted from the overall increases in income to arrive at that part of growth

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unaccounted for by labor. The difference is then divided by the share of investment in output to arrive at the figure of 13.2% just noted.

As discussed variously above, however, the proportionate increases in labor's income arising from redeployment are underestimated by this procedure. Consider, for example, a generation of workers entering industry in a particular period and whose formal educations have by then been completed. There are three ways in which their incomes may increase the average income level of the labor force over time as a consequence of investment:

(i) with structural changes in the economy, they may increase the proportion of the labor force in higher paid industrial jobs instead of lower paid agricultural jobs than would otherwise be the case;

(ii) They may belong to higher paid, higher educated groups than the generation preceding them; and

(iii) with structural changes and growth within industry, many of these workers will be redeployed at various times in their working lives to work on or with new methods of production involving higher outputs and ultimately higher earnings per worker. Some retraining may be needed for this, though often with little change in their formal educational status.

The procedures followed by Denison and later writers allow for the effects of (i) and (ii) on labor's income but neglect (iii), which appears in the "residual" or technical progress term. Similar remarks apply to the labor force becoming redeployed by within agriculture by agricultural investments, e.g. in irrigation, new seed-fertilizer varieties, tractors, and so forth. If the "residual" is included in the capital account, the implied rates of return to capital do seem high.1/ But if it is seen as the returns to labor arising from investment in methods of production with higher outputs per worker, this is no longer the case. The actual rates of return to capital turn out to be lower than Scott's estimates, and strengthen his argument.

Two estimates of the returns to investment in various developing and industrialized countries are presented in the table (columns 9 and 10). The first is based on an aggregate form of equation (10)2/:

\[ r_1 = \frac{g(1-\lambda')}{(1-\delta)} \]

---

1/ Though not as high as Denison suggested, if Scott's accounting procedures are followed--in particular, if gross rather than net investment is used.

2/ Recall that \( g = \frac{1}{T} \int_0^T r(i-d)/(1-\lambda'^{-})dt \). \( \lambda^{-} \approx \lambda' \) and, since \( \lambda' \) varies slowly over time, we can to a good approximation factor it out of the integral and write \( \bar{g}(1-\lambda') = \frac{1}{T} \int_0^T (i-d)dt \), from which it follows that the average value of \( r \) is given by \( \bar{g}(1-\lambda')/(1/T) \int_0^T (i-d)dt = \bar{g} (1-\lambda')/(1/T)(1-\delta). \)
where $\bar{g}$, which is shown in the first column, is the average rate of growth of GDP (taken to be close to that of net national income), $\lambda'$ labor's share in net output (taken to be approximately equal to labor's share in the change in net output, denoted above by $\lambda''$), and $i$ and $d$ the average rates of investment and depreciation respectively. It is apparent from the identities on which this relation is based that $r_1$ corresponds more closely to what is sometimes called the accounting rate of return (or the rate of profit) based on revalued assets.

The second is the economic rate of return, and is based on an aggregate form of the general relationship (8) derived in Part III:

$$r_2 = \bar{g}(1-\lambda)/\sigma I$$

where $\lambda$ is the present worth of labor's share in the output of investments, and $\sigma$ is a parameter (or near-parameter) to allow for the financing costs of investments during their gestation periods and for the eventual retirement of investments. It can be seen from a comparison of columns (6) and (7) that $\lambda$ is somewhat less than labor's share in net output, the reason being that discounting leads to relatively low weights being placed on labor's share in the later years of an investment, when the shares are at their highest (and quasi-rents at their lowest), and relatively high weights in the early years, when the shares are at their lowest. The estimates of $\sigma$, which are shown in column (8) rise directly with the financing costs of investment, and thus with the lead times and the cost of capital, but tend to decrease with the allowance for retirement, to an extent depending on $\bar{g}$ and the cost of capital (see formula for $\sigma$).

From an economic point of view, it is more appropriate to concentrate on the estimates of the economic rate of return to investment shown in the last column. As Fisher and McGowan (1983) have shown, it is only by co-incidence that the two measures of the return to investment will be equal, even assuming (as is done implicitly in the above analysis since we are working with a measure of investment in terms of its share in real income) that the accounting rate of return is based on revalued assets. The estimates of the two quantities are often in the same vicinity, but sometimes depart significantly.

