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DETERMINANTS OF TECHNOLOGICAL ADVANCE

TWENTY COUNTRIES - 1950/63.

by

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PREFACE

This study attempts to investigate the main causes of technological change in a very broad framework - an international comparison of 20 countries taken over 14 years. While serious problems arise as a result of such aggregation, it is suggested that this is a fruitful approach if we wish to allow for what appears to be a very considerable mobility of technology. The results presented in this work seem to confirm this supposition and offer a basis for some rather novel conclusions especially with regard to the importance of experience and long-run effects of capital accumulation in determining output.

Conceptually, the dissertation consists of two parts. One, an econometric study of the available data which also constitutes an example of using the analysis of covariance to produce a measure of technological change. And two, a theoretical analysis of the results with respect to their relationship with some of the more important studies in this field.

I am indebted to professors Alfred Conrad, Peter Gutman, Bernard Okun, and Gerald Sifkin who read the dissertation and made valuable comments which helped to improve the

quality of the analysis. Professors Alfred Conrad and Bernard Okun gave special attention to the econometric part considerably improving some of its aspects. My greatest debt is to Professor Alvin Marty, who served as the chairman of the dissertation committee. His generous helpand the many hours of intensive discussion greatly contributed to the substantive quality of this work. Any errors that remain must be attributed to me.

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M.F.

CONTENTS

CHAPTER I

INTRODUCTION

In trying to account for productive capacity of an economy one might consider three determinants: labor, capital, and land. If this specification were correct, that is if the above list of three factors contained all three determinants of capacity output, the output of the economy would be fully explained by the three inputs. Except for errors of measurement, there could be no "residual" output.

Over the last 15 years a large number of studies attempted to test the validity of this specification. It was soon found that, at least for the industrialized countries, land was not a very important input and could usually be omitted. The two remaining factors, labor and capital, were shown to be important and could account for a large part of the total output (from approximately one-half to one-third; Nelson, 1964). But the two factors could not explain all of the output - a considerable residual remained which could not be accounted for by labor and capital alone. For more recent periods this residual, which was usually called "the level of technology", was often found, in fact, to be much larger than that part of output which was explained by labor and capital (Solow, 1957; Nelson, 1964). The importance of that residual is now obvious - if it can be so large that it may amount to more than one-half of the total output, then it is essential that we gain some understanding of the nature of the residual if we want to make intelligent predictions and exercise some control over the outputs of the present-day economies.

It seems that the best approach to this problem is to postulate a production function; that is to assume that a unique relationship exists between the inputs and the output for all values within the field of our study. We can then follow the established practice in assuming that there are only two inputs: labor and capital. This relationship can be written as follows:-

$$V = f(L,K) ,$$

where V is output measured as value added, L is labor input, and K is capital input. Note that usually no time-lags are assumed between the variables so that the effect of the two inputs of a given year is supposed to work itself out on output fully within the same year.

Definition of Technological Change

The above assumptions enable us to formulate a definition of technological change. Taking total differential, the above equation can be, after some manipulation, written in the following form:-

$$\dot{V}/V = a_1(\dot{L}/L) + a_2(\dot{K}/K) .$$

The rate of growth of output is equal to the weighted sum of the rates of growth of the two inputs. If, however, this specification is incomplete, so that there exist some other inputs contributing to the output, then the rate of growth of output will be not equal to but greater than the weighted sum of the rates of growth of labor and capital. Thus we will obtain a "residual" which is usually added to the above equation as follows:-

$$\dot{V}/V = a_1(\dot{L}/L) + a_2(\dot{K}/K) + \dot{A}/A ,$$

where $\dot{A}/A$ is the residual represented as a percentage change in the level of technology A. (Solow, 1957)

The definition of technological change can then be given as follows: Technological change is the residual in the production function after the effects of changes in labor and capital inputs on output have been accounted for. This measure is "neutral", that is, it is independent of the levels of the two factors of production or of their ratios.[1] The same definition is sometimes given in a perhaps less accurate but much simpler form: Technological change is the rate of increase of output per unit of input (Solow, 1963). Moreover, for a homogeneous production function with constant returns to scale, the definition can be further simplified (Solow, 1957):

1) This is a Hicks-neutral technological change where for $\dot{A}/A = m$, $\partial m/\partial K = 0$, $\partial m/\partial L = 0$, and $\partial m/\partial k = 0$. For a Cobb-Douglas production function with coefficients constrained to one this is the same as a Harrod-neutral technological change where $\partial V/\partial K = f(V/K)$. See Uzawa (1961).

Technological change is an increase in output per man not explained by increses in capital per man. Solow derived this definition by postulating a linear homogeneous production function which, when differentiated, gives

$$\frac{\dot{v}}{v} = \frac{\dot{A}}{A} + a_2\frac{\dot{k}}{k} ,$$

where $v = V/L$, and $k = K/L$. If a Cobb-Douglas function is assumed, then a_2 becomes a constant.

Out of the definitions given above, the first one will be adopted for this study since it is more exact and does not require the assumption of any particular form of the production function. Even so, defining technological change as a residual can hardly be accepted as a very satisfactory solution. The residual of the production function is the effect not only of all unspecified inputs, including changes in natural resources, but also incorporates errors of measurement and errors caused by the rigidity of the mathematical form of the function. As explained by Lawrence Klein (1962) technological change should be defined as only that part of the residual which is the effect of the determinants of technological change. In other words, the estimation of technological change should begin with economic theory which specifies the determinants of technological change and which, therefore, can be tested. Inserting these determinants into the production function would reduce the residual by some, probably a very large part and thus impute what has been often unsatisfactorily called technological change to specified inputs in the production function. This procedure is a basic requirement of econometric theory. In contrast to the above, Solow defined technological change as a residual of the production function and, as a result, ... "Other than as a mechanical trend varying in some fixed chronological way, Solow did not have a direct measure of A(t) - a nebulous concept of technical progress." (L. Klein, 1962, p. 110.) Domar (1961) also thought that a more appropriate name was "the residual".

Nevertheless, Solow's definition has been widely accepted. Undoubtedly, one reason was that the term was introduced into this context by Solow as a part of a brilliant analysis. But another, perhaps more substantive reason lies in the fact that it is expected that technological change amounts to virtually all, or at least to a very large part of the entire residual. Since there is not much quantitative difference between technological change and the residual, there would be a natural tendency to use a more expressive term which conveys far more information about its nature.

While this line of reasoning is not accepted in this study, there would be perhaps little point in using here the term"residual" while a large majority of studies in this field use the term "technological change". The definition of technological change as the residual of the production function will thus be unwillingly adopted for this study. The method of estimation, however, will follow the precepts of econometrics as described above.

Measurement of Technological Change

Defining technological change as the residual will make the measurement depend both, on the form of the function chosen, and on the factor coefficients. The latter may be obtained directly by estimating the production function or from other equations in the model as was, for instance, done by Solow (1957) who used relative shares of national income as estimates of factor coefficients in a linear homogeneous production function. Theoretically, there should be no difficulty in chosing an appropriate form of the function and the same estimates of factor coefficients should be obtained with both methods as long as the assumptions are correct. Unfortunately, our knowledge of reality is so limited that there is little agreement as to what assumptions are realistic. As a result we are faced with a considerable number of studies many of which are based on widely differing assumptions giving entirely different estimates of technological change.

Form of the Production Function

The choice is usually limited to Cobb-Douglas, Constant Elasticity of Substitution (CES), and Homothetic Isoquant (HI) production function. While the flexibility of the functions increases from Cobb-Douglas to CES and from CES to the HI function, the increased generality is costly mainly because a larger number of parameters is required and, in the case of the HI function, also because of the need to assume perfect competition and the marginal productivity principle as applied to factor prices. But the gain that can be obtained from using a CES function is small: ... "The analysis could have been built around the more general CES model, but within a wide range which probably brackets the elasticity of substitution the conclusions are little different from those drawn from the simple Cobb-Douglas model." (Nelson, 1964.) The same conclusion was drawn for our data from a comparison of results obtained from the Cobb-Douglas and the HI functions. Hence our study will be based on the Cobb-Douglas function with unrestrained coefficients (constant returns to scale not assumed so that the coefficients can add up to more, or less than one).

Estimates of Factor Coefficients in the Cobb-Douglas Production Function

Numerous studies in the past involved fitting the Cobb-Douglas production function to data and widely differing estimates of factor coefficients were obtained. Solow (1962) fitted his function with a time trend variable as a determinant of technological change to US data for 1909-61 and obtained $a_1 = 0.89$ for the coefficient of labor and $a_2 = 0.11$ as the coefficient of capital. The capital coefficient is here very small indeed. Nelson (1964) suggests that for the US data for 1929-60 the estimate of the capital coefficient, a_2, obtained by regression may be as high as 0.5 or greater. "Working econometricians" concerned mainly with practical models capable of forecasting economic variables within a 5% error or better, frequently assumefixed capital-output, Harrod-Domar model with very good results. This model was used by Kristensen (1960) for long-run forecasts for eight regions of the world and by Krengel (1962) for Germany. The fixed capital-output model is written: $A = V/K$, where A is a constant. Multiplying both sides by K, we get: $V = AK$, which is the Cobb-Douglas function with the coefficient of capital $a_2 = 1$ and the coefficient of labor $a_1 = 0$. Thus in these models the coefficient of capital has been increased to one. Our own data for 20 countries over the period of 1950-63, when fitted to this model (without labor input and without technological change variable) gives $V = e^{-1.34} K^{1.09}$, $r^2 = 0.98$, $s_V = 0.22$. Finally, though it is not often realized, the coefficient of capital can be larger than one as, for example, in the model used by the Central Planning Bureau of the Netherlands (1956): $V = AK^{a_2}$. In fact, Solow (1962) in the study mentioned above re-run his regressions without the time trend variable representing technological change. His estimate of capital coefficient now became $a_2 = 1.24$, and Solow, somewhat hastily, dismissed this estimate as a nonsense result. Actually, this result is unacceptable only under Solow's assumption that his specification of labor and capital as the only determinants of output is a correct one. We know, however, that this specification is incomplete. Assume, for instance, that there exists another determinant of output, say, the level of education of labor, E, which has a coefficient of 0.24 and happens to be strongly correlated in a given sample with capital input K. Then the correctly specified function would be

$$V = AK^{a_2} E^{0.24} .$$

Since E and K are strongly correlated, however, omitting variable E would increase the coefficient of capital considerably above one. Note that this conclusion would be valid even under the conditions of constant returns to scale since capital here partly serves as a proxy for the quality variable E. Under these circumstances the estimates of the coefficients of labor and capital would add up to more than one even though constant returns to scale do apply t@ labor and capital. If increasing returns to scale are admitted, then there is no reason why the capital coefficient should not exceed one even when there are no other determinants of output which would be strongly correlated with capital.

The above discussion is really nothing but a review of results of various studies which form the basis for the controversy between the neoclassical school and the Harrod-Domar school. One school supports the idea that smooth substitution between factors of production is possible. The other contends that the capital-labor ratio is fixed. Good empirical results can be found to support both hypotheses.

Measurement of Technological Change

Much of the classical theory of economic growth was mainly based on two assumptions: the law of diminishing returns, and, implicidly, constant level of technology. Labor was measured in natural units and, in addition, its quality was assumed constant so that labor in efficiency units was equal to labor in natural units. Assume that labor in natural units is constant. Now, if we increase capital input we will have diminishing returns to capital so that, on Diagram 1, the curve representing production function F_1 will have a gradually diminishing slope. If actual data gives points which lie on line $\bar{F}$, then we must assume that the production function F_1 shifted upwards to F_2 at the same time as capital increased from K_1 to K_2. This shift represents technological change which is here considered as a separate factor operating entirely outside any changes in labor or capital inputs.

This, however, is not the only possible model. It is equally valid to postulate non-neutral change in technology where, for instance, with capital input and technology perfectly correlated by a logarithmically linear function, the regression would produce the coefficient of capital input $a_2 = 0.95$ with a zero residual.[1] Regressing K in natural units against output V would give here an

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1) For the sake of simplicity it is assumed throughout this argument that the stochastic error for each observation is zero.

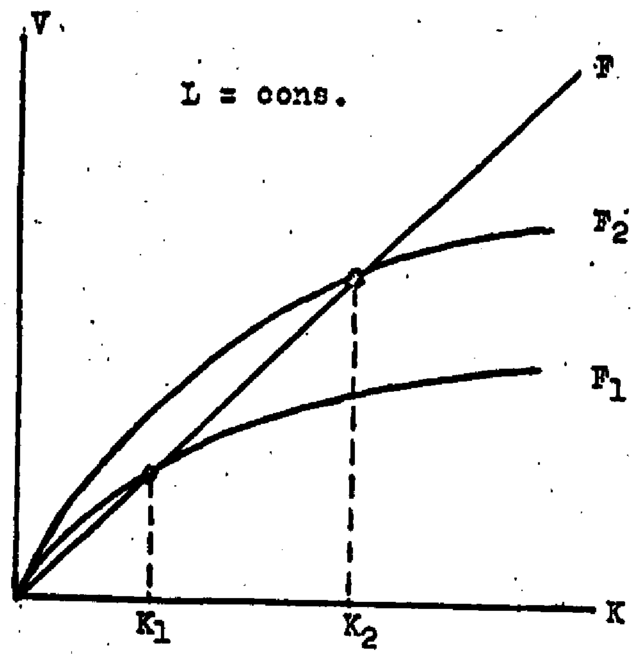
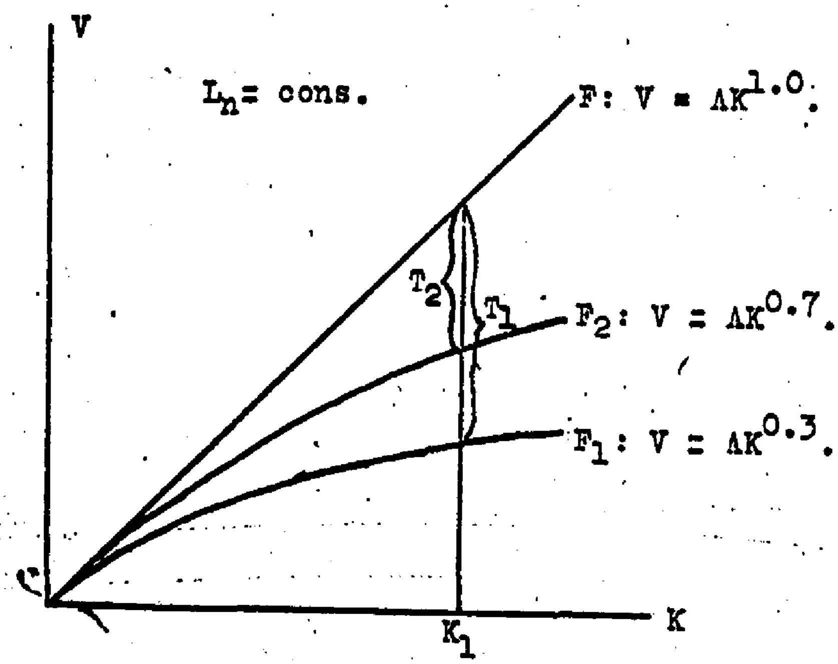


Diagram 1



L_n= labor in natural units.

Diagram 2

incorrect result, due to improper specification of the function, that the growth of output of a given percentage requires almost the same percentage increase in K and hence would appear to imply almost a fixed K/V ratio. This result would be wrong since what did in fact happen was that non-neutral innovations biased the estimate of the elasticity of output with respect to capital input, a_2, towards unity.

If, on the other hand, technological change is at least partly neutral and capital input and technology not fully correlated by a log-linear function, then there will be some dispersion of the points about the regression line and the slope of the regression line will be smaller. The coefficient of K will be now smaller and, due to the dispersion of points which will produce the residual, will explain only a part of the variation in V. Thus we will obtain a smaller value for the estimate of the coefficient a_2 (such as, e.g., 0.5)[1] and a residual (such as, e.g., approx. 45%)[1] which is identified as technological change.

Lastly, we may chose to constrain a_2 to a given value by, e.g., identifying it with the relative share of capital. The coefficient a_2 will now be likely to be even smaller (e.g., 0.25)[1] and the residual larger (60% or more).[1]

It therefore follows that in this model the smaller is the value of a_2 the greater will be the residual - see Diagram 2.

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1) These figures are for the United States, 1947-60, as suggested by Nelson (1964, p. 599).

If this residual is imputed to technology, then the size of the technological change obtained from the regression will depend on:-

1) the extent to which technology and capital input are uncorrelated by a log-linear function. Note that if correlation between technology and capital is zero, this assures Hicks-neutral technological change (and Harrod-neutral in the case of constrained Cobb-Douglas production function) but the converse is not necessarily true (see p. 14 below).

2) assumptions regarding the value of a_2.

The example used above was purposely oversimplified. Labor in natural units does not usually remain constant but this does not matter here since the entire argument can be re-written in terms of K/L and V/L without affecting its validity. The assumption of constant returns to scale is also here necessary but this would alter our results only in so far that any increasing returns to scale would be added to technology.

We have seen that the results of regressions fitted to sets of data which should not be very different in basic structural parameters, can vary considerably when the underlying assumptions are changed thus giving us different estimates of the levels of technology. Moreover, it must be borne in mind that Solow's (1957) estimate indicates that while changes in K/L account for only 10% of the changes in V/L, changes in technology explain the remaining 90%. Clearly even relatively small non-neutrality of technology can greatly affect the value of the factor coefficients in the production function.

Assuming neutrality of technology and leaving the job of estimating factor coefficients and the level of technology to the regression is far from satisfactory. More information, either about the size of factor coefficients or about the extent of correlation between technology and capital and labor inputs, must be added to the model. It is very important, therefore, that any information added must have a very sound basis in economic theory.

<u>Additional Assumptions in Past Studies of Technology</u>

In a number of past studies the possibility of technology occurring as a factor separate from labor and capital inputs was not admitted. Some of those studies seem to have produced very high coefficients of capital spuriously suggesting the applicability of a Harrod-Domar model. It was only natural, therefore, that this model, requiring data for only one factor, would gain some popularity among "working" econometricians where it produced very satisfactory results in forecasting without any need for technological change (T. Kristensen et al., 1960; R. Krengel, 1962). If technological change does, in fact, occur in such a way that it brings the rate of growth of labor in efficiency units up to equality with the rate of growth of capital in natural units (Harrod-neutral technological change), then diminishing returns to capital will appear to heve been eliminated an a spurious fixed K/V, Harrod-Domar result will be obtained from the regression. In this special case even the fact that technological change is Harrod-neutral will not enable us to isolate technological change since technology is here perfectly correlated with capital input by means of a log-linear function. The estimate of a_2 will be 1.0 and technology will demonstrate itself entirely through this very large coefficient rather than to accumulate in the residual of the production function.

Non-neutral technological change could also bias upwards the estimate of the capital coefficient a_2 sufficiently to create a mistaken impression that a fixed K/V ratio may, in fact, exist. Since the fixed K/V ratio model does produce good results in empirical work, and produces these results with less information, it could be selected over all others especially when estimation of structual parameters is not the main object of the study. On the other hand, allowing technology to work itself entirely, or largely, through labor or capital makes learning about its size and nature very difficult. Since the purpose of this study is to gain some insight into the way in which technology is determined, we are prepared to sacrifice the spurious simplicity of the fixed K/V ratio for the sake of a more properly specified model with several inputs.

In many other studies of the type described above, where the estimation of the coefficients was left to the regression and where technological change was not explicidly allowed for, the capital coefficient was estimated at much less than unity. As mentioned earlier, Nelson (1964) suggested that for his data the capital coefficient might have been 0.5 or a little larger. As would be expected, this, much lower coefficient would allocate a substantial part of the change in output to change in technology ($\dot{V}/V$ = 3.1% p.a., and $\dot{A}/A$ = 1.7% p.a., for the US, 1929-60, Nelson, 1964).

Another set of studies relies on the assumption of perfect competition and the principle of marginal productivity to derive the coefficients of labor and capital from relative shares of national income. In the face of the evidence on the extent of monopolistic power in our economy, the assumption of perfect competition seems to be extremely tenuous. But to adopt the principle of marginal productivity on the aggregate level after its inapplicability at that level has been repeatedly shown (see, e.g., a masterly exposition by Joan Robinson, Economic Journal, June, 1964, pp. 410-7), is very questionable. It is agreed that, under perfect competition, marginal product of labor would be equal to the wage. To the extent, which is obviously not insignificant, that this ideal state is not achieved in industrial countries, the marginal product of labor must differ from the wage. Notealso that the assumption of perfect competition, in this case, involves the state of full employment without inflationary pressure. It seems, therefore, that this approach lacks a proper basis in economic theory. Nevertheless, it was employed on a number of occasions. For the US the relative shares of income accruing to labor and capital are approximately 0.70 and 0.30, respectively (0.75 and 0.25 for more recent periods. Nelson, 1964). Since the capital coefficient has been further reduced, the effect of technology on output is greater - with capital coefficient of 0.25 Nelson (1964) obtains $\dot{A}/A = 2.1\%$ p.a., for his data.

Lastly, there is a number of studies based on the assumption that the level of technology is a function of time (Solow, 1962; Nelson, 1964). It seems that this method produces the smallest capital coefficient, 0.11, and the largest increase in technology, 2.5% p.a. (Solow, 1962).

Two comments must be made regarding tha last method. On the one hand, the procedure for inserting into the production function a determinant of technology, rather than some theoretically tenuous restriction on factor coefficients, is much more acceptable from the point of view of econometric theory (see p. 4 above quoting L. Klein). On the other hand, the determinant chosen is time and there seems to be little in economic theory to support the hypothesis that technology is a function of time. Much better determinants can be found in economic theory than the chronologically mechanical variable representing merely a time trend.

Plan of Study

Past investigations can be divided, then, into two groups: those based on the fixed K/V ratio, and those based on the neoclassical model.

In the studies of the first group there is no, or very little technology as a separate factor in the function and most of it seems to work itself out through quality adjustments of labor and capital. Even if this model were a better representation of reality as far as its assumptions are concerned, it would be a very difficult model with which to study the determinants of technology. The hypotheses on technology given by economic theory do not always clearly distinguish between determinants which work with labor only, or with capital only, or entirely separated from the two factors. In fact, in some cases such a clear distinction does not seem at all possible - e.g., in Arrow's hypothesis on learning by doing (see below Chapter V) learning occurs in the labor force but it cannot be passed on from capital industries to consumer industries except when it is embodied both in the capital of capital industries itself, and in the capital goods sold to consumer industries. It is not clear how this effect could be entirely allocated to either labor or capital since the extent to which it will increase total output of the economy depends not only on how much labor learned but also on how much of this new knowledge could be used, given the rate of investment and of adaptation of the existing capital assets.

Since the fixed K/V ratio model limits us to one factor, either labor or capital, it is difficult to see how this problem could be satisfactorily solved.

The second group of studies is based on the neoclassical model which produces varying, but usually substantial, estimates of technological change. It seems that, in order to establish which determinants of technology are applicable to our data, the best method is to add the determinant variables to the production function and to postulate sufficiently low correlation between technology and capital and between technology and labor so that significant estimates of the coefficients can be obtained for the determinant variables. To the extent to which technology is not correlated with capital and labor, this ensures that technological change will be neutral or offsetting. Both, the assumption of substitutability between capital and labor and the assumption of low correlation between technology and the two factors of production, are very tenuous but they do enable us to isolate technology as a separate factor which makes it much easier to study it. In this context, then, adding the determinants of technology to the production function is the proper method from the point of view of econometric theory. The determinants, however, should not be limited to a mechanistic time variable but should include all determinants which are offered by economic theory, which are relevant, and for which data can be obtained.

The following general plan will, then, be used for this study. To obtain results of wide applicability, highly aggregated data will be selected consisting of pooled time-series, cross-section figures for 20 countries over the period of 1950-63. Form of the function will be tested and the Cobb-Douglas production function with unrestrained coefficients will be adopted. Since both time-series and cross-sectional data are used, it will be possible to employ the analysis of covariance and so to find proper estimates of factor coefficients together with an estimate of neutral or offsetting technological change. This excellent technique, which became practicable only recently due to the availability of electronic computers, will produce separate series for technological change over time and for technological change over countries, both series net of random errors. Determinants suggested by economic theory will then be fitted to both series. It will be found that the same determinants, with nearly the same coefficients, apply to both series. This will enable us to shed the framework of the analysis of covariance which, though very efficient, nevertheless does impose its own rigidity and to fit the determinants directly into the production function applied to all data. This process will test a number of hypotheses and thus establish which determinants of technology apply to our data.

It will then be shown that the complete function can be transformed, under the assumption of steady growth, in such a way that the variable representing the most important determinant of technology can be merged with capital input. This will have the effect of increasing the value of the estimated capital coefficient to 0.70 and will thus offer one explanation of the way in which a basis for a spurious constancy of the K/V ratio can be created.

What is more important, this very large value of the capital coefficient implies that in the long-run, steady growth models the importance of capital input is much greater than that of labor input. This result contradicts the conclusions drawn in a number of recent studies which tended to discount the importance of capital in favor of labor input.

Since the determinants of technology tested in this study explain a very large part of the residual, it will be suggested that the results of this analysis may be useful in contributing towards a formulation of a basis for a self-contained, endogeneous theory of technological change.

CHAPTER II

GENERAL OUTLINE OF THE STUDY

The Purpose

This study will explore one approach to finding the main determinants of technology in a wide framework. The choice of a wide field, involving a very considerable aggregation in contrast to studies limited to one industry, was based on two considerations. Firstly, that relatively little is as yet known about technology, so that a study of a very basic but general nature seem to be justified. Secondly, it would appear that large external economies may be associated with technology so that disaggregated studies may well give entirely different results from those that would be obtained for entire economies.

Method

An econometric study using a production function will be carried out over the field of data covering 20 countries over the period of 1950-63. In order to establish what are the determinants of technology in this wide context, some generalizations of the presently available hypotheses will have to be made. These, however, will turn out to be relatively minor. The choice of determinants will also be affected but all major hypotheses will be tested with the exception of only one (research and development expenditures) for which no data are available.

Finally, the resulting production function, together with the determinants of technology, will be subjected to several transformations in order to gain some insight into the nature of technology and the difference between the Harrod-Domar and the neoclassical model.

Framework

Since the purpose of this study is to find determinants of wide applicability, the analysis will be made on a macroeconomic level with a sample of 20 countries taken over 14 years. This will give a large total of 280 observations for each variable. The agricultural sector, however, will be excluded throughout the sample. The reason for this exclusion is that in many countries the agricultural sector shows a very rapid growth of technology, mainly as a result of breaking down of institutional barriers to growth. In those countries the agricultural sector can now release resources which leave this field with its relatively low productivity (even with the new techniques) and enter manufacturing and service sectors where productivity is usually much higher. This shift of resources is often responsible for a large inflation of the technology index without any change in the underlying determinants of technology in those sectors. While we cannot eliminate all changes in the level of technology due to shifts of resources, we have the necessary data to exclude the most important source of those shifts, i.e., the agricultural sector.

Macro versus Micro

It is frequently contended that a microeconomic study must be superior to a macroeconomic one since the latter must be based on sweeping, and therefore unrealistic assumptions. Thus changes in opposite direction within the total may offset each other and the changes in the total itself, therefore, may be of little or no value. Furthermore, the measure of the total may be meaningless. If a production function, for example, is applied to an entire economy, the underlying assumption is that the same function applies to each productive process in the economy, be it a provision of some simple personal service or manufacture of computers. Since such an assumption is not very realistic, the meaning of the aggregate production function is far from clear and cannot be considered rigorous.

On the other hand, it must be noted that many of the macroeconomic functions have remained remarkably stable over time. Moreover, from a purely practical point of view, it will be probably a long time before we are ready to invest sufficient resources in econometric studied to measure our variables sector by sector in the entire economy. And even then the sum of the sectors will almost certainly not addup to the whole owing to the interaction of the component parts. In the meantime, however, we surely need some indication as to how our economies operate and thus must use the admittedly crude techniques to the best of our ability. Lastly, it can be shown that with the assumption of perfectly specified micro equations various errors must result from aggregation (Theil, 1954; R. G. D. Allen, 1956; Z. Griliches, 1957). But in practice we do not have such a perfect specification and then aggregation may explain our data better than a combination of all micro equations (Grunfeld & Griliches, 1960).

Field of Study

To assure that our finding will have broad applicability, we have decided to use a macroeconomic approach. Now we have to chose between time-series, cross-section, or pooled data, and between intra and inter-country studies.

Time-series data are more accurate and more of them are available. But using time-series data with year by year figures cannot be properly associated with the theoretical concept of comparing an economy in equilibrium at various points of time. Certainly we would expect that much more than one year is required before the effects of changes in factors could work themselves out fully throughout the economy. Thus it is very likely that time-series data gives us figures for the economy which is, at each point of the series, some unknow but probably substantial and changing distance behind its equilibrium position.

Secondly, it frequently happens that the predetermined variables, i.e., labor and capital, are serially correlated and the independent variations in them are very small if data from one country are used. Thus the number of independent observations on predetermined variables may be reduced, in effect, to many less than the recorded observations (Minhas, 1963).

Lastly, it can be argued that the exponents of labor and capital estimated from time-series data are, in an aggregate production function, nothing but the ratios between the differential rates of growth. In addition, Menderhausen (1938) showed that if labor, capital, and output grow at constant rates, then the ratios between the differences in growth would be secularly constant. Such historically constant ratios would not give us estimates of exponents of a production function.

Intra-country cross-sections are far more satisfactory but they also have one deficiency: a relatively narrow range of variation in factor prices over the regions of the same country will limit the number of techniques actually in use to comparatively few. Hence, it may be impossible to obtain statistically significant estimates. Furthermore, the results obtained will be of limited value for making generalizations which would be applicable to a very wide framework such as is planned for this study. Their relevance to problems of other nations or to problems of development and growth would be very small.

Inter-country cross-sections do broaden the field considerably. Although this further strains the meaning of the aggregate production function, factor markets and factor prices differ sufficiently between countries to provide enough variation for meaningful estimates.

Pooling time-series and cross-sectional data offers further important advantages. Firstly, it is possible that different determinants play different roles in creating technological change over time as against technological change over countries. In this respect much more information can be derived from pooled data. Secondly, if considerable correlation exists between independent variables inour sample but is limited to time-series or cross-section only, using pooled data may help to overcome this multicllinearity (L. Klein, 1962, p. 61-9) Lastly, pooling is likely to reduce the least-squares bias (Klein, ibid).

One serious difficulty remains: assuming that different industries in each country are on the same production function is not very realistic. Extending this assumption further to cover different countries makes it weaker still though it is much less difficult than extending it over different industries in the same country. The reason for this is that technical differences between different industries in the same country obviously are quite large. Technical differences between the same industries in different countries, on the other hand, are probably smaller with approximately the same technical knowledge largely available to most countries. Thus it can be suggested that the very large diffrences between factor proportions employed by the same industries in different countries are due not to different technologies (different production functios) but mainly due to large differences in factor prices (diffrent points on the same production function) (Minhas, ibid., p. 15).[1] Nevertheless, the meaning of a production function at this level of aggregation is far from clear. We would much prefer to use inter-country data disaggregated into narrow sectors so that separate production functions could be derived. This data, however, is not available and, in any case, the sum of the sectors would give different results from those obtained from aggregative studies due to the interaction of the sectors.

In the case of technology, where very large mobility over sectors is likely to exist, this becomes an important aspect. Consider, for a moment, a hypothesis that technology is mainly on-the-job-learning dependent on the size of cumulated per capita output, which, inturn, depends on cumulated capital per man-hour. If capital per man-hour increases in one sector, the skill and knowledge of labor and, given the necessary minimum rate of investment, the techno-

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1) The suggestion that technology is sufficiently mobile to support the assumption that the non-agricultural sectors of different countries may lie on the same production function confirmed by, e.g., P. Temin (1966) who concludes that even in the first half of the XIX century, when communications between countries were limited, "... it would appear that the American and the British employed essentially the same technology in their industrial production." (even though the factor proportions may have been different).

logy in that sector will increase. But there are additional considerations: the nature of inventions and innovations is uncertain so that frequently they are useful to other industries rather than to the industry where they originated and with high labor mobility secrecy may be impossible; since technology is here mainly an improvement in the skill and knowledge of labor, with high mobility of such labor technological advance will often spread through much of the entire economy. The original increase in capital per man-hour in one industry would, under these circumstances, affect the level of technology in other industries. Moreover, in some cases, the resultant increase in technology may be greater in some other industry than in the industry in which it originated. This very high mobility of technology seems to make it impossible to test empirically the relationship between technological change and capital per man-hour suggested by this hypothesis if it is limited to a single industry or sector. Thus it would appear that testing of hypothesis about determinants of technology can be more usefully carried out in a highly aggregated, international framework.

Form of the Production Function

Since correct asessment of the determinants of technology critically depends on a correct measurement of the residual, it is necessary to avoid any errors which could be introduced by inaccuracies in measuring inputs or by an incorrect, or too restrictive, form of the production function. Thus it is very important here that the specification of the production function be done very carefully.

Cobb-Douglas production function has the advantage of simplicity and economy in the number of parameters. On the other hand, it is rigid in that it assumes a constant ratio between marginal and avarage productivity for each factor which, in turn, implies elasticity of substitution equal to one (L. Klein, 1962 and M. Brown, 1966). This rigidity alone is probably enough to introduce some distortion into our results. In addition, there is a problem of underidentification: withour an independent estimate of the rate of growth, it is impossible to estimate the returns to scale, and vice versa (McCarthy, 1965). Moreover, two additional assumptions are frequently made: constant returns to scale, and coefficients of labor and capital equal to relative shares of output. Both assumptions are suspect. Taken together they may lead to such results as technological change in the US, 1929-58, supposedly consisting of 1.67% p.a. unembodied change, 4% p.a. embodied in capital, and <u>zero</u> percent embodied in labor - with all that training and education labor did not improve in quality since 1929! Obviously an unacceptable result (Intriligator, 1965). The second of the above assumptions, taken separately, gives labor and capital coefficients for the US, 1929-60, of approximately 0.75 and 0.25. But when the assumption of perfect competition or of sufficiently rapid approximations to equilibrium positions is abandoned, the regression is likely to give coefficients of 0.5 and 0.5 approximately (Nelson, 1964). Neither the assumptions, nor such a discrepancy in results could be accepted for this study.

Constant Elasticity of Substitution function is less rigid and would, therefore, give better results in most cases. It does, however, suffer from two disadvantages. Firstly, it is less economic in the number of the parameters needed. Secondly, the distribution of parameter δ must work jointly with the elasticity of factor substitution parameter ρ and the factor intensity ratio K/L to determine factor shares. A CES function cannot be completely specified by knowing δ and ρ alone. The units to be taken for output and the two inputs must also be specified. Since the CES function is thus not input unit free, its usefulness in international comparisons, where the problem of units is very important, is somewhat limited (Clemhout, 1964).

A Homothetic Isoquant production function which has been recently developed (Clemhout, ibid.) is more general than other functions in this field. The form of this function is:-

1. $$V = Az^{\lambda}, \quad \text{where} \quad z = Le^{\int \phi(x)dx} = Le^{\sum b_n (K/L)^n} .$$

Taking logarithms, we obtain

2. $$\ln V = \ln A + \lambda(\ln L + b_0 + b_1(K/L) + b_2(K/L)^2 + b_3(K/L)^3 + \ldots\ldots) ,$$

3. $$\ln V = \ln A^* + \lambda(\ln L + b_1(K/L) + b_2(K/L)^2 + b_3(K/L)^3 + \ldots.) ,$$

where the constant term is $\ln A^* = \ln A + \lambda b_0$, and λ is the measure of returns to scale.

The only a priori assumption made here is that the elasticity of factor substitution is constant for all isoquants along a ray from the origin but it is not necessarily constant along one isoquant. With the help of a computer this function can be calculated quite easily. The main disadvantage is that the assumption of perfect competition is required in order to estimate the parameters of this function. Also the number of parameters is likely to be quite large.

It has been shown by Kmenta (1964) that the CES function can be converted within a very close approximation into a form containing the Cobb-Douglas function:-

Cobb-Douglas: $$\ln V = a_0 + a_1 \ln K + a_2 \ln L .$$

CES (Kmenta's approximation): $$\ln V = a_0 + a_1 \ln K + a_2 \ln L + a_3(\ln(K/L))^2 .$$

Starting with this we have found a way to show that Kmenta's form of the CES function can be brought, in turn, to a close approximation of the main part of the HI function.

Taking Kmenta's form as given above, we rewrite it as follows:-

$$\ln V = a_0 + a_1 \ln(K/L) + (a_2 + a_1)\ln L + a_3(\ln(K/L))^2 .$$

Now chose units for L and K such that:

$$K/L = 1 + y, \qquad \text{where } |y| \text{ is small.}$$

We know that: $\ln(1 + y) = y - \frac{1}{2}y^2 + {}^1/_3 y^3 - \frac{1}{4}y^4 - \ldots\ldots$.

Then,

$$\ln V = a_0 + (a_2 + a_1)\ln L + a_1(y - \tfrac{1}{2}y^2 + \tfrac{1}{3}y^3) + a_3(y - \tfrac{1}{2}y^2 + \tfrac{1}{3}y^3)^2.$$

Since y is small, all 3rd and higher powers of y are ignored. Multiplying out, simplifying, and rearranging, we get:-

$$\ln V = a_0 + (a_2 + a_1)\ln L + a_1 y - \tfrac{1}{2}a_1 y^2 + a_3 y^2 - a_3 y^3 + a_3 \tfrac{1}{4} y^4$$

$$= a_0 + (a_2 + a_1)\ln L + a_1 y + (a_3 - \tfrac{1}{2}a_1)y^2$$

$$= a_0 + (a_2 + a_1)\ln L + a_1((K/L) - 1) + (a_3 - \tfrac{1}{2}a_1)((K/L)^2 - 2(K/L) + 1)$$

$$= a_0 + (a_2 + a_1)\ln L + (a_3 - \tfrac{3}{2}a_1) + (2a_1 - 2a_3)(K/L) + (a_3 - \tfrac{1}{2}a_1)(K/L)^2$$

$$= (a_0 - \tfrac{3}{2}a_1 + a_3) + (a_1 + a_2)(\ln L + 2\frac{a_1 - a_3}{a_1 + a_2}(K/L) + \frac{a_3 - \frac{1}{2}a_1}{a_1 + a_2}(K/L)^2) .$$

But this form of the CES function is the same as an approximation of the HI function with the 3rd and all higher powers of K/L ignored. Rewriting the logarithmic form of the HI function (3) again, we have:-

3. $\ln V = \ln A^* + (\ln L + b_1(K/L) + b_2(K/L)^2 + b_3(K/L)^3 + \ldots).$

This is of the same form as the approxomation to Kmenta's CES function given above where:-

HI coeff's		CES coeff's	Cobb-Douglas coeff's
$\ln A^*$	=	$a_0 - {}^3/_2 a_1 + a_3$	a_0
λ	=	$a_1 + a_2$	a_1
b_1	=	$2(a_1 - a_3)/(a_1 + a_2)$	a_2
b_2	=	$(a_3 - \frac{1}{2}a_1)/(a_1 + a_2)$	

This transformation is also of theoretical interest since it shows very clearly the relationship between the three functions: Cobb-Douglas, CES, and HI. Generalization of the function and thus an improvement in the fit is essentially obtained by adding to the Cobb-Douglas function progressively higher powers of the factor intensity ratio, K/L, until the best fit is obtained.