Some comments on the range of uncertainty in the estimates might be useful. First, it was necessary to make some allowance for the opportunity cost of the owner's and family labor in what is termed in the accounts "entrepreneurial income from unincorporated enterprises". This is, perhaps, too fanciful a description for many of the activities coming under this heading in developing countries, since they mostly comprise peasant farmers and small scale manufacturing and tertiary activities in households and workshops. Nevertheless, the total income from this source is often comparable to and sometimes greater than that from wage and salaried employment (c.f. columns 4 and 5). For the industrialized countries it is a comparatively small, though not a negligible source. Since entrepreneurial

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1/ Using an averaging procedure for the rate of investment similar to that used in the preceding footnote.
income is made up of the returns to investment plus the returns to the owner's and family labor, it is necessary to make some assumptions as to the relative magnitudes of the two. In the absence of direct evidence on this point from family or firm-level surveys, I have followed Harberger's example 1/ and considered a range of values, the lower one being that the returns to investment contribute one third, and the higher one, one half, to reported entrepreneurial income from unincorporated enterprises. For the developing countries, where labor is surely the principal input, both are probably over-estimates, and, in consequence, imply an over-estimate of the returns to investment in columns 9 and 10 (and thus under-state my argument).

To estimate the present worth of labor's share in output (column 7), and also the parameter $\sigma$, it was necessary to make some assumptions about the economic lifetime of investments. For infrastructure and construction projects, lifetimes are typically 20-30 years, sometimes longer, while for agricultural and industrial projects, where economic obsolescence may be more rapid, depending on the returns to new investments and the rate of growth, lifetimes of 10-15 years may be typical. The estimates in the table are based on 15 years. It turns out that the results are not overly sensitive to this assumption; e.g. an increase from 15 to 20 years raises the estimated economic rate return by a factor in the range 1.05 to 1.15.

The estimate of $\sigma$ also requires some assumptions as to the lead time of investments. The figure in the table is based on an average of 5 years - though it is possibly longer than this for many investments in the developing countries; e.g. it may be 5-10 years or more between the initial investment in agricultural projects and the achievement of a sustainable increase in yields. Lead times for infrastructure projects are typically 4-7 years, though those for manufacturing may be less than this. An increase from 5 to 6 years would reduce the estimated rates of return in column (10) by a factor of 1.05 to 1.1, depending on the rate of interest assumed, and from 5 to 7 years by a factor of 1.1 to 1.2.

The estimates shown also exclude investment in vocational training, education, and health. For the developing countries some of the costs of agricultural extension should also be counted as investment (as they are in project analysis). Investment in education, for example, is around 4% of GDP for the countries listed; if this were included in $i$, the estimated returns in the last column would be reduced by a factor of about 1.15 to 1.2.

With these qualifications in mind, it does not seem that omitting the "residual" leads to implausibly high estimates of the returns to investment 2/, inconsistent with project experience. The accounting rates of

1/ In his article "Capital and Technology in Less Developed Countries". Harberger (1979).

2/ The estimates for several of the countries listed are remarkably similar to those made by Harberger, op. cit., 1979, who estimated the reproducible capital stock of 18 countries using the perpetual inventory method, and divided this into his estimates of annual income from the stock.
### THE RATES OF ECONOMIC GROWTH AND THE RATES OF AND RETURNS TO INVESTMENT FOR SOME DEVELOPING COUNTRIES (1970-80) AND SOME INDUSTRIALIZED COUNTRIES (1960-80)