Thus we are now in a position to use the HI function in this study to take advantage of its very general nature. We can also derive values for the approximations to the CES and Cobb-Douglas functions by means of our transformation. This gain in generality, however, does not come free as it is necessary to adopt a larger number of parameters in order to use the CES function and, in the case of the HI function, we must also add the assumption of perfect competition. In this way we shall test simultaneously for two things: one, is the assumption of perfect competition valid; and two, if it is valid, how much improvement will the HI function give over the CES and Cobb-Douglas functions.

Variables and Data

Annual data for the period of 1950-63 was obtained for the nonagricultural sectors of the following twenty countries:

Belgium	United States
Luxemburg	Mexico
Netherlands	Australia
Germany	South Africa
France	Colombia
United Kingdom	Japan
Sweden	India
Norway	Italy
Yugoslavia	Denmark
Canada	Israel

The variables are as follows:-

V - output measured as value added, i.e., gross domestis product in 1954 US dollars at factor cost. Since an aggregate production function will be used, value added is the proper measure of output because it eliminates double accounting in compiling national output figufes. Strictly speaking, net domestic product should be used but experience indicates that available depreciation figures are so often of questionable value that it is widely believed that at present more accurate results can be obtained by assuming the same depreciation rates for the entire sample and using gross domestic product as the measure of output.

L - labor input measured in man-hours employed per year, adjusted for the lenth of the work-week and for holidays and vacations.

K - capital input measured by the stock of capital. Estimates of domestic reproducible tangible fixed assets of enterprise and goverment in 1954 US dollars at market prices were used.

$\sum_{-1}^{-7} \frac{V}{L}$ - sum of output per man-hour over the last seven years serving as a measure of technical experience - see Hypothesis 1, Chapter V.[1]

E - level of education of the population serving as a proxy for the educational level of the labor force. Measured by average equivalent years of primary education per capita, adjusted for differences in the length of the academic year. Education at secondary and higher levels was converted into equivalent years of primary education by weighting. See Hypothesis 2, Chapter V.

U - rate of labor unemployment serving as a proxy for the rate of unemployment of all resources in the economy. See Hypothesis 3, Chapter V.

Sources and Construction of Variables

Data for V, L, gross investment I_G, and U were obtained

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1) This variable will be discussed fully in ChapterV. It can be indicated here, however, that the basis for this variable lies in the work of Hirsch and Alchian, and in Arrow's learning by doing hypothesis where experience is viewed as a function of cumulated output.

from Unite Nations Statistical Yearbooks, annual issues of United Nations National Accounts Statistics, and International Labor Organization Yearbooks. Whenever possible figures given by more than one source were cross-cheked against each other and against other evaluated data in "Some Factors in Economic Growth in Europe During the 1950's", United Nations, 1964; "Europe's Needs and Resources", by J. Frederic Dewhurst, Twentieth Century Fund, 1961; "Economic Growth in the West", by Angus Maddison, Twentieth Century fund, 1964; "Economic Development of Latin America in the Post-War Period", United Nations, 1964; and, for some very limited data, the official yearbooks issued by the goverments of South Africa, Australia, and India. Some discrepancies were found, especially in the data for the developing nations. In those cases the choice was made in favour of evaluated data as against raw data because of the element of unreliability which is frequently encountered in census figures and official estimates published by those nations. Some difficulties were encountered in obtaining figures for some countries for gross domestic fixed capital formation excluding the agricultural sector. In those cases it was necessary to make crude estimates by deducting from the total investment figures the same proportion of the total investment as that devoted to agriculture in nations with very similar economies. Similarly, for Mexico, Colombia, and India, only spot estimates of the rate of labor unemployment were available for some years of the 1950-63 period. These had to be interpolated to obtain complete time-series and this was done by making the unemployment rate follow the same trend as the total volume of exports of the country involved and by comparison with the variations in the unemployment rates of countries with similar economies. The correlation between the changes in the rate of unemployment and the changes in the volume of exports seems to be very high for the three developing countries and within the short period of 1950-63. No regression was run, however, and only rough estimates were made since most unemployment rates are very inexact and are presented as only two-digit indeces anyway.

Data for capital stock for all countries with the exception of Italy, Denmark and Israel, were obtained from: "Statistics of National Wealth for 18 Countries", by Th.D. van der Weide in Income and Wealth, Series VIII, 1959, International Association for Research in Income and Wealth, Bowes & Bowes, London. For Denmark, a very long series for net domestic investment was extracted from "The National Product of Denmark, 1870-1952" by Kjeld Bjerke, the same source as above but Series V, 1955. The series for net domestic investment was then updated till 1963 and used to construct, by the perpetual inventory method, estimates of capital stock for 1950-63. Depreciation rate used was that given for Denmark by Colin Clark in "The Conditions of Economic Progress", St. Martin's Press, 1957. For Italy, an estimate was made by Vera Cao-Pinna in

"Validité Théorique et Empirique d'une Prévision Globale de la Croissance de L'économie Italiennede 1958 À 1970", Europe's Future In Figures, J.R. Geary, editor, Amsterdam, 1962. For Israel: "Capital Stock Employment and Output in Israel", by A.L. Gaathon, Special Studies No.1, Bank of Israel, Jerusalem, 1961. Both estimates were evaluated by E.S. Kirschen in "A Projection Model For The Developed Market Economies", Studies In Long-Term Economic Projections for the World Economy, United Nations, 1964, and are comparable with the estimates for the other countries given above. All capital stock estimates were extended to give in each case a complete time-series for the period 1950-63 by applying the series for net domestic fixed capital formation quoted above. Where necessary, these were derived from gross investment figures by employing Colin Clark's estimates of depreciation rates.

Data on educational levels of the population are extremely scanty and very unreliable. Even for the United States, where the quality and breadth of statistical data seems to be much greater than in other countries, educational levels data are available only for census years. In trying to constuct, therefore, a reasonably good measure of educational levels for all countries and all years of the 1950-63 period, the following method was employed. The best source that could be found was the Adjusted (for comparability) School Enrollment Ratio in the Statistical Yearbook, 1963, pp.96-110, UNESCO, United Nations,

1964. This series gives the percentage of the total population of the eligible ages enrolled in both, primary and secondary schools. The figures given have been made comparable by adjusting for the length of the academic year which varies from country to country, but the weight attached to one year of secondary education is the same as for a year of primary education. Since this is not very realistic, the series was reconstructed with heavier weight given to secondary education. This was achieved by disaggregating the unweighted series by means of comparison with unadjusted disaggregated data given in the Compendium of Social Statistics, 1963, UNESCO, Tables 60 and 61, United Nations, 1964, in order to isolate the adjustment factor used. This factor was then applied to the unadjusted disaggregated data in the compendium thus givingtwo adjusted series for enrollment rates in primary and secondary schools separately. Relative weights were obtained by converting into index numbers average wage rates for workers with different educational levels. Thiswage data was easily obtained for the United States from the Statistical Abstract For the US for 1965. The weights obtained were: 1.00 for primary, 1.34 for secondary, and 1.74 for higher education. But no sources could be located for any of the other countries in the sample. It was found, however, that the government of Egypt established wage differentials which would give weights of 1.00, 1.67, and 3.34. This information was obtained from the Egyptian Consulate. Since Egyptian economy is similar to the less developed economies in our sample, these figures can be adopted as the higher limit of the range of weights applicable to our countries. In addition rough estimates were made by several officials in the Statistical Department of the United Nations which suggested that for the United Kingdom, France, Western Germany, Belgium, Netherlands, Denmark, and Norway the following weights might be suitable: 1.00, 1.45, and 2.35. This is approximately one third of the way between the weights for the United States and the weights for the underdeveloped countries and appears to cover by far the largest number of observations in our sample. Since even quite large differences between the various sets of weights would not affect very much the general pattern of the changes in the weighted measures, this set was accepted.[1] The weights were then applied to the two series of enrollment rates for the primary and secondary levels and a single adjusted and weighted series of enrollment rates was produced. The data for both, the unweighted and weighted enrollment rates was available for all countries in the sample and for three well-spaced years for each country: 1950, 1955, and 1960. This data

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1) Zwi Griliches (JPE, 1963) shows that for the US agriculture in recent years it makes little difference what weights are used for constructing a single measure of education.

now had to be lagged a minimum of five years. If school enrollment figures are to serve as a proxy for the educational level of the labor force, the enrollment measure must be lagged until the students at the average level of advancement leave school and join the labor force. Since most primary and secondary school systems require ten years of study, the average level of advancement must be five years, assuming a constant rate of enrollment and no loss of students in the intermediate years. Probably a longer lag would be more realistic as graduates newly joining the labor force would not be likely to be able to exert much influence on the productive processes for several years. Introducing a lag longer than five years, however, would bring our data into the World War 11 years which would introduce undue distortion for most of the countries used in this study. Thus the lag of five years was applied to the figures of the two sets of the enrollment rates previously obtained. As the next step, interpolation was carried out to produce complete series of rates for each year from 1950 to 1963 for each country. Since interpolation over 14 years on the basis of only three observations is somewhat uncertain, the following test was made. It is expected on the theoretical grounds that considerable correlation exists between changes in educational levels and changes in the level of capital per man-hour. The general pattern of change of the enrollment rates obtained by interpolation was, therefore, compared for each country with the general pattern of the change of the level of capital per man-hour. The patterns obtained were very similar in each case and the two series (weighted and unweighted enrollment rates) were accepted, therefore, as variables for testing in regressions.

Finally, an attempt was made to construct a direct measure of the level of education of the population by collating data on the average number of years of education for the population of each country. Census figures giving average number of years of education for various countries were found in the Demographic Yearbook, 1963, Table 14, and 1964, Table 35, United Nations, 1964 and 1965, respectively, and this was complemented by few, but carefully evaluated, figures given in "The Residual Factor and Economic Growth", pp. 44 and 60, Organization for Economic Cooperation and Development, 1964. These sources produced disaggregated data on primary, secondary, and higher education which was combined into a single statistic of "equivalent" years of primary education by applying the set of weights used previously. The data was also adjusted for the length of the academic year by means of the correction factor obtained above. This gave a relatively good measure of education in terms of the average number of adjusted, equivalent years of primary education for each population.

The figures thus obtained were then evaluated and it became immediately obvious that census figures given for some countries and some years were completely unreliable. Thus, according to figures quoted in the Mexican census for 1950, the educational level in Mexico was higher than the educational level of France. It seems that the method by which these data were collected allowed considerable exaggeration without a provision for cross-checking of the final results. Considerable improvement seems to have occured, however, by the time the 1960 census was taken.

As a result of evaluation, figures for only 14 out of 20 countries were accepted and out of these only for four countries we had figures for both, 1950 and 1960. This would have made it impossible to construct a reliable series for each year of the period selected for this study if it were not for the complete data on the adjusted and weighted enrollment rates which were found to be highly correlated with the number of years of education ($r = 0.89$) so that they could be used for extending the partial data on the years of education over the remainder of the countries and years in our sample.

The high correlation between the enrollment rates and the years of education is not unexpected. Allowing for the necessary lags, the following relationship exists between the average number of years of education of persons transferring from schools to the labor force, N, and the enrollment rates among persons of eligible age, E: $N = Ea$, where **a** is the number of years required to complete primary and secondary education. Since the figures for E used by us are already adjusted for differences in the number of years of study at those levels, a can be assumed constant. Ignoring higher education and education required by persons above the school age, and allowing for the required lags, we would expect that E would be very highly correlated with N. This would be especially true if the lags used were long enough to cover the transfer of a great majority of students and, therefore, involve a relatively large proportion of the total labor force. In addition, we must assume that the average level of education among the students leaving education and joining the labor force is the same as among all the students leaving the schools including the ones who will not join the labor force, and that the level of education among the students joining the labor force is correlated with the average level of education of the entire labor force. Even though strong correlation exists for our data between the enrollment rates and years of education, it would seem that these assumptions may prove to be too tenuous to allow us to use the enrollment rate data as a proxy for education. They may, however, be considered more acceptable if cross-checked with less complete but more reliable data as, e.g., when we use the enrollment rate figures only as a help in interpolating the years of education data. Thus it seems that enrollment rate data should provide a reasonably good basis for extending the data on years of education over the entire field and the series of the years of education thus constructed will be adopted as the main proxy variable for the level of education of labor.

All three series will be used in regressions. In the case of the first proxy of adjusted but unweighted enrollment rate, however, the coefficient obtained will turn out to be very small. The second proxy of adjusted weighted enrollment rate will give a much greater coefficient but with a substantial variance. The third proxy of adjusted equivalent years of primary education will give a slightly smaller coefficient but with considerably reduced variance.[1] Thus the choice of this series as the main proxy measure of the educational level of labor appears to have been justified.

At this point it should be perhaps mentioned that this study does not assume that education is all investment and not consumption. This point is fully discussed in Chapter V where it is suggested that the low estimate obtained for the coefficient of education may well be an indication of the extent to which formal education is in fact consumption as far as the total material output of the economy is concerned.

Raw exchange rates for national currencies are far too much affected by various controls to be used as a real in-

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1) The estimates of the coefficients of all three measures are significant at the 95% level. The t ratios are: 3.25, 5.81, and 7.69, respectively.

dicator of the true exchange value. Fortunately, several sources were found of evaluated data. It seems that the best of these is the set of adjusted exchange rates given in the "Growth of World Industries, 1938-61", p. 310, United Nations, 1963, and that is the set that was adopted for this studyafter it was carefully compared with exchange rates also given in: "Yearbook of National Accounts, 1964", p. 389, United Nations, 1965; and "Patterns of Industrial Growth, 1938-58", p. 444, United Nations, 1960.

Expected Errors and Bias

All figures for developing nations may well be low due to inadequate data collection machinery. Some error is expected from this source but nothing very important because the number of developing countries in our sample is small and we are dealing with the nonagricultural part of the economy only where data collection is more efficient in those countries.

In less developed nations a larger percentage of the total output of goods and services is not exchanged on the market and is not, therefore, included in national figures. On the other hand, this effect is likely to apply to a much smaller extent to labor, and particularly to capital, both of which will probably be reported in national figures more fully than output. Thus relative efficiency of those countries, in comparison with industrialized nations, will probably be shown lower than it should be. In actual results for this study, however, it was not apparent that this bias caused any distortion.

The main measure of the educational level of labor adopted for this study has two main weaknesses: firstly, it employes the average number of years of education for the entire population and not for the nonagricultural labor only; secondly, it uses the trends of the enrollment rate for the purpose of extending the measure of average years of education over the entire field - hence biases of the enrollment rate will be partly imposed on the measure of the average years of education.

Regarding the first point, some bias is expected from the fact that the measure covers the entire population rather than the labor force alone. It is reasonable to expect that the less skilled part of the labor force has an educational level lower than any other group in the economy. Thus increases in the general educational level of the entire population may well occur in such a way that the increases in the education of less skilled labor are proportionately greater than the increases in the education of non-workers. To the extent that, with development, the educational level of workers increases faster than that of non-workers or that the proportion of workers in the total population increases at the expense of more highly educated non-workers, a consistent bias will be introduced which will result in the proxy measure showing a smaller increase in the educational levels than in fact occurred among the labor force. While perhaps not very large, this bias will operate to some extent both, over time and over the range of countries from less to more developed.

Another source of bias is created because the proxy measure, which covers the entire population, should exclude not only the non-workers but also all the labor engaged in the agricultural sector. We would expect that the educational level of agricultural labor is lower than that of non-agricultural labor. For the United States that difference amounts to some 18%. (Average, unweighted number of years of education of the farm and non-farm population in 1960 was 8.8 and 10.7, respectively. This was extracted from the 1960 Census of Population, Vol. I, Part 1, p. LII, US Dept. of Commerce, 1961.) Hence a bias will be introduced due to large differences between the relative sizes of the agricultural sectors of the less developed countries (India: 50%, Colombia: 37%) and those in industrialized nations (Germany: 8%, Belgium: 7%, U.K.: 4%, U.S.: 5%; all figures are for 1958), and because of varying educational differentials between the two sectors. The bias is likely to consist of exaggerating the decline in the number of years of education from the industrialized to the developing countries beyond what it really is in the nonagricultural sectors. A similar effect may be expected to exist over time as the relative size of the agricultural sectors diminishes over time in virtually all the countries in the sample, but this effect is not likely to be large due to the fact that the period involved is not very long (14 years).

Thus the variations in the proxy variable will be somewhat greater than the variations in the level of education of nonagricultural labor. On the other hand, out of 20 nations in our sample 14 have agricultural sectors which are very small in relation to the total size of their economies (from 4% to 16%) and the bias in question would be, therefore, of little importance for 70% of the observations in our sample. Since the two biases described in this section are not very large and have opposite effects, it seems to be reasonably safe to assume that the extent of their combined influence will be very limited.

The second point is concerned with the bias caused by using the enrollment rate as the proxy for the average years of education. Here two sources of possible bias come to mind. Firstly, the proportion of persons dying and persons completing their education and entering non-school population, i.e., the proportion of net change in the non-shool population to its total, is assumed constant. This unrealistic assumption is probably a source of an error rather than a bias.

Secondly, a lag of at least five years must be assumed to allow changes in the enrollment rate to change the level of education measured in the average number of years of education per person. But this lag will vary considerably from nation to nation since it tends to be shorter for countries with lower average level of education of the youth than for those with higher educational levels. This will introduce a consistent bias because there was a substantial increase in educational levels over time for virtually all countries. As we have assumed an uniform lag of five years for all countries, the countries where the actual lag is less than five years will have a higher level of education shown than that actually attained and the opposite will be true for countries with an actual lag greater than five years. That is, the enrollment rate as a proxy measure will tend to give too high a level of education in less educated countries and too low a level in highly educated ones. This proxy will thus tend to contract the range of the educational variable. Furthermore, an error will be introduced due to differences in the rate of increase in educational levels between the countries. Fortunately, the rates of increase of the educational levels did not vary excessively for our countries (from 10 to 30% approximately, over 1950-60) and for 12 out of the total of 20 countries the variation was only from approximately 20% to 25%. In addition, the period of 14 years is relatively short so that it is relatively unlikely that a large bias could be accumulated. Furthermore, this measure of the enrollment rate only <u>partly</u> affects the series of the average years of education and only a part of its bias, therefore, can affect the measure of the average years of education. Again it seems reasonable to assume that the influence of the bias discussed under the second point will be very limited though some accumulation of errors should perhaps be expected.

In conclusion, only very small, possibly insignificant, bias is expected to apply to this proxy measure consisting of the average, equivalent years of education for the population as a whole and constructed by computing an adjusted, weighted, arithmetic mean of the years of education obtained at the primary, secondary, and higher levels.

Regarding capital input, we know that capital stock is a poor measure of capital input mainly because of variations in the rate of capital utilization. Thus, we would expect not only that there will be considerable errors in the measure, but also that a consistent bias will be introduced. Variations in capital stock are probably smaller than the variations in capital utilized since changes in capital stock are a smoothed out version of changes in utilized capital due to changes in the rate of utilization which allows for a time lag and a reduction in the strength of immediate response to changes in demand. Given the same changes in output, therefore, the coefficient of capital stock will be larger than the coefficient of utilized capital would be. Using capital stock as a measure of capital input will, in this case, give an upward bias to its coefficient since we know that over time the capital utilization rates were in general increasing between 1950 and 1963. On the other hand, this was not a very regular trend and, in any case, this factor would not apply to the cross-sectional part of our sample. While some upward bias may be expected, it is not likely that it would be very large.

Variations in labor employment are sometimes used as a proxy for changes in capital utilization but in a cross-sectional sample these two measures would differ far too much to be emploed effectively. For example, labor employment rates for US and Germany in 1954 were both approximately 94.8% but capital utilization was 78% for the US and 92% for Germany. Moreover, the capital utilization rate in Germany slightly declined between 1954 and 1959 from 92% to 90% while labor employment over the same years increased from 94.8% to 98.2% (World Economic Survey, 1957, p. 159, United Nations, 1958, and Economic Survey of Europe, 1961, United Nations, 1962).

Exchange rates are very likely to introduce errors but there are two mitigating circumstances. Firstly, the rates used in this study are a considerable improvement on the rates used in the SMAC study (Solow, Minhas, Arrow, and Chernery, 1961) because the exchange rates used by us are given by a more recent United Nations study which evaluated several previous studies, one of which was used for the SMAC paper. Moreover, the set of exchange rates accepted for this study was checked by us for consistency with other, more recent but less complete sets and was found free of unexplainable deviations. Even the less elaborately evaluated set used by the SMAC study, however, was acceptable since no difficulty on its account was apparently encountered in that study. Secondly, covariance analysis is used in our work and country dummies will pick up any errors arising out of exchange rate distortions. This will still affect our measure of changes in technology from country to country (relative efficiency) but it will leave our measure of technological change over time (technological advance) free from any errors caused by exchange rates.

In general it appears that there is no reason to expect that any large biases would occur in the variables discussed above. Much larger errors, on the other hand, must be expected than those that would be normally encountered in a study of a single process industry. This deficiency must be accepted as the price to be paid for the advantage of obtaining broadly applicable results which also reflect the great mobility of technological knowledge.

Errors of Specification

The very purpose of this study is to use multiple regression with the analysis of covariance and a relatively large number of variables to eliminate the possibility that a particular variable would appropriate much of the influence of other, and perhaps more relevat variables merely because it happened to have been correlated with them. It seems that in economics many variables are highly correlated with ech other so that it is frequently possible to explain most of the variation of one variable by a greatly oversimplified and incorrectly specified model. The numerous examples of spurious correlation in economics are well known.

To minimize errors of specification both, the form of the function and all the variables suggested by economic theory were carefully scrutinized. Out of the hypotheses that have gained more general acceptance, several are not applicable to a pooled, time-series, cross-section study using entire non-agricutural economies and some of the others had to be adapted. Of those that were relevant, however, all were tested with the exception of research and development expenditures for which there was no data. In addition, final results were used to give some support to a further hypothesis concerned with the effect of fast growth of output on the coefficient of education.

CHAPTER III

PILOT STUDY AND TESTS OF FUNCTIONS

To ascertain that the data lends itself to the treatment suggested in Chapter II, a pilot study has been carried out. All 20 countries have been included but only the period of 1952-56 has been used, taken as a single time interval, thus eliminating changes over time. The suggested functional relationship is as follows:-

$$V = f(L,K) .$$

This study is, therefore, a cross-sectional analysis and, since considerable time is allowed for the economic forces to work themselves out, the economies can be considered to be near their equilibrium points. Thus this pilot study is in the nature of a long-run analysis.

The study will also test relative suitability of production functions of different mathematical forms and the validity of the associated assumptions.

Cobb-Douglas Production Function

All data have been converted into natural logarithms and a multiple regression has been run on a computer of the followin function:-

1. $$\ln V = a_0 + a_1 \ln L + a_2 \ln K .$$

Stepwise multiple regression program has been used throughout this study to be able always to observe the effects of adding further variables into the function. For this function the following values have been obtained:-

1a. $$\ln V = -1.23815 + \underset{(0.06274)}{0.18916} \ln L + \underset{(0.06844)}{0.92027} \ln K .$$

R = 0.99168 ; standard error of estimate, $s_e = 0.2003$. Numbers in parenthesis are standard erros of the coefficients.

This result with its very good fit, small errors, and coefficients summing to a value not too different from one, can be subjected to the usual criticizm levelled against Cobb-Douglas studies. Phelps Brown (QJE, 1957) points out four features of the Cobb-Douglas results, three of which are relevant here: a good fit of the regression, the coefficients summing up to approximately unity, and stability of the coefficients over time and over sections. Regarding time series studies, Menderhausen (1938) showed that the estimated coefficients will be very likely simply to express a relation between two differential rates of growth which are purely historical. Phelps Brown concludes: "... fitting of Cobb-Douglas function to time series has not yielded, and cannot yield, the statistical realization of a production function." Now the regression given above is a cross-section and not a time-series study. But fitting of the Cobb-Douglas function to cross-sections over industries in the same country is also criticized by Phelps Brown: "... the goodness of fit and ... the frequency with which the exponents ... sum to near unity would both follow from a predominating tendency of ... (output, labor, and capital) to vary in the same proportion between one industry and another. ... the extent of agreement between the values found for (the coefficient of labor) in different times and places would be explained if these values in fact depended on the actual share of earnings and this was much the same in the cases concerned." The latter will tend to occur if

"the differencesbetween the net value product associated with differences in relative factor intake will be in great part simply the counterpart of the costs of those intakes reckoned at prevailing factor prices. It is true that the rates of return to labor and capital, industry by industry, differ for various reasons, random and systematic, from the average rates reckoned for the whole economy; but in general the difference between the net value products of two industries will be correlated with the difference between the total remuneration of their factors reckoned at the average rates found in the two taken together."

Since we are using here cross-sectional data taken over countries, the applicability of Phelps Brown's criticizm is limited because the basic observations he makes regarding inter-industry comparisons are less relevant in international studies. Specifically, the scatter of observations on the production surface will tend to be much greater in international studies than in cross-industry studies; and secondly, while the differences between the rates of return to labor and capital from industry to industry in one country may be small, they would be expected to be much larger between different economies so that the effect of this source of bias would also be very considerably reduced. Thus it may be suggested that although the goodness of fit, nearness of the sum of the coefficients to unity, and the stability and meaning of the coefficients in regression (1a) are all subject to some doubt because of the limitations inherent in fitting Cobb-Douglas functions, nevertheless, these estimates should be much more reliable than those obtained from time-series data only or from cross-sections limited to only one country.[1]

Another problem involved here is heteroskedasticity. If reference is made to the list of countries in our sample, it can be seen that extreme differences in the size of the economies are very likely to cause increases in the variance of the coefficients as the size of the economy increaes. Hence the estimated coefficients, while remaining unbiased, will nevertheless become inefficient (Klein, 1953, p. 53; Johnston, 1963, pp. 207-11). This point will be discussed in Chapter IV.

Homothetic Isoquant Production Function

The form of this function is $V = Az^{\lambda}$, as described in Chapter II. The function is very flexible and allows for

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1) Note, however, that this regression includes no provision for estimating the level of technology, the influence of which seems, in this case, to have been appropriated by the capital input. Thus the meaning of this coefficient is not at all clear - see discussion in Chapter I.

variable elasticity of factor substitution. In order to calculate the values for this function, however, it is necessary to use $-dK/dL = w/r$ to obtain dK/dL, where $\underline{w}$ is the wage and $\underline{r}$ is the return on capital (see Clemhout,1965). For this we must assume perfect competition. This restrictive assumption is, therefore, the price we must pay for the gain in flexibility.

The CES function does not require the same assumption of perfect competition but it is also more restrictive than the HI function since it is based on constant elasticity of substitution and it needs a larger number of parameters than the Cobb-Douglas function. As, however, we have found a way of deriving from the HI function very close approximates to coefficients of both, Cobb-Douglas and CES, functions, the usefulness of the CES function in this context would be very limited. It is now possible to calculate the more flexible HI function and compare the results with those obtained from the Cobb-Douglas function. If necessary, a choice can then be made between the assumption of constant proportionality between average and marginal product of each factor (Cobb-Douglas function) or of perfect competition with a more flexible HI function.

The HI function was calculated as follows:-

$V = Az^{\lambda}$, where λ is a measure of returns to scale, and $\ln z = \sim \ln L + \Sigma b_n(K/L)^n = \sim \ln L + \phi(K/L)$ with $\phi(K/L) = b_0 + b_1(K/L) + b_2(K/L)^2 + b_3(K/L)^3 + \ldots\ldots$.

$\phi(K/L)$ can also be calculated from:-

2. $\phi(K/L) = 1/((1 - wL/rK)(K/L))$.

Thus we calculate $1/((1 - wL/rK)(K/L))$ for each point and fit a polynomial of K/L to it. Then we add lnL to the value of $\phi(K/L)$ given by the polynomial for each point and obtain a series for lnz. From this we obtain the regression of $V = Az^{\lambda}$.

In order to make the conversion of YI function coefficients into CES and Cobb-Douglas coefficients possible, however, units in which K/L is measured must be changed so as to bring the K/L ratio as near to one as possible. The unit of measurement of K was changed, therefore, from \$1.00 to \$2.50 . This still gives a range which is far too large (0.13 to 2.78) but after four poorest and five richest nations are excluded the range is reduced to 0.80 - 1.18 which is quite acceptable. Moreover, if the best fitting polynomial consists of lower power terms only, the size of the range would matter much less.

The results of $\phi(K/L) = 1/((1 - wL/rK)(K/L)$ were plotted on the y axis and 0.4K/L on the x axis. The above formula shows that when wL/rK approaches one, the (negative) value of $\phi(K/L)$ approaches infinity. This immediately eliminates the four nations with lowest wL/rK which are also the four least developed economies. The remaining countries fall very near to a linear regression line indicating that the polynomial will be probably of a very low order and the large range of K/L values obtained when five most advanced countries are included should not distort our results.

India, Colombia, Mexico, and Japan were, therefore, excluded and values of 0.4K/L from power one to power ten were calculated for the remaining 16 countries. Powers higher than ten were not calculated because with higher order polynomials the results willoften be meaningless due to the accumulating errors in computing an ill-conditioned matrix. The data for 16 countries have been fed into the computer and the following has been obtained:-

2a. $$\phi(0.4K/L) = -2.921 + \underset{(0.16786)}{1.0009}(0.4K/L).$$

$$r = 0.83862\ , \qquad s_e = 0.3859\ .$$

The computer has also worked through higher powers and has given this result for the highest r:-

2b. $$\phi(0.4K/L) = -2.20093 - 0.2605(0.4K/L) + 0.51155(0.4K/L)^2 - 0.00106(0.4K/L)^7\ .$$

Now $R = 0.84603$ but $s_e = 0.4057$ and standard errors of all coefficients are much higher. The previous result seems to be better.

It would appear, therefore, that a linear function gives the best fit, with all the higher powers of 0.4K/L getting zero coefficients. This strongly suggests that it is reasonable to assume the Cobb-Douglas function and that making provisions for more flexible functions would not improve our results materially.

Adding values given by $\phi(0.4K/L)$ to the values of lnL for each observation we obtain the series for lnz. The following regression was then fitted:-

$$3. \qquad \ln V = \ln A + \lambda \ln z \ .$$

The results were:-

$$3a. \qquad \ln V = 1.55720 + \underset{(0.10555)}{1.01866} \ln z \ .$$

$$r = 0.92806 \ , \qquad s_e = 0.6166 \ .$$

Next, we insert the coefficients obtained previously in (2a), $b_0 = -2.921$, $b_1 = 1.0009$, $b_2, b_3, b_4, \ldots = 0$, into the formula converting them into approximate Cobb-Douglas (or CES) coefficients (see Chapter II). The results are that the capital coefficient, a_2, comes out close to one and the labor coefficient, a_1, close to zero.

Thus we obtain, as a long-run result, a spurious, fixed K/V ratio, Harrod-Domar model. This is not too different from the Cobb-Douglas result we obtained before (1a) where the capital coefficient was 0.92 and the labor coefficient was 0.19 . The HI function does not seem to have any advantage and it forced us to exclude four countries fromour sample and to assume perfect competition. The assumption of perfect competition, particularly for studies involving international comparisonswhere there is very little labor mobility, does not appear to be realistic. The HI function will be discarded, therefore, in favor of Cobb-Douglas.

We know, however, that the numerical result we have obtained strongly suggests that a spurious, fixed K/V ratio, Harrod-Domar model may apply to our data. This is not unusual and, as mentioned earlier, this model was used by Klein, Kirschen, et al., on many occasions. This model seems to give excellent results in long-run studies. On the other hand, we know that for short-run[1], time-series studies we should perhaps expect much smaller coefficients for capital input, viz. Nelson's (1964) coefficient for the United States amounting to only 0.5 . Since the pilot study is based on cross-sectional data, results spuriously implying a Harrod-Domar model should not be perhaps unexpected. This, however, still leaves the conflict between a fixed K/V ratio model and the neoclassical approach unresolved. The difference between coefficients produced by the long-run as against the short-run studies will be examined later in the light of results obtained from the main study based on pooled data.

As the final result of this pilot study we will conclude that the cross-sectional part of our data, which forms

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1) By short-run we mean here one calendar year since annual figures are usually employed in time-series studies. Long-run is a period of time sufficiently long to allow the main effects of changes in the economy to work themselves out to such an extent that the economy may be considered near its equilibrium point in respect to those changes. In our case those changes would be changes in labor and capital inputs. Cross-sectional and even perhaps time-series studies using decade rather than annual figures are usually considered to be long-run studies.

a majority (approx. 60%), is amenable to a production function approach and we will accept the Cobb-Douglas function with unrestrained coefficients as a most convenient and realistic form of the production function for our data.

CHAPTER IV

ESTIMATION OF TECHNOLOGICAL CHANGE

This chapter describes the statistical technique and the estimation procedure used to derive separate time series and cross-section series for the level of technology. Both series will then be converted into index numbers to eliminate negative values which cannot be converted into logarithms. In this way we will obtain two separate series, one giving technological advance over time and the other relative efficiency of various countries. This will enable us to test the two series separately so that, if necessary, different determinant variables or the same variables with different coefficients can be fitted to the two series.

Form of Function

Cobb-Douglas function (not restrained to constant returns to scale) will be used as the result of our pilot study. That study showed that the Cobb-Douglas function offered greater advantages than the HI function. Firstly, it did not need the assumption of perfect competition or the use of the wage rate data - both very unreliable in international studies. Secondly, it did not require excluding four countries from our data. Thirdly, the K/L polynomial fitted to the $\phi(K/L)$ series was of the first order and, as expected, the results given by the two functions were very similar. All of the above points, with the exception of the second one, also apply to the CES function.

Statistical Technique

Multiple regression with analysis of covariance will be used. Covariance analysis involves inserting into the production function a dummy variable for each country and each year. This method has a number of theoretical and statistical advantages over the traditional methods of measuring productivity, such as the single equasion least squares method applied to non-pooled data or the factor shares method, or the two methods combined. Firstly, it allows to separate technological change from the contribution of physical factors without making it necessary to impose on the empirical model the twin restrictive assumptions of constant returns to scale and competitive factor pricing. Both assumptions must be used in the factor shares method as exemplified by the work of Solow, Kendrick, and others. Secondly, it produces the actual rates of technological advance for each year and the rates of relative efficiency for each country rather than accept the assumption of constant rate of technological change as is usually done when production functions are fitted to time-series data

(Tinbergen, Solow). Thirdly, it reduces the simultaneous equasion bias of single equasion least squares regressions (I. Hoch) and lowers the tendency towards indeterminacy of the production function coefficients due to multicollinearity in data (L. Klein). Fourthly, the technological change series is computed rather than obtained as a residual and is, therefore, net of errors which in the traditional residual methods are collected in the productivity index. The disadvantage of the method lies in the very large number of parameters which must be estimated, thus considerably reducing the number of the degrees of freedom (A. Goldberger, Econometric Theory p.222 1964). The method can only be used efficiently, therefore, when large blocks of data are available (the number of observations in this study is 280). Secondly, the computational burden is typically so large that it usually cannot be tackled without the help of an electronic computer - 12 hours of machine time were used in this study.

Estimation Procedure

Regressions were run on output V with labor and capital inputs, L and K, as independent variables, and with time and country dummies to remove from the coefficients of L and K as much of the influence of other unspecified but correlated independent variables as possible. Next, the technological advance (technological advance over time obtained from the coefficients of the time dummies) and the relative efficiency series (technological change over countries obtained from the coefficients of the country dummies) were each tested separately for the determinants suggested by the hypotheses. That is, regressions using the same variables were run separately on the time-series data and the cross-sectional data. The coefficients designated as determinants of technology turned out to be very nearly the same in both cases. It was possible, therefore, to pool time-series and cross-sectional data. After the form in which the determinants of technology were to be inserted was ascertained, the complete function was run using the full set of data and final values for all the coefficients obtained. As the last step, the entire regression, including the determinants of technology, was re-run together with all dummy variables to see if there was still enough unexplained residual left to give significant coefficients for any of the dummies and if there was any trade-off between dummy variables and any of the other independent variables.

Assumptions

1. Capital input can be defined, measured, and is independent of other variables. The difficulties encountered in formulating the concept of capital are well known (Joan Robinson, et al.). This study assumes that this problem can be solved. In addition, the study employs successfully an alternative measure of capital input, called "new capital", which allows for differences in

capital utilization.

2. The relationship between the inputs and the output in our sample can be represented by a Cobb-Douglas production function, without any time lags in any of the variables and with unrestrained coefficients.

3. Technological change is unembodied, i.e., it is not associated with labor or capital inputs.

In contrast to capital-embodied technological change which consists of the development of the new <u>models</u> of capital goods, unembodied technological change involves the development of the new <u>methods</u> of production (H. Green, 1966). Embodiment of those methods in new capital goods is here considered of little consequence to changes in output in relation to the importance of the development of the new methods. This approach may be of questionable value where the rate of gross investment is near zero but it is probably reasonable to suggest that once a new machine is being built it makes little difference to its cost whether very little or a great deal of new technology is embodied in it. In this case it would be the level of technology and not the rate of investment that would be the main determinant of output (after labor and capital). Embodiment in capital (Solow) is, however, rejected mainly because it is not clear how it can be relevant in the long-run (cross-sectional analysis) - see Phelps (1962) and Chapter V below. Moreover, embodiment usually assumes constant rate of technological change which is contradicted by our results. On the other hand, due to the form of the function, the determinants of technology are entered multiplicatively and thus can be viewed as weights for labor and capital inputs.