<table>
<thead>
<tr>
<th>Country</th>
<th>Rate of Growth of Wages &amp; Salaries Gross Net Share in Output of: Labor's Share in Net Output of: PW of Labor's Returns to Investment</th>
<th>Shares in Output of:</th>
<th>Average Rate of Investment/1</th>
<th>Parameter 5/</th>
<th>Returns to Investment 1/2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rate of Growth of GDP</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>Kenya</td>
<td>6.5</td>
<td>22</td>
<td>17</td>
<td>0.39</td>
<td>n.a.</td>
</tr>
<tr>
<td>Ivory Coast</td>
<td>6.7</td>
<td>24</td>
<td>19</td>
<td>0.39</td>
<td>n.a.</td>
</tr>
<tr>
<td>India</td>
<td>3.6</td>
<td>20</td>
<td>14</td>
<td>. . . . . . . . . . . .</td>
<td>0.71-0.80</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>4.1</td>
<td>18</td>
<td>11</td>
<td>0.45</td>
<td>0.44</td>
</tr>
<tr>
<td>Thailand</td>
<td>7.2</td>
<td>25</td>
<td>18</td>
<td>0.27</td>
<td>0.49</td>
</tr>
<tr>
<td>Philippines</td>
<td>6.3</td>
<td>27</td>
<td>18</td>
<td>. . . . . . . . . . . .</td>
<td>0.70-0.78</td>
</tr>
<tr>
<td>Colombia</td>
<td>5.9</td>
<td>20</td>
<td>12</td>
<td>0.40</td>
<td>0.45</td>
</tr>
<tr>
<td>S. Korea</td>
<td>9.5</td>
<td>27</td>
<td>20</td>
<td>0.37</td>
<td>0.32</td>
</tr>
<tr>
<td>Japan</td>
<td>-1970-80</td>
<td>10.9</td>
<td>36</td>
<td>24</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>-1970-76</td>
<td>5.0</td>
<td>36</td>
<td>21</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>-1960-80</td>
<td>7.9</td>
<td>35</td>
<td>22</td>
<td>0.57</td>
</tr>
<tr>
<td>UK</td>
<td>-1970-76</td>
<td>2.9</td>
<td>19</td>
<td>11</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>-1970-76</td>
<td>1.9</td>
<td>20</td>
<td>9 0.59</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>-1960-80</td>
<td>2.4</td>
<td>19</td>
<td>10</td>
<td>0.67</td>
</tr>
<tr>
<td>USA</td>
<td>-1960-70</td>
<td>4.3</td>
<td>19</td>
<td>8 0.68</td>
<td>0.09</td>
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<tr>
<td></td>
<td>-1970-76</td>
<td>3.0</td>
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</tr>
<tr>
<td></td>
<td>-1970-76</td>
<td>3.0</td>
<td>18</td>
<td>7 0.69</td>
<td>0.07</td>
</tr>
</tbody>
</table>

**Footnotes and Basis of Estimates**

1/ Averages over the periods 1970-77 for the developing countries and 1960-70 and 1970-77 for the industrialized countries. The bracketed figure of the rate of net investment for Kenya assumes ß = 5% (actual estimates are not available).

2/ Entrepreneurial income of unincorporated enterprises. For the industrialized countries, the income from ownership of dwellings was excluded (it amounts to around 5 to 10% of entrepreneurial income); it was not possible to exclude it for the developing countries because it is not shown separately.

3/ Since λ and λ₁ (cols. 4 and 5) relate to shares in gross output, they are divided by (1-λ) to give shares in net output. The two estimates of λ₁ relate to λ = 0.5 λ and λ = 0.7 λ respectively (see text for further discussion). For Kenya, Ivory Coast, India and the Philippines, for which separate estimates of λ and λ₁ were not available, we have assumed λ(1-λ₁) , by reference to the data for the other developing countries listed.

4/ The p.w. of labor's share in output is estimated from the formulae footnoted in Part III, which give the relation between A and A (see pages 9 and 10 ). A simple way of writing the relation is λ₁/λ₁ = (1-λ₁)/λ₁ = (1-λ₁)/λ₁ = (1-λ₁)/λ₁, where λ(1-λ) in the present value of "one" over n at a discount rate of a; i.e. A(n,x) = (1_ (1-n,x))/a. We have also multiplied by (1-a) to re-express labor's share in terms of gross output (see f.n. 3). Here c is the rate of growth of the labor force, sod appears in the expression because it influences how the labor force is deployed on the various vintages of investments (see Part II); the estimates of this quantity for the developing countries are unreliable, since the annual surveys often exclude certain categories of self and family employment. Hence we took c = population growth rate for the developing countries, as listed in the IBRD World Development Report, 1982, Table 17. For the industrialized countries, the estimates of c were taken from the ILO Yearbooks of Labor Statistics, 1973 and 1979, Table 3. For the developing countries, beginning with Kenya and reading down the list, the values of c used were 3.4, 5.0, 2.1, 1.6, 2.3, 2.7, 2.3 and 1.7, the high value for Ivory Coast being due to immigration; for Japan, 1.4, 1.0 and 1.2 for 1980-70, 1970-80 and 1960-80; for the UK so in all three periods; and for the US, 2.1, 2.4 and 2.3.