It is also assumed that technology is independent of capital input to an extent sufficient to enable us to obtain a significant measure of technology. This requirement must apply, of course, to all variables but it is being mentioned explicidly here and in the case of capital above because of the conceptual difficulties associated with these two variables. If technology is a function of K, and not, for example, of K/L, we shall be unable to disentangle the two variables.

Regression Functions

As a result of the above assumptions we arrive at the following function:-

1. $$Q = A_0^* L^{a_1^*} K^{a_2^*} M^{a_3^*} e^T ,$$

where Q is output, M materials input, and T technology. This function can be transformed (Minhas, 1963) into the well-known Cobb-Douglas form:-

2. $$V = A_0 L^{a_1} K^{a_2} e^T ,$$

where V is value added.

Regression Function with Analysis of Covariance

This method adds dummy variables for all years and all countries thus removing from the coefficients of L and K as much of the influence of other correlated independent variables as is possible. The method is not perfect since it assumes that there exist cross-sectional coefficients which are constant over the 14 years, and time-series coefficients which are constant over the 20 countries. This, however, is a less restrictive assumption than those usually adopted and the method should enable us to obtain a vry important improvement in technique. The general form of the function is now:-

$$3.\quad \ln V = a_0 + a_1 \ln L + a_2 \ln K + b_0 D_0 + b_1 D_1 + \dots + b_{13} D_{13} + c_{BE} D_{BE} + c_{LU} D_{LU} + \dots + c_{IS} D_{IS} + u,$$

where numerical subscripts are given to time dummies (0 = 1950, 1 = 1951, etc.) and letter subscripts to country dummies (BE = Belgium, LU = Luxemburg, etc.). u stands for a multiplicative error term assumed to give

$$E(u_i) = 0, \text{ for all } i\text{'s};$$

$$E(u_i u_j) = \begin{cases} 0, & \text{for } i \neq j; \\ \sigma_u^2, & \text{for } i = j. \end{cases}$$

In order to fit this function it is necessary to set either the general constant a_0 and one of the dummies equal to zero, or one of the time and one of the country dummies equal to zero. Otherwise we shall get a singular matrix which cannot be inverted (A. Goldberger, 1964, p.220). In this study D_1 and D_{AU} were chosen for supression since this would give the smallest loss of information - among the coefficients of several time and cross-sectional dummies which were all near zero, these two had the largest variance and were, therefore, least significant.

Taking total differencial of this function and integrating we obtain:-

$$3.1 \qquad \ln V = a_0 + a_1 \ln L + a_2 \ln K + b_i + c_j + u ,$$

where b_i's give the level of technology for each year for all the countries taken together, and c_j's give the level of technology for each country over the entire period of 1950-63. Since b_i's are measured from zero, Δb_i's will give technological advance over time; c_j's are measured from the general constant a_0 and Δc_j's, with each $\Delta c_j = c_j - a_0$, will give differences in relative efficiency of the countries in the sample.

We can thus obtain two series, one for technological advance and the other for changes in relative efficiency. For convenience, we will reserve the term "technological change" for denoting both, changes over time and changes over countries, while the term "technological advance" will be used, as before, for changes over time only and the term "changes in relative efficiency" for changes over countries.

All regressions in this study were run with stepwise multiple regression programs.

Fitting (3) to our data gave the following result:-

$$\text{3a.} \quad \ln V = 0.09954 + \underset{(0.05823)}{0.60163} \ln L + \underset{(0.03539)}{0.41959} \ln K +$$

-0.01342	D_0	(0.02023)	$+0.03263$	D_{BE}	(0.03867)
$+0.0$	D_1	supressed	-0.03923	D_{LU}	(0.017510
$+0.00000$	D_2	(0.02004)	-0.21463	D_{NE}	(0.03529)
$+0.03500$	D_3	(0.02017)	-0.30731	D_{GE}	(0.11366)
$+0.05130$	D_4	(0.02054)	-0.05597	D_{FR}	(0.09266)
$+0.06190$	D_5	(0.02137)	-0.07056	D_{UK}	(0.11872)
$+0.07254$	D_6	(0.02249)	$+0.11158$	D_{SW}	(0.02868)
$+0.07104$	D_7	(0.02370)	-0.16105	D_{NO}	(0.05969)
$+0.08572$	D_8	(0.02460)	-0.50140	D_{YU}	(0.04135)
$+0.10763$	D_9	(0.02597)	$+0.31800$	D_{CA}	(0.03814)
$+0.13633$	D_{10}	(0.02762)	$+0.54498$	D_{US}	(0.16825)
$+0.14762$	D_{11}	(0.02921)	-0.06740	D_{ME}	(0.05255)
$+0.15978$	D_{12}	(0.03089)	$+0.0$	D_{AU}	supressed
$+0.17369$	D_{13}	(0.03265)	-0.32350	D_{SA}	(0.04241)
			-0.42790	D_{CO}	(0.06953)
			-0.91843	D_{JA}	(0.13418)
			-1.09731	D_{IN}	(0.14636)
			-0.49241	D_{IT}	(0.08639)
			$+0.00871$	D_{DE}	(0.05405)
			-0.32760	D_{IS}	(0.10465).

$R = 0.99921$; standard error of estimate, $s_e = 0.0634$. Numbers in parenthesis give standard errors of the coefficients.

All coefficients are significantly different from zero at the 95% level of confidence except for D_0, D_{BE}, D_{FR}, D_{UK}, D_{ME}, and D_{DE}. All of these wre very nearly zero anyway so that very little information is lost by assuming them equal to zero. Regarding the time dummies, the standard errors are in most cases too large to give the 95% level of confidence between the adjoining coefficients but this is not true for the non-adjoining coefficients. The time dummies were naturally arranged consecutively from 1950 to 1963. Since the differences between the levels of technology for each two adjoining years cannot be large, the differences between the coefficients of adjoining time dummies in our array must be relatively small. Statistically there is no reason, however, why the time dummies should be arranged in the order of years - any random arrangement is equally acceptable. Since the number of such non-consecutive arrangements is very large, and the coefficients would be significantly different (at the 95% level of confidence) in all of them, it can be assumed that all time coefficients are significant.

The problem of heteroskedasticity may, however, have some adverse effect on our ability to test the significance of the above coefficients. As mentioned previously, extreme differences exist in the size of the economies in our sample. It is very likely, therefore, that heteroskedasticity will occur (Malinvaud, 1966, p. 256; Kuh, 1963, p. 92.) and its effects must be considered:- underestimation of the variance of the coefficients which may amount to as much as 25% (Theil, 1951) or even to 44% (Johnston, 1963, p. 210) in an extreme case; the resultant possibility of errors in testing hypotheses; and finally, making the method of least-squares applied to untransformed variables inefficient (Malinvaud, 1966, pp. 256-57). There exist methods, however, which can be used for countering heteroskedasticity. Firstly, using logarithmic forms of functions, such as, for example, a Cobb-Douglas production function, where "extreme value problems are mitigated since extreme large or small values are given relatively less weight." (Kuh, 1963, p. 93.)

Secondly, by replacing the initial variables with variables divided by a quantity measuring the size of the economic unit (Kuh, Malinvaud).

In the case of our estimates we have used logarithmic relationships and it is reasonable to expect, therefore, that the effects of heteroskedasticity were mitigated to some extent. Secondly, in estimating the coefficients of labor and capital together with those of the dummy variables, the estimates of of the coefficients of labor and capital were not efficint and, while the relationships do not seem clear, a possibility exists that, because the dummy variables pick up the size effect, the estimates of the coefficients of the dummy variables may be inflated. Since these in turn are used as a measure of technological change, some inflation of the coefficients of the determinants of the technological change could also occur. On the other hand, the technological change series is measured in logarithmic terms so that differences between observations are <u>percentage</u> changes in the level of technology. Secondly, 40% of our sample is taken over time and is not, therefore, affected by heteroskadasticity. Both series are then separately regressed on the determinants of technological change, all of which are in a deflated form. The estimated coefficients are very similar in both cases and both series, therefore, are pooled together in final regressions. It would thus seem very likely that, as a result of using logarithmic relationships, pooled data, and a deflated form for the dterminants of technological change, the effects of heteroskedasticity on the determinant variables have been largely eliminated.

Level of Technology: Time-Series and Cross-Sectional Series

We have obtained from our regression two series. One, a series giving technological advance from 1950 to 1963 extending from -1.3% to 17.4%, or a total of some 19% for 14 years. There was no technological advance from 1951 to 1952 and from 1956 to 1957. The other, a series of relative efficiency ranging from -1.10 for India to +0.54 for the United States. Since all relationships are logarithmic, all differences between coefficients of the dummies within each set are percentage differences in terms of output V. Thus technological advance from 1952 to 1953 was equal to 3½% increase in output, after the effects of changes in labor and capital inputs have been accounted for. Similarly, the difference in the level of technology (relative efficiency) between Germany and the United States is approximately 85%. With the same labor and capital (but also with a much larger K/L) in terms of the total number of equivalent units of input,[1] the United States produces 85% more output.

Both, the technological advance series and the relative efficiency series, had to be converted into index

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1) Input in equivalent units is that amount of labor and capital inputs which, ceteris paribus, produces the same output. Thus any combination of labor and capital inputs along the same isoquant represents a constant number of equivalent units of input.

numbers before they could be used in further regressions. The two series, as given above, contain negative numbers of which logarithms cannot be taken. We must, hoever, allow for the possibility that a non-linear relationship may exist between technology and some of its determinants. In that case it would be necessary to convert all values into logarithms in order to obtain a log-linear relationship. The technological advance series was converted into index numbers by adding 1.00 to each observation, giving a range of 0.9866 to 1.1737. The relative efficiency series was based on 10.00, giving a range of 8.003 to 10.440.

Different numbers were used for the index base in the two cases but this does not matter as long as the determinants of technology all enter the function multiplicatively in the same way as labor and capital. This can be demonstrated by showing that the index base will be absorbed by the general constant of the equation. Consider equation (3). Adding the index base constant $\bar{b}$ to all dummy coefficients will give us $(b_i + \bar{b})D_i$ for each dummy term. The dummy can only assume the value of zero or one. In the first case the entire term disappears. In the second case the term becomes $b_i + \bar{b}$, where $\bar{b}$ is a constant and will be incorporated by the regression into the general term a_0.

CHAPTER V

HYPOTHESES

This chapter describes the hypotheses about the determinants of technology which have received some support in the literature, are relevant, or can be adapted to a macroeconomic framework, and are suitable for quantification and econometric testing.

Hypothesis 1: Technology is partly determined by technical experience acquired in the course of production activity and is a function of output per man-hour cumulated over the entire period of that activity.

This hypothesis is a result of studying a family of several hypotheses, all of which concern themselves with this type of an effect which has been shown to be very important.

The first one of these is the "Horndal Effect" as reported by E. Lundberg and elaborated by I. Svennilson into the hypothesis that technological change is partly determined by on-the-job-learning by labor, working with new and old capital. Further studies in the United States attest to the surprisingly great importance of this factor (S. Boris, W. Salter, T. Wright, Z. Hirsch).

Another hypothesis was presented by A. Alchian (1959 and 1963) who differentiated two dimentions related to output: the rate of output per unit of time and the total volume of output (output cumulated over the entire period of production). Alchian suggested that the larger the total volume, holding the rate constant, the lower will be the average cost. Technology is here a function of output cumulated over the life of the technique. As the same productive process is repeated, experience is gained and productivity increases. But if a new, entirely different process is started, all old experience is lost and we must start with zero experience.

Z. Hirsch (1952 and 1956), in an earlier work, tested two aspects of a very similar hypothesis. Firstly, he showed that it is not the <u>time</u> over which production has been carried out that matters but the <u>cumulated output</u>. Secondly, Hirsch demonstrated that in reality the differences between the old and new techniques are usually very small as far as most individual work is concerned. Hence experience acquired with the old technique is very largely applicable to the new technique so that productivity at any time <u>t</u> is essentially a function of experience acquired during the entire life of the plant and not of experience acquired over the life of a single technique only. P. Verdoorn (1956) also used output cumulated over the life of the plant and confirmed Hirsch's findings.

On the other hand, cumulating output over the entire life of the productive unit is not really necessary. Firstly, if the productive unit existed many decades, very old experience acquired when, e.g., it was producing nails, is of little usefulness now when the unit is producing, e.g., tractors. It is relatively recent experience that is most important. In international comparisons we know that manufacturing production has been carried on for a very long time in all countries in our sample. Some countries commenced industrial production much earlier than others but, as very old experience is not of much value now, such differences can be ignored and the time over which to cumulate output can be assumed the same for all countries.

This assumption may appear to stand in contradiction to the fact that technological advance proceeds at different rates in different countries. Thus it may seem that in the United States, where technological advance is rapid, old experience becomes outdated faster and cumulation of output should be carried back over a smaller number of years. In India, on the other hand, where technological advance is probably much smaller, old experience becomes outdated more slowly and cumulation should be carried back over a greater number of years. This argument, however, is fallacious. It is the relative, and not the absolute levels of technology that count. Technological advance in the United States may have been faster but, at the absolute level of technology in the United States, techniques 30 years old may be more similar, in terms of experience secured from them, to the present techniques used in the United States than techniques only 20 years old are similar to techniques used in India now. Hence, from the point of view of the usefulness of old experience, cumulation of past output should be greater in the United States despite faster technological advance. There is no a priori reason why we should not assume the same time period for cumulation of output in the measure of the level of experience in various countries.

In addition, even if such changes in the length of cumulation were relevant, they could apply to a very small part of our sample. Out of 20 countries, 16 are similar in technology used in nonagricultural sectors. Time-series data over 14 years would not be affected at all. Thus only 12% of all of our data would be affected seriously by this consideration even if it were shown to be relevant. Hence it seems safe to assume that a constant period of cumulation will not distort our overall results.

Secondly, given a constant period of cumulation, we can decide on the length of that period. Ideally, we would wish to use long periods of several decades but this is not possible due to lack of data. We know, however, that the rates of growth of output in our countries remained very stable over long periods of time (S. Kuznets, 1961; C. Clark, 1957). But given a constant period of cumulation and a constant rate of growth, any short period cumulation will give an exactly proportional measure of any long period cumulation.

Over more recent periods, considerable variations occurred during the Great Depression and World War II but the relative patterns of growth for 16 out of 20 of our countries remained surprisingly stable (D. C. Paige, et al., 1961). Hence, in most cases, short period cumulation will not be likely to misrepresent the international relationships between the long-run cumulations even when those include large short-run disturbances. In addition, the importance of these short-run disturbances will rapidly decline with the passage of time owing to fast economic growth in the post-war years.

The practical limitations on our choice are, on the one hand, a period longer than that of the business cycle within which the rate of growth varies considerably, and, on the other hand, a period as long as is compatible with the availability of reliable data. Unfortunately, both availability and reliability of data were gravely affected by World War II. Thus cumulation of output for 1950 (first year of our time-series) should not go back further than 1946 or 1947 which would give a cumulation of 5 or 4 years only. This is long enough to smooth out business cycles but is still very short so that it must lean rather heavily on the assumed regularity of the patterns of the rates of growth. Since longer cumulation can be made for later years of our time-series, a compromise choice was made of 7 years cumulation.

This period may have an additional advantage in that it seems to be near to the average life of techniques as indicated by the average life of machinery (U.S. Internal

Revenue Service, Schedule D, gives for 1962 a number of estimates of the average life for various types of machinery. Allowing for differences between the United States and other nations, 7 years could be chosen as a reasonable overall average). Even though Hirsch demonstrated that almost all of the experience from one technique is usually "inherited" into the operation of another, some advantage may accrue from that, on average, our period of cumulation spans one complete technique.

Quite short periods of time were used effectively for cumulation in several studies - 4 to 6 years (monthly data) by Hirsch, 10 years by G. Sahota (1964). Our own results also show that 7 years may be a sufficient period for our data. Correlation between this variable and the residual of the production function was very high (r = 0.98) and the variance of the coefficient very small indeed.

The early studies (Hirsch, Alchian) used cumulated output as a measure of on-the-job-learning. Those studies, however, dealt with productive units of approximately fixed size in terms of inputs over the periods studied. On-the-job-learning accrues, however, mainly to individual workers. Thus, the hypothesis of on-the-job-learning suggests that doubling of the output associated with a doubling of the labor force (and the necessary increase in capital) would not increase appreciably on-the-job-learning of each worker since output per worker would remain the same. In our sample, however, very large changes in the size of the labor force occur and it is necessary, therefore, to employ cumulated output <u>per man-hour</u> rather than cumulated total output. The use of this measure for experience was suggested by J. Verdoorn, T. Haavelmo, G. Sahota, and others.

It appears, hoever, that on-the-job-learning hypothesis has been too narrowly formulated. Assuming constant life of productive facilities, it is only the amount of output per man-hour prevailing in the particular productive process, or in the sector of the economy studied, that affects on-the-job-learning. According to the hypothesis, the amount of output per man-hour in other sectors does not matter. In other words, learning acquired on the job is perfectly immobile. This restriction seems unnecessary and is removed by postulating above the much broader Hypothesis (1) where by "technical experience" we mean not only the experience acquired due to sectional V/L but also that communicated from other sectors, i.e., that due to global V/L. Thus mobility of locally acquired experience is allowed for.

It is now necessary to design a suitable measure. The measure used for on-the-job-learning is $\sum^{-t} \frac{V}{L}$, where t is the length of the productive process. Since the results of our regressions, as will be seen later, strongly indicate the existence of constant returns to scale, we can write: $\frac{V}{L} = A_0 \, e^T \left(\frac{K}{L}\right)^{a_2}$. But this means that our measure is really cumulated capital per man-hour, subjected to the exponential coefficient a_2, and multiplied by the level of technology. That is, the measure uses K/L measured in efficiency units.

Now it is implied that this measure reflects local on-the-job-learning only since only local K/L is used. It is apparent from the above formula, however, that V/L also includes A_0e^T which will clearly vary with changes in global K/L and the associated changes in the level of experience as long as there exists some mobility of technical knowledge. Thus using $\Sigma\frac{V}{L}$ as a proxy measure automatically allows for learning from the experience of others and, in fact, this proxy is not suitable for on-the-job-learning but is far better suited for measuring "technical experience" as defined above. The formulation of the technical experience hypothesis does not require any change in proxy measures in an aggregative study, such as this one, where entire non-agricultural economies are used as single units. On a more disaggregated level, however, it would be probably useful to employ instead two proxies, one local $(K/L)^{a_2}$ and one $(K/L)^{a_2}$ for the entire manufacturing sector, especially where the difference between the two variables is considerable.

The second type of hypothesis that was considered was dealing with a partial determination of technological change by improvements in the quality of new physical capital. The need to evaluate these improvements is suggested by two considerations:-

1. The conventional price indeces used to convert

capital in current prices to a measure in constant prices overdeflate it because they do not take into account changes in the quality of capital (D. Jorgenson, Z. Griliches). This source of error exists only over time and is thus partly eliminated in our study by the cross-sectional influence which is also larger (20 countries vs. 14 years). Also using K* will eliminate much of this error.

2. Cambridge school of capital embodied technological change as given, e.g., in N. Kaldor's "technical progress function". There are two variants of this approach:-

(a) Vintage embodiment of technological change (R. Solow, L. Johansen, B. Massel) involves an exogeneously given constant rate of technological change which is embodied every year in that year's investment. Thus old capital develops relative inferiority and it becomes necessary to convert all vintages into equivalent capital stock by weighting each vintage by the technology of the year in which it was produced. The long-run implications of this hypothesis, however, do not appear to be relevant to this study which is concerned with the determination of the rate of technological change itself. In periods ofrelatively high investment the average age of capital will be lowered, the rate of modernization higher, and the productive system nearer the technological frontier. This improvement, however, can last only as long as the investment is increasingat an increasing proportionate rate. When invetsment activity declines, the process is reversed. This approach is relevant as to the effects on productivity of short-run bursts of investment but it does not seem to contributeto the determination of the long-run rate of technological change (Phelps, 1962).

In my paper on "Growth Implications of Optimum Allocation in Diminishing Cost Industries" (1964) I postulated a hypothesis that the rate of technological change is not an exogeneously given constant rate but is itself a function of the gap between the technology actually used by the productive system and the technological frontier. I have not yet, hoever, elaborated this idea into a formal presentation and this hypothesis will not be, therefore, tested here.

(b) Learning by doing in capital goods industries hypothesis as proposed in Arrow's celebrated paper suggests that the rate of technological change is partly determined by the rate of investment in producer capital goods. In capital goods industries, on-the-job-learning in one period is embodied in capital goods produced in the next period. Hence the rate of quality improvement of machines is a function of experience gained in producing them. This self-contained theory of endogeneous technological change possesses great intellectual attractiveness and has been shown, for individual industries, to be as important as the on-the-job-learning effect. It is not at all clear, however, why on-the-job-learning should occur in capital goods industries only and not in services and consumption industries as well.

Thus, despite the fact that Arrow applied his hypothesis to the entire economy, it is believed that it should be applied to sectional studies only (F. Hahn & C. Mathews, 1964). When the entire economy is used, it seems that this hypothesis largely reduces itself to our technical experience hypothesis which embraces all productive processes.

To test Arrow's hypothesis we would have to use investment as a determinant of technology. We have good reason to believe, however, that investment is very highly correlated with capital input (simple correlation between K and $\sum^{-3} I$ is 0.987). Neither is this correlation spurious. Goodwin's hypothesis that investment is a function of the difference between actual and the optimal levels of capital utilization implies that investment could be used as a proxy measure for capital input. It is thus not clear how Arrow's hypothesis can be tested in a Cobb-Douglas production function framework. Nevertheless, Arrow's hypothesis provides additional theoretical justification for our hypothesis since Arrow's basic idea is the same as ours: in a macro-economic context the level of technology is largely determined by learning by experience which is a function of cumulated output.

Joan Robinson also suggests (1962) that the rate of technological change is not autonomous but that "there is a strong connection between the drive to accumulate and the drive to increase productivity". This probably implies that $\Delta T/T = f(\Delta K/K)$, using K for size deflator, which integrates to $T = f(K)$. If this function is assumed logarithmic, K^{a_3} will be the proxy for technology in $\ln V = a_0^* + a_1 \ln L + a_2 \ln K + K^{a_3}$. If the function is assumed linear, technological change cannot be isolated and will come out through a larger coefficient of capital and increasing returns to scale. Thus it is not clear how this hypothesis should be interpreted and it cannot, therefore, be tested until it has been restated in more formal terms.

Thus it seems that, out of the above set, some hypotheses, while interesting, are not yet sufficiently formulated for testing in this model, and others can be shown to be either irrelevant or to reduce to our single hypothesis of technical experience. This is applicable only to our aggregative study where entire nonagricultural sectors of the economies are used as single units. We shall test, therefore, only for one hypothesis in this field, namely the technical experience hypothesis, using $\frac{\Sigma V}{\Sigma L}$ as the measure of this experience.

After all the results of this study have been obtained, prof. Alvin Marty drew my attention to an inaugural lecture by Nicolas Kaldor delivered at the University of Cambridge on Nov. 2, 1966. Prof. Kaldor's lecture covers what is, in effect, an outline of a theory of economic growth:-

"... the purpose of my lecture to-day is ... to suggest an alternative approach which seeks to explain the recorded differences in growth rates in terms of the stage of economic development attained by different countries ... ."

The first part of his lecture, however, offers an extensive theoretical discussion of the most important, in his view, determinant of technological advance which, though it is a broader concept, is in part similar to that offered in our study: learning as the product of experience measured by cumulated past output. Kaldor's lecture seems to provide an additional theoretical justification for our hypothesis and his conclusions based on the results of his brief econometric study closely parallel our first results: increases in the productivity of labor are due less to increases in capital than to increases in technology which itself is, to a large extent, determined by cumulated past output serving as a measure of acquired experience.

Kaldor begins his analysis by suggesting that changes in the productivity of labor are mainly due to two factors. The first but a much less important factor is investment: "differences in investment behaviour explain residual differences which are relatively less important (in relation to increasing returns)". Much more important is the second factor which consists of increasing returns in the Kaldorian sense which are mainly increases in the skill of labor due to an increasing division of labor and learning from experience. The level of productivity due to this factor "is a function of cumulative output".

Kaldor poses his problem as follows:-

"Since the differences in growth rates are largely accounted for by differences in the rate of growth of productivity (and not of changes in the working population), the primary explanation must lie in the technological field - it must be related to the behaviour of productivity growth. Is there some general reason which makes the rate of increase of output-per-man, for the economy as a whole, dependent on the rate of growth of manufacturing production?"

As a result of some statistical evidence, Kaldor limits the dependence to the rate of growth of manufacturing production only, not to that of the entire economy. The rate of growth of the manufacturing sector has been selected by Kaldor as the main determinant of productivity in the entire economy. Kaldor continues:-

> "It has been suggested that because the level of productivity in manufacturing activities is higher than in the rest of the economy, a faster expansion of the high-productivity manufacturing sectors pulls up the average; and also that the incidence of technical progress - as measured by the rate of growth of productivity - is higher in manufacturing activities than in the other fields, so that a greater concentration on manufacturing increases the overall rate of advance. ..., neither of these suppositions seem capable of explaining the facts. The differences in the level of output per head between different sectors, as Beckerman (1965) has recently shown, are quite incapable of explaining more than a small part of the observed differences in productivity growth rates, in terms of inter-sectoral shifts.[1] The second proposition, if it were factually correct, would relate the rate of economic growth to the size of the manufacturing sector (in relation to the whole economy): ... it would make the rate of economic growth the highest in those countries whose industrial sector ... is the largest. On this test, therefore, Britain ought to come out near the top, not at the bottom of the league-table. But quite

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1) For Britain. For other countries the agricultural sector would have to be, in most cases, excluded from this argument.

apart from this, the proposition is factually incorrect ...; in many of the countries examined, productivity growth in agriculture and mining has been higher than in manufacturing.

There is, however, a third possible explanation - the existence of economies of scale, or increasing returns, which causes productivity to increase in response to, or as a by-product of, the increase in total output. that manufacturing activities are subject to the 'law of increasing returns' was of course a well-known contention of the classical economists. ... As (Adam) Smith explained, the division of labor depends on the extent of the market... . Neo-classical writers, with one or two famous exceptions, like Marshall and Allyn Young, tended to ignore, or to underplay, this phenomenon. As Hahn and Matthews (1964) remarked in a recent article 'the reason for neglect is no doubt the difficulty of fitting increasing returns into the prevailing framework of perfect competition and marginal productivity factor pricing'."

In our study, however, we are using neither of the above assumptions and are allowing the data itself to give us an estimate of the coefficients of capital and labor. Nevertheless , our estimates, like those of virtually all econometric investigators before us, still indicate constant returns to scale. Kaldor continues:-

"However Adam Smith, like both Marshall and Allyn Young after him, emphasized the interplay of static and dynamic factors in causing returns to increase with an increase in the scale of industrial activities. A greater division of labor is more productive, partly because it generates more skill and know-how; more expertise in turn yields more innovations and design improvements. ... Learning is the product of experience - which means, as Arrow has shown, that productivity tends to grow the faster, the faster output expands; it also means that the level of productivity is a function of cumulative output (from the beginning) rather than of the rate of production per unit of time." 1

We can see that Kaldor includes in his "increasing returns" three separate factors. Firstly, the effect of

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1) My italics.

indivisibilities to which Kaldor does not seem to attach much importance - this is in line with most econometric findings. Secondly, learning produced by increased specialization due to greater division of labor. This effect would take place when total output increases but output per worker remains constant. In this case the skill of labor increases because the field of productive activity of each worker has been narrowed so that each produces more of fewer items. The output per worker of each item produced has been increased by reducing the number of items each worker is producing. It is an increase in the cumulated output per worker of each item that enables the worker to acquire greater experience in relation to each item he is producing and it is also, therefore, a cause of an increase in his total productivity due to specialization. But this is not the only way in which "learning as the product of experience" can be obtained since an increase in the cumulated output per worker can also be secured by other means such as increasing the amount of capital per worker, increasing his education, etc. Thus increases in the cumulated output per worker due to, e.g., increases in capital per worker, and not to pure increases in scale holding capital per worker constant, will also lead to increases in his experience and skill and this is the third factor which must be included in Kaldor's total effect. In fact, most studies indicate that increases in returns to scale are probably very small while large unexplained residuals are allocated to increases in technology. It seems that the third factor must be an important one and this is not unexpected since increases in the cumulated output per worker contribute fully to experience while in the case of increases to scale only that part of the increase in scale contributes to experience which will be associated with an increased division of labor - and in many instances this part may be very small indeed.

If we ignore the first factor, we are left with experience as the main determinant of productivity and we can then say with Kaldor that "Learning is the product of experience - which means that the level of productivity is a function of cumulated output..." Since Kaldor does not differenciate between the second and third factors, he uses cumulated output as a proxy measure for experience. In our study we must rely, however, on the long series of econometric studies which, beginning with P.H. Douglas's celebrated work, seem to be consistent in indicating the existence of constant returns to scale (A.A. Walters, Econometrica,'63, Tables I through V). In steady growth (where the percentage rate of growth of output is constant) using cumulated output as an independent variable in a Cobb-Douglas function will reduce itself to increasing returns to scale by increasing the sum of the coefficients of capital and labor. (Kaldor overcomes this difficulty by assuming that the K/L ratio is constant.) Since many of the econometric studies mentioned above must have to an extent covered periods of approximately steady growth, increasing returns would have demonstrated themselves at least to some extent on a substantial unmber of occasions. Since this was not the case, we seem to be justified in rejecting pure increases in scale (increases in total output with K per worker constant) as an important factor in increasing productivity. As a consequence we are induced to rely only on the third factor in Kaldor's total productivity effect, that is on learning by experience which is a function of cumulated output per worker.

This, however, does not undermine the relationship between Kaldor's main argument and our hypothesis of technical experience. Thus Kaldor's discussion provides a basis and a broad theoretical framework for our hypothesis and a justification for using cumulated output as a proxy variable for experience.

In the next section Kaldor quotes Allyn Young to establish the applicability of this hypothesis in a macro-economic context. He suggests that so many of these activities associated with expanding experience involve "...the emergence of new processes and new subsidiary industries, (that) they cannot be 'discerned adequately by observing the effects of variations in the size of an individual firm or of a particular industry'."

At any time there may be industries in which learning from own experience may become relatively small. "They may nevertheless benefit from a general industrial expansion which, as Young said, should be 'seen as an interrelated whole'." It would appear that this argument refers to what we have described as a high mobility of technical experience within one economy. It was for this reason that we have decided to use an international comparison of entire nonagricultural sectors of different economies since it would not have been possible to associate properly the full effects of the determinants with the changes in the level of technology caused by them if this were to be done within one narrow sector or industry.

The very important question of the direction of causality is discussed next:-

" There are some economists who, whilst admitting the statistical relationship between productivity growth and production growth, argue that it says nothing about cause and effect: the Verdoorn Law, according to this view, may simply reflect the fact that faster growth rates in productivity induce, via their effects on relative costs and prices, a faster rate of growth of demand, and not the other way around.

This alternative hypothesis, however, is not fully specified - if it were, its logical shortcomings would at once be apparent. If the rate of growth of productivity in each industry and in each country was a fully autonomous factor, we need some hypothesis to explain it. The usual hypothesis is that the growth of productivity is mainly to be explained by the progress of knowledge in science and technology. But in that case how is one to explain the large differences in the same industry over the same period in different countries? How can the progress of knowledge account for the fact, for example, that in the period 1954-60, productivity in the German motor-car industry increased at 7% a year and in Britain only 2.7% a year? Since large segments of the car industry in both countries were controlled by the same American firms, they must have had the same access to the improvements in knowledge and know-how. ...

Moreover, to establish this alternative hypothesis, it is not enough to postulate that productivity growth rates are autonomous. It is also necessary to assume that differences in productivity growth rates between different industries and sectors are fully reflected in the movement of relative prices (and not in relative movements of wages and other earnings) and further, that the price-elasticity of demand for the products of any one industry, or for the products of manufacturing industry as a whole, are always greater than unity: none of this, as far as I know, has been submitted to econometric verification."

In this study Kaldor relies on the above argument to justify the direction of causality between productivity and the cumulated output representing experience. The argument appears to be quite sufficient to establish unidirectional causality in the desired sense and is, therefore, gladly adopted for our study. In addition to this argument, however, we are employing, in effect, a time-lag in our regression functions since the output is cumulated over a number of past years - thus our claim regarding the direction of causality from cumulated output per worker to current output is strongly supported by this factor.

Kaldor then goes on to discuss the possibility that the effect of experience, as measured by cumulated output, on current output "is a phenomenon peculiarly associated with ... 'secondary' activities - with industrial production, including public utilities, construction, as well as manufacturing - rather than with the primary or tertiary sectors of the economy."

"I am not suggesting that the Verdoorn relationship applies only to manufacturing activities ... . But its application outside the industrial field is clearly far more limited. It certainly does not apply, on the evidence of the statistics, to agriculture and mining, where the growth of productivity in agriculture is merely the passive consequence of the absorbtion of surplus labor in secondary and tertiary occupations, and not necessarily a reflection of true technological progress or of higher investment per unit of output."

It is this last point that induced us to exclude the agricultural sector from our study. Mining, however, was not excluded partly because of the lack of sufficiently detailed data but mainly because there appears to be no "hidden unemployment" in mining as a whole. Moreover, unlike Kaldor, we are not interested in the inter-sectoral relationships within the economy but in the overall importance of various determinants of technology.

There remains the tertiary sector, services, - which together account for 40-50 per cent or more of the total output and employment of the advanced countries. Over much of this field learning by experience must clearly play a role ... . But ... in transport and communications statistical evidence shows no correlation between productivity growth and production growth. In ... distribution, productivity - meaning sales per employee - tends to grow the faster the faster the rise in aggregate turnover; but in this case, it is merely a reflection of the changing incidence of excess capacity generated by imperfect competition, and not of true economies of scale. In other words, productivity may rise in automatic response to the rise in consumption caused by the growth of production in the primary or secondary sectors - just as the productivity of the milkman doubles, without any technological change, when he leaves two bottles of milk outside each door instead of one bottle."

Exclusion of the tertiary sector enabled Kaldor to obtain some interesting results regarding the relative importance of experience in various sectors and as a factor in the theory of growth. This undoubtedly was a fruitful approach in Kaldor's study which was designed to elucidate a specific application of the theory of growth. Our investigation, however, is mainly concerned with only one, and a different aspect of the theory of growth, namely the estimation of the relative importance of what appear to be the main determinants of technological change. Hence the relationships between the sectors and their relevance to the theory of growth are outside our terms of reference, while our attention is centered on the determinants of technology relevant, if possible, to all the important sectors of the economy. It is necessary to exclude the agricultural sector because, as mentioned above, the existence of "hidden unemployment" would seriously distort our results. It would not seem that this would apply, however, to the mining sector and even more to the tertiary sector. As Kaldor himself says regarding the tertiary sector: "Over much of this field learning by experience must clearly play a role ...". Thus in the tertiary sector there is considerable learning by experience and any "automatic response"of its productivity to the rise in demand will not distort the aggregate result since it will merely represent an actual extension to the tertiary sector of a change in overall productivity. Hence the inclusion of this sector will result in our study producing valid estimates of coefficients applicable to the entire nonagricultural economy.

A regression run by Kaldor for data on 12 countries in the period 1953/4 - 1963/4 gave numerical results which are very close to those obtained by Verdoorn and other investigators. We have also compared Kaldor's estimates with our coefficients and found the same similarity in the results though the coefficient of experience given by our regressions is somewhat larger (about 0.6 against Kaldor's 0.5). It must be borne in mind, however, that our results are not, strictly speaking, comparable with Kaldor's results. Kaldor assumed factor intensity ratio, K/L, constant which enabled him to simplify the relationships in his regressions to two variables only. Since in our study data, statistical techniques, and computing facilities were all available, it was not necessary for us to adopt this relatively rigid method. Consequently, multiple regression techniques were used in our work enabling us to avoid making unnecessarily restrictive assumptions, and largely eliminating the possibility, always present in simple regressions, that the coefficient of the independent variable has appropriated the influence of other independent variables not specified in the regression function but correlated with the specified independent variable. On the other hand, Kaldor's method seems to have the advantage of allowing the dynamic relationships to have a greater influence on his estimates since he uses long-run rates of change as his data rather than the annual figures of the levels of variables. Because Kaldor is very interested in the dynamic asp ct of the theory of growth, this advantage might well have more than offset for him the disadvantages of his method.

In general, Kaldor's analysis, as presented in his inaugural lecture, provides us with additional theoretical basis for our hypothesis of technical experience, measured by cumulated output per worker, as the main determinant of technological change. However, my findings indicate that the cumulated levels of output per worker are themselves crucially dependent on cumulated levels of capital per worker and not on pure changes in scale holding capital per worker constant. With this distinction in mind, it remains the case that Kaldor's theoretical analysis and his empirical findings are in the spirit of one of our basic hypotheses, namely that technical experience, as measured by cumulated output per worker, is the most important determinant of the level of technology.

Hypothesis 2: Technology is partly determined by the level of formal education of labor.

This hypothesis has been first proposed and tested by T. Schultz, and later studied by Z. Griliches, A. Tang, and G. Becker. While this hypothesis has been well worked, I have never seen a very convincing explanation why more formal education should, of itself, make labor more productive, to the great extent usually suggested, in producing what is predominantly physical output. It seems rather that, granted some basic level of education, more formal education would mainly affect output by increasing learning ability and adaptability to change. This would tend to close the gap between technology used and the technological frontier and could also perhaps push the frontier further on by increasing worker's ability to gain more technical experience from the same amount of K/L. Barring, however, strong correlation between the level of education of workers and that of research and development teams, this effect could not be as strong as is implied. Even if higher formal education of workers were strongly associated with the educational levels of scientists and development engineers, this would still make it very unlikely that a strong effect on the rate of technological change could be produced. This is not to say, of course, that formal education is not producing possibly very large non-monetary gains which may greatly enhance national welfare. But there does not seem to be a plausible explanation of how formal education of workers could increase material output of the economy to any large extent.