Note also, that to estimate λ₁, it is necessary to begin with an estimate of r and iterate; the estimate taken was that given in column (9). The value of n was taken to be 15 years (see text).

5/ A = t (1-λ₁)/λ₁, a lead time, i, equal to 3 years. See text for further discussion.

6/ r₁ = (1-λ₁)/λ₁, see text for further discussion. The two estimates of r₁ correspond to the two values of λ₁.

7/ r₂ = (1-λ₁)/λ₁, see text for further discussion. The two estimates of r₂ also correspond to the two values of λ₁.
return for Japan, the UK and the USA are estimated to be around 8–9%, 5% and 9% respectively over the period 1960–80. For the lower growth developing countries, they are in the range 7–11%, but nearly twice this level for the high growth E. Asian countries (except for the Philippines). The economic rates of return are generally lower all round – particularly if one allows for investment in education – but are again consistent with project experience. It should be noted also that the estimates shown are averages, and will be higher than the marginal rates of return.
VI  DOES THE ABSENSE OF A RESIDUAL IMPLY NO TECHNICAL PROGRESS?

The answer to this question follows from the analysis provided in Part II, in which it was shown that the technical progress parameter was in fact equal to an aggregate form of the accounting relationship derived in Part III, less an adjustment for the growth of output associated with the growth of labor inputs (measured in natural units). The answer can also be derived using Solow's non-vintage model of growth, as presented in his 1957 paper on the subject; this will be done below in order to make an elementary point about how technical progress is in practice reflected in the returns to investment.

Solow's non-vintage model of growth with technical progress was of the form \( \frac{Y}{L} = f(t, K/L) \), where \( L \) is the size of the labor force measured in natural units (say, man years per year), \( K \) is the net capital stock, \( Y \) value added and \( t \), time. Taking a Cobb-Douglas form, assuming constant returns to scale and letting \( \lambda' \) denote labor's share in value added, then:

\[
\frac{Y}{L} = B(t)(K/L)^{1-\lambda'}
\]

where \( B(t) \) is a trend representing the contribution of technical progress to output as distinct from the contribution of capital per worker. From this it follows that:

\[
y_t = b_t + (1-\lambda')k_t
\]

where \( y_t \) is the rate of growth of output per worker, \( k_t \) of capital per worker, and \( b_t \) the contribution of technical progress to \( y_t \).

For the industrialized countries the rates of growth of output and of net capital stock have tended to be about the same over long periods (one of the "stylized facts" of growth theory). Solow (1970, Ch.1) remarks that this has always been a rather controversial reading of the facts because of the difficulties of measuring capital stock and, second, because however the measurement problems are resolved, the evidence is inconclusive. However, over long periods, the capital-output ratio for the industrialized countries has appeared to remain roughly constant. Putting \( k_t \equiv y_t \), the percentage contribution of technical progress to the growth of output is then \( 100 \frac{b_t}{y_t} = 100 \lambda' \). If \( \lambda' \) is around 0.75 to 0.8, then roughly three-quarters to four-fifths of the growth of output per worker is attributed to technical progress. This finding was common in the earlier studies up to the mid-1960s. Later studies modified this conclusion by allowing for changes in the "quality" of the labor force following the procedures summarized in Part I. When this was done, the contribution of technical progress to growth was reduced to about half of the earlier estimates, and to about a third if, in addition, changes in the (broadly defined) occupational structure were allowed for.1/ Rather than working with "quality-adjusted" estimates of the size of the labor force, however, some points of principle emerge if we retain Solow's original model and work with natural units.

\[1/ \text{ See e.g., Denison (1967, Chapter 21).} \]
It is possible that there is a specification problem with (13), since if we used it to obtain an independent estimate of \( \lambda' \) by regressing \( k_t \) on \( y_t \), we would find \( \lambda' = 0 \) and \( b_t = 0 \) given the close relation between the two variables. (If we took the stylized fact literally, \( \lambda' \) and \( b_t \) would both exactly equal zero.) Hence it is instructive to look at the assumptions again.