A. Maddison ('64) comments regarding 12 largest western nations:- "... it may be concluded that in the 1950's governments made little attempt to gear their educational spending to the growth needs of the economy. Nor is there any evidence that the educational effort bore much relation to the growth rate of the economy." T. Balogh's criticism (Kyklos, '64, p. 263) goes even further in that he discounts the possibility of the existence of a functional relationship between education and output:- "The precisely proportional relationship between the number of educated and national income means that education is regarded as a homogeneous input with simple constant returns, stable over time and between historical periods. This is even in respect of the relatively more highly developed countries an odd sort of supposition, which could not be sustained for a second on mature reflection." Lastly, the International Policy Conference on Economic Growth, O.E.C.D., Summary Reports, Washington, Oct.,'61, p. 10, reports: "The Conference had a full discussion on whether expenditure on education should be viewed as consumption or investment. It was accepted that these two aspects of educational spending could not be disassociated ...". (The participants were: W.A. Lewis, I. Svennilson, J. Tinbergen, F. Harbison, H.C. Boss, T. Schultz, T. Balogh, et al.)

On the other hand, the four studies mentioned at the beginning of this section give, in most cases, large coefficients to education. The following criticisms, however, can be made: most studies did not use competing variables such as technical experience associated with cumulated V/L with which education is strongly correlated. Secondly, it is possible that able persons obtain more education rather than the education produces more ability. In this case the index of education would serve merely as an index of ability and would have nothing to do with the contribution of education to output, unless the study uses international comparisons (such as this one) where this effect is eliminated. Lastly, education is likely to be, to some extent, a consumption good. Thus it will be probably purchased in greater (possibly in increasingly greater) quantities by those who have higher incomes, ie., by those who, by and large, already are more productive. This effect will also tend to attribute un unduly large importance to education.

In this study the first two effects have been eliminated by employing analysis of covariance with other variables and by using international data. The third effect cannot be entirely eliminated but it is expected that it is far less important than the other two. Moreover, while higher income recipients probably purchase more education in all countries, considerable variations in this propensity from country to country are likely to diminish the correlation between labor productivity due to other factors and the amount of education purchased for consumption. Thus even the third effect will be smaller in an international study than in a national study where the differences in the above propensity from sector to sector are likely to be much smaller.

The level of education of the non-agricultural labor force was measured by three proxy variables (see Chapter II, pp. 31-36, and pp. 37-40) . First, primary and secondary school enrollment rate for the population of eligible ages, lagged 5 years. Second, the same enrollment rate but weighted for the primary and secondary levels by the indeces of estimated average earnings of prsons with primary as against persons with s condary education. Third , average weighted years of education for the whole population. Complete data were not available for this proxy and the figures obtained had to be extended over the entire field of the sample by using the measure of the weighted enrollment rate which is highly correlated with average weighted years of education.

The simple correlation between the proxy measures and the level of technology varies from r = 0.64 to r = 0.94. Variance of the coefficients is so small that even coefficients as small as 0.014 are significant at the 95% level of confidence.

<u>Hypothesis 3: Technology is partly determined by the relationship between the aggregate demand and supply.</u>

A. Maddison (Eco. Growth in the West) expresses this hypothesis as follows: "High demand also had an effect on productivity. The direct impact of a high level of activity may well be to lower productivity by bringing the least efficient resources into operation, though this is probably offset by the better use of resources made possible by the greater steadiness of demand. But high and steady demand also affects productivity favorably by stimulating investment, research and product development." Maddison then explains that this is subject to the limitation that there is no rapid inflation which would increase considerably the risks of investment and force the entrepreneurs to retrench. The hypothesis is really quite simple: if all resources are already well committed and aggregate demand is still pressing for more output, entrepreneurs will turn to the only alternative left - more productive techniques - and will invest in research and innovation. High and steady demand with no rapid inflation will accelerate technological change.

Since there was no rapid inflation in any of the countries here studied over the period 1950-63, while the rates of unemployment of labor varied greatly (decade average for FR: 1.3%, U.K.; 2.5%, U.S.: 4.5% - variation of 92% and 80% respectively), we need not concern ourselves unduly with price variations and can concentrate on unemployment rates. No measure exists for unemployment rates for all resources but relatively good data are available for labor. Since it seems that in the above hypothesis unemployment of labor may well be much more important than that of other factors (due to its effect on higher wage demands and entrepreneurs' attempts to meet those demands and offset higher wage costs with higher productivity), the unemployment rate of labor suggests itself as a very good proxy measure.

<u>Hypothesis 4: Technology is partly determined by time.</u>

If this relationship exists, then it is a measure of our ignorance. This hypothesis has been used by J. Tinbergen and by Solow in his vintage embodiment approach. If our study produces a significant coefficient for the time variable, then that part of technological change must be imputed to it until better or more explanatory variables are found or better analytical tools constructed. After the variables explaining technological change are inserted back into the production function, it will be tested again with time dummy variables to see if any time trend remains.

Hypotheses Not Tested

A number of hypotheses were not tested for lack of data. Of these the only one that is widely accepted as very important is the hypothesis concerned with the effect of research and development expenditures on technology. Unfortunately, so little data is available in this field that we are unable to test this hypothesis. It is very likely, therefore, that our other variables, which may well be strongly correlated with the expenditures on research and development, will appropriate some unknown part of the influence of this variable on technological change.

Lastly, something perhaps should be said regarding the methodology employed in this type of econometric testing. The method used here is that we take an accepted or a widely discussedhypothesis and use a variable to test it. The result, then, is in one sense negative in that the hypothesis is "not rejected rather than definitely "proven". In general, if it is possible, we try to cover the entire field by testing as many hypotheses as are relevant,reasonably widely accepted, and capable of econometric testing. We then accept the "not rejected" hypotheses and, since there are no other hypotheses which are a recognized part of economic theory and are capable of explaining our phenomena, we construct our conclusions on the basis of the "not rejected"hypotheses as if those hypotheses were actually proven. This, of course, has the obvious weakness that in many cases the tested proxy variable may be considered to represent some other, less known or even not yet formulated hypothesis. This, for example, may be shown in the case of on-the-job-learning hypothesis where the proxy variable used would be compatible with a hypothesisthat technology is a function of past technological progress and capital accumulation which, in turn, were due to an exogeneous factor of high propensity to innovation and capital accumulation. Our tests do not differentiate between these two hypotheses - the only grounds for not considering the alternative hypothesis is that it has not been widely accepted or discussed in economic literature and is not, therefore, a part of accepted economic theory in this field.

CHAPTER VI

METHOD OF ESTIMATION

Since it is possible that different determinant variables and/or different coefficients apply to technological advance over time as against relative efficiency over countries, we will run separate regressions on these two series. The level of technology over time is given by the series of coefficients of time dummies converted into index numbers and the level of technology over countries is given by the coefficients of country dummies, less the general constant a_o, converted into index numbers as described earlier (see Chapter IV, pp. 65-67).

Variables

The following variables were used in regressions:-

G - level of technology over time (technological advance).

F - level of technology over countries (relative efficiency).

$\sum\frac{Y}{L}$ - output per man-hour cumulated over the past seven years serving as a measure of technical experience.

E - average, weighted years of education for the entire population. This variable was chosen as the proxy for the level of formal education of nonagricultural labor. Enrollment rates were also tested but gave poorer results.

U - adjusted rate of unemployment of labor serving as a proxy variable for the relationship between aggregate demand and supply.

The same three variables, $\sum\frac{V}{L}$, E, and U, were fitted to the G series and to the F series.

Form of the Function

Two forms will be tested (following L. G. Telser, 1962):

4.1 $$G = b_0 + b_1 \ln\sum\frac{V}{L} + b_2 \ln E + b_3 \ln U + u \,.$$

This corresponds to:

$$V = A_0 L^{a_1} K^{a_2} \left(\sum\frac{V}{L}\right)^{a_3} E^{a_4} U^{a_5} u \,.$$

And,

4.2 $$\ln G = b_0 + b_1 \ln\sum\frac{V}{L} + b_2 \ln E + b_3 \ln U + u \,,$$

which corresponds to:

$$V = A_0 L^{a_1} K^{a_2} e^{B_0 \left(\sum\frac{V}{L}\right)^{b_1} E^{b_2} U^{b_3}} u \,.$$

Both forms will also be used with the F series. The two forms are tested in order to minimize the possibility of mis-specification of the form of the function and have different implications regarding the nature of the returns to the variables concerned. The characteristics of the returns to a variable, say E, can be determined by taking the second derivative of the function with respect to that variable.

Thus,

$$\frac{\partial^2 G}{\partial E^2} = \frac{-b_2}{E^2} < 0 , \qquad \text{for (4.1),} \quad \text{and}$$

$$\frac{\partial^2 G}{\partial E^2} = \frac{b_2 G(b_2 - 1)}{E^2} \gtrless 0 , \qquad \text{for (4.2).}$$

Hence the variable concerned has a decreasing marginal product in (4.1) and an increasing, constant, or decreasing marginal product in (4.2) depending on whether b_2 is greater than, equal to, or less than one. Function (4.2) can tell us whether any countries are investing too much in the second input and also if it is proper to use (4.1) in the first place. As can be seen from the results of the four regressions given in the next chapter, function (4.1) appears more consistent and gives smaller standard errors of the only significant coefficient. The numerical values of the coefficient of $\sum\frac{Y}{L}$ is less than one indicating decreasing marginal product and, therefore, noevidence of underinvestment in this input. It is also proper to use this form since the results of fitting (4.2) indicate diminishing returns to all inputs.

If the results of regressions indicate that the same variables with very similar coefficients apply to both, the technological advance G series and the relative efficiency F series, we will be in a position to insert these determinants directly into the production function. This would enable us to test the relevance of the determinants in both, the time-series and the cross-sectional data.

In any case, asthe last step, we will re-run the regressions with determinants of technology and also with time and country dummies to test for the relevance of the time trend, to assess the extent of the trade-off between the determinants of technology and the dummy variables, and to obtain an estimate of the final residual.

CHAPTER VII

TESTS OF HYPOTHESES

This chapter describes tests of all hypotheses used in this study beginning with the test of the form of the function suitable for regressions on technological advance G series and relative efficiency F series (see Chapter VI, above).

<u>Regression Functions</u>

The following regressions were obtained:-

4.1a $$G = -2.123160 + \underset{(0.10790)}{0.747309} \ln\Sigma\frac{V}{L};$$

$$r = 0.99110, \quad s_e = 0.0974.$$

4.2a $$\ln G = -3.064657 + \underset{(0.09704)}{0.645812} \ln\Sigma\frac{V}{L};$$

$$r = 0.99187, \quad s_e = 0.0924.$$

5.1a $$F = 7.965928 + \underset{(0.04575)}{0.663612} \ln\Sigma\frac{V}{L};$$

$$r = 0.97850, \quad s_e = 0.3037.$$

5.2a $$\ln F = 2.088055 + \underset{(0.00508)}{0.068940} \ln\Sigma\frac{V}{L};$$

$$r = 0.97661, \quad s_e = 0.3162.$$

Figures in parenthesis give standard errors of coefficients. Coefficients of E and U were not significant at the 90%

level of confidence.

Functions (4.1) and (5.1) seem to be more consistent regarding the value of the coefficient of $\Sigma\frac{Y}{L}$ which appears to decline suddenly in (5.2) to a very low value of 0.069. What is more important, standard errors of the coefficients are lower in (4.1) and (5.1) in relation to their coefficients (F values are: 47.9 against 44.2, and 209.9 against 183.5). The differences between the coefficents of correlation and the standard errors of estimate are not significant. Finally, the form of (4.1) and (5.1) lends itself to a simpler and theoretically more acceptable insertion into the production function (see Chapter VI above). Functions (4.2a) and (5.2a) will be, therefore, rejected.

While analysis of covariance enables us to get much better estimates of the coefficients of labor and capital, and to isolate and separate technological advance and relative efficiency series, it does impose its own rigid form. Bearing in mind this shortcoming of the method, the above test gave us the following results:-

1. There is no evidence that E and U are important determinants of technological advance and relative efficiency.
2. Changes in technical experience are a very important determinant of both, technological advance and relative efficiency. In view of large r^2 and small s_e, this one variable seemingly explains some 95% of the variation in technology, this conclusion being reinforced by its

consistency over time-series and cross-sectional analysis. But we have not specified all determinants (e.g., expenditures on research and development) and, to the extent that our variable may be strongly correlated with other determinants, it will appropriate their share of influence on the level of technology.

3. The coefficient of $\Sigma\frac{Y}{L}$ is very similar for both, technological advance and relative efficiency. The same probably applies to E and U where the coefficients were not significantly different from zero (both, the absolute values of the coefficients, and their variances, were very small). We are justified, therefore, in inserting all three variables back into the production function. This will eliminate the rigidity associated with the analysis of covariance method and thus should enable us to obtain better results.

<u>Regressions of Expanded Production Function</u>

The following was obtained:-

$$6. \quad \ln V = -1.81124 + \underset{(0.01616)}{0.88496} \ln L + \underset{(0.01851)}{0.11358} \ln K + \underset{(0.01776)}{0.83722} \ln \Sigma\frac{Y}{L} + \underset{(0.00894)}{0.06875} \ln E \, .$$

$$R = 0.99921 \, . \qquad s_e = 0.0598 \, .$$

The results for R and s_e are very impressive indeed. Clearly, a very considerable improvement occurred over the two input production function (where R = 0.9917 and s_e = 0.2003) and this function with only two determinants of technology gives results as good as the production function with 34 dummy variables (see p. 73 - R = 0.9992 and s_e = 0.0634). The coefficient of E is small. The coefficient of U is not significant at the 95% level of confidence.

This function was also run with weighted enrollment rates rather than the average years of education as a proxy for the educational level of labor. This, however, gave poorer results because although the coefficient was slightly higher (0.07703), its standard error was much greater (0.01325 against 0.00894). This was also reflected in the standard error of estimate which was 0.0622 against 0.0598.

Next, the same regression was run with the analysis of covariance to test for the time trend and the unexplained residual.

7. $$\ln V = -1.25621 + \underset{(0.01233)}{0.72443 \ln L} + \underset{(0.01937)}{0.25234 \ln K} +$$

$$+ \underset{(0.01529)}{0.62491 \ln \Sigma \tfrac{V}{L}} + \underset{(0.00465)}{0.03911 \ln E} +$$

+0.04725	D_{50}	(0.01101)	-0.05988	D_{NO}	D_{NO} D_{YU} 01488)
-0.02367	D_{58}	(0.01019)	-0.12701	D_{YU}	D_{US} 01398)
+0.07628	D_{BE}	(0.01319)	+0.14016	D_{US}	(0.02078)
+0.11591	D_{LU}	(0.02699)	-0.03498	D_{AU}	(0.01160)
+0.02879	D_{GE}	(0.01501)	-0.12980	D_{CO}	(0.01611)
+0.13719	D_{FR}	(0.01576)	-0.19742	D_{IN}	(0.01965)
+0.07101	D_{UK}	(0.01602)	-0.06229	D_{IT}	(0.01489)
+0.10098	D_{SW}	(0.01369)	+0.03860	D_{DE}	(0.01395).

R = 0.99958 . s_e = 0.0411 .

We observe that all time trend has been eliminated. The range of the relative efficiency has been reduced from -1.10 (IN) to 0.54 (US), down to -0.20 to 0.14, a mere 21% of the previous range, six countries out of 20 eliminated, and the pattern of the rest largely reduced to minor variations. The coefficient of U is still insignificant and the coefficient of E has been somewhat reduced. But this trade-off between dummies and the weaker variables must be exoected and need not necessarily be taken as lowering of the validity of their coefficients.

One qualification of our results must, however, be made here. The coefficients of $\sum\frac{V}{L}$, when regressed with the G and F series where there was apparently no possibility of a spurious correlation between the technological change series and $\sum\frac{V}{L}$, were 0.747 and 0.663. In equasion (6), however, the coefficient of $\sum\frac{V}{L}$ is 0.837 and it is possible that, to the extent to which it exceeds the value of the previous two coefficients, it has been biased upwards as a result of a spurious correlation with output V.

The following conclusions are now drawn:-

1. Technical experience appears as by far the most important determinant of technology.
2. Educational level of the labor force seems to be a weaker determinant of secondary importance.
3. We can explain, mainly by means of the technical experience variable but also with some assistance from the educational variable, practically all of technological advance and over 3/4 of the relative efficiency.

4. Hypotheses 1 and 2 (technical experience and education) are accepted subject to the qualifications under points 2 and 3 above. Hypotheses 3 and 4 (demand and time trend) are rejected.

Effect of Growth on the Importance of the Determinants.

While discussing Hypothesis 2, it was argued that the function of formal education, among others, is not so much to contribute to material output as to produce adaptability and ability to learn. The negative part of that suggestion seems to be amply confirmed but to support the positive part we would have to show that, under conditions where adaptability and ability to learn are very useful, the coefficient of E is higher. The coefficient of E should be higher for fast growing, and slower for slowly growing economies than the value given by function (6). The following hypothesis attempts to deal with this problem.

Hypothesis 5: The coefficient of the level of formal education of labor variable is a function of the relationship between the rate of growth of output per manhour and the level of formal education of labor.

As an example: $a_4 = f(\frac{\Delta (V/L)}{V/L} - E)$, where the coefficient of E is simply a linear function of the difference between the percentage change in output per manhour and the level of formal education of labor. Thus E has a greater positive effect on V/L in fast growing than in slow growing countries, where it may even become negative. The suggested causality is as follows:-

a. The higher is the V/L, the higher is the level of complication of techniques, and the higher is the necessary basic rate of E.

b. The faster is the growth of V/L, the greater the need for adaptability and ability to learn and the greater, therefore, is the output productivity of E.

c. Since education offers probably very large non-material gains (which are not included in V), it is very likely that E is usually increased far beyond the basic rate to secure such gains. Thus consideration (a) above would not be important. But such high rates of E would drive its marginal product in terms of V down to very low levels.

d. In fast growing economies this effect would be partly offset. But where V/L is constant or only growing very slowly, such high rates of E may provide labor with learning and adaptability levels much higher than those required to execute their present tasks. This "lack of challenge", perhamps combined with a "revolution of expectations" effect, may make the marginal product of E negative in terms of V. This would be especially true for those slow growing countries where high value is attached to non-material gains accruing from formal education.

<u>Evidence Supporting Hypothesis 5.</u>

Ideally, we would wish to run regressions to obtain a series of coefficients of E for countries with varying rates of growth, and then to run a regression to estimate the functional relationship suggested in this hypothesis. Unfortunately, this cannot be done here because our model of 20 countries becomes very unstable when fewer than 5 or 6 countries are used in a regression (adding, removing, or exchanging one country seriously affects the values of the coefficients) . The best we can do under these circumstances is to divide our countries into two or three groups according to their rates of growth. This will not enable us to test this hypothesis formally but will provide us with useful indications as to the validity of this approach.

Regression Functions Assessing Effects of Growth.

The following table gives 1963 V/L levels in 1954 US dollars per man-hour and the percentage change in that level from 1950 to 1963.