It might be questioned, for example, whether the technical progress term, \( B(t) \), is independent of the rate of investment. If instead it is assumed to change with changes in \( K \), then multiplying the expression preceding (13) by \( L \), so that we are considering changes in total output again, differentiating and dividing through by \( Y \) we obtain:

\[
\frac{1}{Y} \frac{dY}{dt} = \frac{K}{B} \frac{dB}{dt} \frac{1}{K} \frac{dK}{dt} + (1-\lambda') \frac{1}{K} \frac{dK}{dt} + \lambda' \frac{dL}{dt}
\]

or

\[
g = g_b + (1-\lambda')g_K + \lambda'g_L
\]

where \( g \) is the rate of growth of total output, as before, \( g_K \) and \( g_L \) are the rates of growth of capital stock and of the labor force respectively, and \( g_b \) is the rate of growth due technical progress, related in this expression to \( g_K \) and the elasticity term \((K/B)dB/dK\).

The question arises, what is the function for \( g_b \)? If the analysis in Parts III and V is correct, the answer might be provided in an aggregate form of equation (8), namely,

\[
g = \frac{r \sigma}{\bar{1} - \lambda}
\]

where \( r \) is now a weighted average return on investment, \( \sigma \) is the parameter defined previously, and \( \lambda \) is the P.W. of labor's share in the value added by the investments. Comparing this expression with (14) gives:

\[
g_b = \frac{r \sigma}{(1-\lambda) - (1-\lambda')}g_K - \lambda'g_L = \frac{r \sigma}{(1-\lambda)} - g_0, \text{ say,}
\]

where \( g_0 \) is the growth rate that is possible without technical progress—-that is, the growth due to \( g_K \) and \( g_L \) with the methods of production remaining unchanged. Hence the production function would become, with \( B_0 \) being a constant:

\[
Y_o = B_0 e^{((r \sigma/(1-\lambda)) - g_0) t} K(t)^{1-\lambda'} L(t)^{\lambda'}
\]

The exponent of the technical progress term in this expression resembles that proposed by Eltis (1973, Chapter 6), in which the exponent was written in the form \((a+bi)t\), where \( a \) and \( b \) are constants. There is, however, an important difference, since in (15) 'b' would not necessarily be constant. It is equal to \( r \sigma/(1-\lambda) \), and thus varies both with the returns to investment, including those to investments in R&D, and with the manner in which investments deploy the labor force. Thus suppose for instance the political and economic policies of a country were such that investments were consistently ill-conceived and generated poor returns. Then \( b \) would fall to
low levels; it would fall to zero if the returns barely covered operating costs; and it would become negative, implying negative per capita growth, if the returns on a sufficient number of investments could not cover operating costs but continued to function on account of internal or external subsidies. It is, unfortunately, not difficult to find examples. Another instance might be where applied R&D for one reason or another did not succeed in generating investments with good returns.

For these reasons it seems to me desirable to represent the influence of technical progress on growth not by a parameter, but by variables that reflect both the rate of investment (as in Eltis's model) and the efficiency of investment. Since the rate and, in particular, the efficiency of investment are in turn influenced by numerous other variables—e.g., the choice of investments (including investments in R&D), pricing policies, incentive structures, and factors determining what have come to be called management or "X" efficiencies—it would seem unrealistic to strive to represent them endogenously. But the important point is that technical progress is and must be treated by a variable function. Where it is represented by a parameter there is, as Scott remarks, the underlying assumption that it is "manna from heaven", with the implication:1/

"that later vintages of capital goods are better than earlier ones just because they are later, so that their efficiency is purely a matter of time and nothing to do with investment or the yield of investment itself. In vintage theory this is precisely what is assumed to happen, but it is wildly implausible. It implies, for example, that if no investment at all had taken place anywhere in the world between 1881 and 1981, and if the world economy had been static over this period, then miraculously, in 1981 we would have been able to build jet airplanes and electric computers despite this century of stagnation."

Including the rate of investment in the technical progress term helps to remove some of these difficulties; but most economists would agree, I would think, that the yield of investment is equally important, as Scott himself has shown, including, if we may use the term more broadly, labors' share in the yield.

The above equation helps to explain how technical is reflected in the relationships derived in Parts III and V. The absence of the "residual" in the latter does not imply that the influence of technical progress on the growth is ignored. Rather, it is revealed in the following manner. In a growing economy wages are generally rising, unless labor's share is falling inversely or faster with growth. Under these conditions, the quasi-rents on existing types of investment would eventually fall to zero, and further rises in real wages could not be sustained unless investors were able to draw on advances in knowledge and methods of production to find new types of investment with positive rates of return at the higher wage levels. The technical progress term in (15) increases over time so long as investors are able to do this.

If advances in knowledge ceased or were not reflected in new investments and methods of production, wages could not rise in real terms, the rate of investment would decline to levels sufficient only to employ new entrants to the labor force at the prevailing static wage rate, and the growth rate would be given by \( g_0 \). To show that the model satisfies this condition, recall that:

\[
\lambda = \frac{\sum_{t=1}^{n} \frac{w_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{1}{(1+r)^t}}
\]

Recalling that \( Y \) is net of maintenance costs, then with no technical progress and constant wages \( \lambda = \frac{w}{w} \), say) the lifetime of the investment is very long. Furthermore, there is no redeployment of labor from old to new investments. Hence \( E + L \) whereas with technical progress and redeployment it was much less than \( L \). Hence the above expression for \( \lambda \) becomes \( \frac{wL}{Y} \). If labor's share, \( \lambda' = \frac{wL}{Y} \) is constant, then \( \lambda' = \lambda \) and the rate of growth is given by:

\[
g = \frac{ri\sigma}{(1-\lambda')}
\]

Recall that the parameter, \( \sigma \), is unity if \( n \) is large and if we ignore financing costs during the gestation period of the investment. Using this approximation and rearranging:

\[
g = ri + \lambda' g
\]

The first term on the RHS can be re-written as \( r(1/Y)(dK/dt) \), or \( (rK/Y)(1/K)(dK/dt) \), that is to say, as the share of the returns to capital in output times the rate of growth of capital stock. Similarly, the second term can be re-written as \( (w/\lambda)Y_{L}(1/L)(dL/dt) \), which rearranges to \( (wL/Y)(1/L)(dL/dt) \), that is to say, labor's share in output times in the rate of growth of the labor force. Hence:

\[
g = (1-\lambda')Y_{K} + \lambda'Y_{L} = g_0
\]

That is, output increases only with increases in \( K \) and \( L \). (Q.E.D.)
This paper has sought to show how the rate of economic growth can be accounted for by the economist's measures of the rate, allocation and efficiency of investment. The purpose of the exercise, and also its implications, were I think amply summed up in the quotations given in the introduction from Johnson, Schultz and Scott. In the relationship derived, there is no "residual" (as the term is commonly used in the analysis of growth) to represent technical progress. There may of course be a residual arising from errors and omissions, but that is a different question. Instead, it was argued that technical progress is accounted for in the returns to investment plus the changes in labor's income induced by investment. A large number of growth accounting have underestimated the latter because they have underestimated the rate of redeployment of labor, both within and between different sectors of economic activity, or even within given enterprises, brought about by material investment.

In the analysis of growth, the investment approach followed above draws attention to four variables:

- the rate of investment (and thus a country's capacity to raise savings),
- the yields of investment in the various sectors of economic activity,
- the allocation of investment among these various sectors (and thus the weighted average yield of investment), and
- the deployment of labor.

It is perhaps the principal advantage of the approach that through it the methods of micro-economic analysis, and the empirical findings of a large number of micro-economic studies concerning the choice and efficiency of investments, can be brought to bear on the analysis of growth. On savings and investment, for instance, attention is focussed on the incentives to save and invest, on the measurable costs of any distortions or administrative constraints that might be acting on such incentives and, especially in developing countries, on institutional shortcomings in the capital markets that may diminish the financial intermediaries' capabilities to identify and finance "good" projects. On the yield of investment it is focussed on the choice of investments, pricing policies, managerial or "X" inefficiencies and, again, on incentives structures. And on labor it is focussed on educational and institutional factors that facilitate or prevent the redeployment of labor to those investments with higher yields and, ultimately, higher earnings per worker. Other examples could be added. The main point, however, is that many policy implications might emerge from an application of the investment approach to growth which so far have not, I believe, emerged sufficiently clearly from other approaches.
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