JA	0.52	128%	GE	1.05	62%	YO	0.73	30%
IS	1.19	95%	IT	0.81	60%	ME	0.93	29%
SW	2.09	88%	LU	1.29	53%	CA	2.70	26%
FR	1.53	86%	AU	2.05	52%	UK	1.15	24%
NE	1.28	72%	NO	1.61	52%	CO	0.65	20%
SA	1.10	70%	DE	1.36	46%	IN	0.19	9%
BE	1.39	63%	US	3.59	33%			

The 20 countries were divided into two groups of 10 and two regressions were run:-

FAST COUNTRIES

$$8. \quad \ln V = -1.78352 + \underset{(0.04985)}{0.87491} \ln L + \underset{(0.03892)}{0.11906} \ln K + \underset{(0.04935)}{0.86203} \ln \Sigma \frac{Y}{L} + \underset{(0.03024)}{0.08075} \ln E \, .$$

$$R = 0.99763 \, . \qquad s_e = 0.0602 \, .$$

SLOW COUNTRIES

$$9. \quad \ln V = -1.60307 + \underset{(0.01562)}{0.86112} \ln L + \underset{(0.01679)}{0.11497} \ln K + \underset{(0.02032)}{0.81931} \ln \Sigma \frac{Y}{L} + \underset{(0.00697)}{0.04611} \ln E \, .$$

$$R = 0.99904 \, . \qquad s_e = 0.0462 \, .$$

The coefficient of E changes to 0.081 for fast growing countries (which is well above the average of 0.069), and to 0.046 for the slow growing countries. This supplies some support for our hypothesis even though the test is extremely crude.

In order to explore this somewhat uncertain avenue further, a second attempt was made utilizing a more elaborate technique. The 20 countries were divided into three groups according to the order given by $\frac{\Delta(V/L)}{V/L} - E$. This gave a somewhat different order of countries:-

FAST		MEDIUM		SLOW	
JA	0.52	ME	-0.12	BE	-0.21
IS	0.22	CO	-0.12	NO	-0.24
SA	0.21	NE	-0.13	AU	-0.26
FR	0.15	YU	-0.20	GE	-0.29
SW	0.13	BE	-0.21	DE	-0.34
IT	0.07			CA	-0.45
LU	-0.09			UK	-0.51
IN	-0.12			US	-0.67

The fast and the slow groups were made equal but larger than the medium group to provide more stability. For the same reason Belgium was added to the medium group. The results are as follows:-

10. FAST COUNTRIES

$$\ln V = -1.87113 + \underset{(0.05377)}{0.88425}\ln L + \underset{(0.04853)}{0.08279}\ln K + \underset{(0.05108)}{0.90803}\ln\sum\frac{V}{L} + \underset{(0.03322)}{0.10423}\ln E\ .$$

$$R = 0.99484\ . \qquad s_e = 0.0627\ .$$

11. MEDIUM COUNTRIES

$$\ln V = -1.60136 + \underset{(0.05118)}{0.83754}\ln L + \underset{(0.05272)}{0.15743}\ln K + \underset{(0.04945)}{0.83174}\ln\sum\frac{V}{L} + \underset{(0.01888)}{0.05814}\ln E\ .$$

$$R = 0.99911\ . \qquad s_e = 0.0658\ .$$

12. SLOW COUNTRIES

$$\ln V = -1.51002 + \underset{(0.01607)}{0.88791}\ln L + \underset{(0.01776)}{0.11655}\ln K + \underset{(0.02129)}{0.80897}\ln\sum\frac{V}{L} + \underset{(0.00728)}{0.04248}\ln E\ .$$

$$R = 0.99960\ . \qquad s_e = 0.0426\ .$$

These are good results. The coefficient of E varies in accordance with Hypothesis 5, giving it some support.

To conclude, equations (8) to (12) give definite support to Hypothesis 5. But we are unable to test the hypothesis formally and the equations display considerable instability. It seems, therefore, that the data and the model cannot offer us more information in this respect.

Relative Importance of Variables in Accounting for Output

This will be calculated for various countries and groups of countries over time, as also for differences between countries for the entire period. The purpose is to illustrate what part of actual changes in total output could be allocated to changes in various inputs. This will indicate what was the relative importance of various determinants within the sample studied. Function (6) will be used for all cross-sectional calculations and for "medium" growing countries over time since it is the most general function and is more reliable than function (11). Only for studying changes in "slow" and "fast" growing countries of more extreme type, will functions (10) and (12) be used.

It must be borne in mind that these tables should be viewed only as an illustration since it is not proper to apply our functions to single nations or to very small groups of nations. The correct procedure for individual countries would be to estimate their own functions for data disaggregated into as many sectors as possible.

Fast Growing Countries - Function (10).

Variable	% change	Part of total change in V explained by this variable	% of total change in V explained by this variable	Change in L productivity & that % part of it which is explained by this variable
Japan, France, Italy, 1950-63.				
V	161			76
L	52	46.0	28	-
K*	233	26.6	16	22
$\Sigma(V/L)$	104	87.2	54	74
E	31	2.2	1	3
Unexpl.error		-1.0	1	1
		161.0	100	100
Japan, 1950-63.				
V	261			128
L	60.8	53.8	20.6	-
K*	376.0	42.9	16.4	23
$\Sigma(V/L)$	115.0	96.3	36.9	51
E	26.0	1.8	0.7	1
Unexpl.error		66.2	25.4	25
		261.0	100.0	100
France, 1950-63.				
V	118			86
L	20	17.7	12	-
K*	153	17.4	12	14
$\Sigma(V/L)$	111	92.9	65	75
E	37	2.6	2	2
Unexpl.error		-12.6	9	9
		118.0	100	100

Medium Growing Countries - Function (6).

Variable	% change	Part of total change in V explained by this variable	% of total change in V explained by this variable	Change in L productivity & that % part of it which is explained by this variable
Netherlands, Belgium, Norway, 1950-63.				
V	104			57
L	21	17.6	14.5	-
K*	147	23.5	19.4	23
$\Sigma(V/L)$	84	69.7	57.6	68
E	29	1.7	1.4	2
Unexpl.error		-8.5	7.1	7
		104.0	100.0	100

Variable	% change	Part of total change in V explained by this variable	% of total change in V explained by this variable	Change in L productivity & that % part of it which is explained by this variable

Germany, 1950-63.

Variable	% change	Part of total change in V explained by this variable	% of total change in V explained by this variable	Change in L productivity & that % part of it which is explained by this variable
V	143			62
L	45	37.8	23.5	-
K*	242	38.7	24.0	32
Σ(V/L)	92	76.4	47.5	63
E	19	1.1	0.7	1
Unexpl.error		-9.0	4.3	4
		143.0	100.0	100

Slow Growing Countries - Function (12).

United Kingdom, Canada, Denmark, 1950-63.

Variable	% change	Part of total change in V explained by this variable	% of total change in V explained by this variable	Change in L productivity & that % part of it which is explained by this variable
V	50			32
L	14	12.3	19	-
K*	80	8.8	15	19
Σ(V/L)	40	32.0	50	64
E	53	2.5	5	6
Error		-5.6	11	11
		50.0	100	100

United States, 1950-63.

Variable	% change	Part of total change in V explained by this variable	% of total change in V explained by this variable	Change in L productivity & that % part of it which is explained by this variable
V	64			33
L	26	22.9	35.8	-
K*	66	7.3	11.4	19
Σ(V/L)	33	26.4	41.2	69
E	10	0.4	0.7	1.3
Error		7.0	10.9	10.7
		64.0	100.0	100.0

Cross-sectional Analysis - Function (6).

Italy - Germany.

Variable	% change	Part of total change in V explained by this variable	% of total change in V explained by this variable	Change in L productivity & that % part of it which is explained by this variable
V	122			35
L	71	62.4	51.2	-
K*	104	11.4	9.3	23
Σ(V/L)	32	26.5	21.5	54
E	71	4.9	4.0	9
Error		16.8	14.0	14
		122.0	100.0	100

Variable	% change	Part of total change in V explained by this variable	% of total change in V explained by this variable	Change in L productivity & that % part of it which is explained by this variable
Germany - United Kingdom.				
V	30			20
L	9	7.9	18	-
K*	-8	-0.9	2	2
Σ(V/L)	33	27.4	63	80
E	19	1.3	6	7
Error		-5.7	11	11
		30.0	100	100
Netherlands - Sweden.				
V	7.5			55
L	-33	-29.0	35	-
K*	-13	- 1.4	2	3
Σ(V/L)	55	45.5	54	87
E	-12	- 0.8	1	2
Error		- 6.8	8	8
		7.5	100	100
Sweden - Canada.				
V	151			60
L	77	68.0	45	-
K*	185	20.4	14	26
Σ(V/L)	60	49.5	32	64
E	35	2.4	1.6	3
Error		10.7	7.4	7
		151.0	100.0	100
Canada - United States.				
V	953			27
L	915	805	85	-
K*	910	100	11	83
Σ(V/L)	27	22	2	15
E	38	2.6	0	0
Error		23.4	2	2
		953.0	100	100
Japan - United States.				
V	1013			955
L	72	63.3	6.2	-
K*	866	95.3	9.5	10
Σ(V/L)	955	799.0	79.0	85
E	18	1.2	0.0	0
Error		54.8	5.3	5
		1013.0	100.0	100

CHAPTER VIII

CONCLUSIONS

Before the final conclusions can be presented it will be necessary to introduce a number of qualifying statements.

An Additional Qualification.

Our results indicate that technical experience, as measured by $\sum\frac{V}{L}$, is by far the most important determinant of technology. Since this variable explains so much of technological change, it is reasonable to suspect that it may be strongly correlated with capital invested in research and development. Due to lack of data we were unable to include R&D as a variable but on theoretical grounds it should be a determinant of technology of some consequence. To state this hypothesis:-

Hypothesis 6: Technology is partly determined by capital invested in research and development.

It may be suggested, for example, that as K/L increases, the marginal product of capital in production must decrease and eventually it will pay to invest some of it in R&D. Thus as K/L increases so does capital invested in R&D. Each higher K/L would then be associated with higher capital in R&D and a higher level of technology. Due to the nature of R&D, it is likely that it responds only to sustained expenditures and only after a time lag. Thus this effect should be strongly reflected in cumulated K/L. Since K/L is correlated with V/L, R&D expenditures are probably highly correlated with cumulated V/L which was the proxy for technical experience in our functions.

Thus this proviso must be added to our Hypothesis 1: the proxy used for measuring technical experience is probably highly correlated with capital invested in R&D so that some unknown part of the influence allocated by our regressions to technical experience should be imputed to capital in R&D.

Results of Tests of Hypotheses.

In a highly aggregative study using entire non-agricultural sectors of the economies in a pooled, time-series, cross-sectional analysis, $\sum_{-6}^{T}\frac{V}{L}$ variable alone explains almost all of the technological change. We have used this variable as a proxy measure of technical experience which is an expansion of on-the-job-learning and learning by doing and consists of two parts: 1) the Horndall effect - on-the-job-learning with no outside influences, and 2) on-the-job-learning of labor working with larger capital and output elsewhere and communicated to labor in this productive process.

$\sum\frac{V}{L}$ is used as a proxy for technical experience but the proviso given on page 127 must be added to this hypothesis. In view of the importance appropriated by this proxy it is likely that it is appropriating the influence of, at least, one unspecified variable. Capital in R&D suggests itself since it is probably the most important unspecified variable. Thus by far the most important determinants of technology are most likely technical experience and capital in R&D, in unknown relative proportions.[1]

The level of formal education is accepted as a determinant of technology but its importance in our data seems to be very small. In view of the difficulties encountered in the attempts to disentangle the consumption and investment aspects of educational expenditures, this result should not perhaps be unexpected. Reference should be made, however, to two additional observations. Firstly, the long-run, steady growth coefficient of education (see p.130 below) is quite large. Secondly, our Hypothesis 5 (see Chapter VII) suggested that though formal education may not be very important as a determinant of output and is itself partly output, it may have a much greater effect on output when output itself is growing. While it was impossible to test formally this hypothesis, some evidence was found indicating that the hypothesis is compatible with our data.

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1) While it is not proper to make comparisons between this study and investigations limited to sectors or single industries, it should be perhaps mentioned here that empirical results of studies in those fields seemed to have failed to produce satisfactory evidence of the influence of R&D expenditures on technology (Z. Griliches, AER Proc., '65, p.345). These results were not, however, taken by the investigators to mean that such a relationship does not exist.

The two hypotheses offering aggregate demand and the time trend as determinants of technology are rejected.

Some Implications.

Consider the following transformation of our production function:-

1. $$V = A_0 \, L^{a_1} \, K^{a_2} \left(\tilde{\sum} \frac{V}{L}\right)^{a_3} E^{a_4}.$$

Now in steady growth we have $\dfrac{\Delta (V/L)}{V/L} = g = \text{const.},$

so that, $\tilde{\sum} \dfrac{V}{L} = 7(1 - g)^3 \dfrac{V}{L} = n\dfrac{V}{L}$, where n is a constant.

Applying this to equation (1) we get:-

2. $$V = A_0 \, L^{a_1} \, K^{a_2} \left(n\frac{V}{L}\right)^{a_3} E^{a_4},$$

3. $$V = A_0 \, n^{a_3} \, L^{a_1 - a_3} \, K^{a_2} \, V^{a_3} \, E^{a_4}.$$

Combining constants A_0 and n and simplifying, we obtain:-

4. $$V = A_0^* \, L^{\frac{a_1 - a_3}{1-a_3}} \, K^{\frac{a_2}{1-a_3}} \, E^{\frac{a_4}{1-a_3}},$$

where $A_0^* = (A_0 \, n^{a_3})^{\frac{1}{1-a_3}}$.

Inserting the values obtained inregression (6), we get:-

2a. $$V = A_0 \, L^{.88} \, K^{.11} \left(n\frac{V}{L}\right)^{.84} E^{.07},$$

4a. $$V = A_0^* \, L^{.29} \, K^{.70} \, E^{.42}.$$

Thus in steady growth independent variables 2 and 3 reduce to one variable and the steady growth coefficient of capital becomes 0.70. Now two additional considerations must be introduced. In equation (2a) the coefficient of $\frac{V}{L}$ is nearly equal to the coefficient of labor. Assuming that the two coefficients are, in fact, equal, equation (2a) reduces itself to $V = A_0^{\#} K E^{.60}$ - the fixed capital-output ratio of a spurious Harrod-Domar result. Secondly, even if the two coefficients are different, equation (4a) shows that the steady growth coefficient of education is so large that, if there is a considerable correlation between capital and education inputs, omitting variable E from the production function would bring the estimate of the capital coefficient close to unity. In a model with coefficients constrained to one this would again tend to produce a spurious Harrod-Domar result. These purely empirical results explain how for our data in an oversimplified two factor model the technological change may bias the estimate of the capital coefficient for those sectors and periods where steady growth exists to any important extent.

Thus different results in various studies, sometimes giving a small coefficient of capital input in line with the neoclassical model and sometimes producing a coefficient sufficiently close to one to imply a spurious Harrod-Domar model, can be probably explained to a large extent by the following factors.

1. Short-run, time-series models tend to produce small coefficients of capital largely because they give only the immediate effect of capital on output excluding any

effect capital accumulation may have had on the quality of inputs. Statistically, this effect will be thrown out as the residual of the production function, apparently not associated with capital accumulation at all.

2. In the long-run, steady growth models the effect of capital accumulation on the quality of inputs will be imputed to capital giving a large coefficient of capital input. In many cases, including our own data, this coefficient may well approximate the value of 1.0 thus implying a spurious Harrod-Domar result.

3. Even in the long-run, steady growth models the results of various studies may very considerably due to other determinants of technology, such as R&D expenditures, which may be highly correlated with capital accumulation and will affect, therefore, the coefficient of capital. In addition, possibly partly uncorrelated determinants of technology, such as education, may produce some residual in the production function, though it would be probably quite small.

These points seem to throw some light on the possible reasons for large differences in the estimates of the capital coefficient obtained in different studies. The main conclusion here seems to be that the production function studies to be more fruitful should include among the inputs not only labor and capital but also the main determinants of technology. Studies which exclude the determinants of technology, or which simply assume an exogeneously determined, constant rate of technological change, may easily lead to vague and possibly erroneous conclusions.

Since our empirical results give $a_1 + a_2 = 0.999$, we can assume constant returns to scale and re-write (4a) as follows: $\frac{V}{L} = A_0^* (\frac{K}{L})^{.70} E^{.42}$. Ignoring the effect of education, this equation suggests that V/L is a function of K/L.[1] Thus technical experience measure $\sum \frac{V}{L}$ is to a large extent a function of cumulated $\frac{K}{L}$, where the function allows for the original level of technology and diminishing returns to capital. In economic terms this implies that V/L is a function of K/L and technology but since technology itself is largely determined by K/L (if education is ignored), the cumulated V/L variable can merge with capital input giving a very high steady growth coefficient of capital. Thus it appears that the reason why we obtained technological change as a residual of the production function was mainly because it was rather unreasonably assumed that the effects of capital input must work themselves out fully within one year and also because growth was not steady. Since the effects of capital input did not work themselves out in one year, we had technological advance which was either ignored, assumed God-given, or imputed to quality changes of inputs.

1) This applies to steady growth conditions only but if we refer to the argument on p. 130 abve, we can see that, within quite a large range of the variation in the rate of growth, the disruption of the functional relationship between V/L and K/L would not be large. Thus, to a considerable extent, this argument can be generalized to include conditions of non-steady, though regular growth.

As it happens, quality changes of inputs, if that is how we wish to consider changes in technology, seem to be largely dependent on what is basically cumulated K/L. Thus we are back to capital input.

This implies that short bursts of investment activity are not immediately very productive. It is the longer-run, sustained buildup of K/L that gives high returns. Thus it is difficult to start growth but easier to continue it after several years. Also, when investment is drastically reduced, most of the effect on growth is not immediately apparent and thus a temporary illusion can be created that it is possible to have both, more consumption and the same high rate of growth as before.

Similarly, the benefits of investment in education, though these seem to be much smaller as far as the material output is concerned, appear to acrue mainly in the long-run. Rapid changes in the level of educational expenditures will have little immediate effect. In fact, a sudden increase in such expenditures may actually reduce the national product since it will absorb resources and will probably have only a negligible positive effect on total output in the first few years after the students leave their schools. The long-run effects, on the other hand, are likely to be important. In addition, all educational benefits may be somewhat greater in fast growing economies.

The consequences of assuming an exogeneously given rate of technological change, which is independent of K/L, are well illustrated in J. Tobin and A. Okun's statement: "Why should we save now when our saving produces nothing better than jet airplanes, while the saving of our children will produce transport rockets to take us, or rather them, to Europe in 10 minutes?" Solow carries this argument to its logical conclusion (Solow, 1965): "It is commonplace that anticipated obsolescence reduces the return any private entrepreneur can expect to realize on an investment. ..... Indeed, if society to-day suddenly expects a higher rate of technical progress ... , then society must revise downward the rate of return it expects to earn on current saving. ..... The net private rate of return is therefore ... , the same as the social rate of return."

Solow is fully aware of attempts to make technology endogenously determined and recognizes that if, for instance, Arrow's hypothesis is right, Solow's conclusions cannot be valid. It seems, however, that Solow rejected these models since his entire argument and his empirical comparison between the United States and Western Germany are based on an exogeneously determined, constant rate of technological change.

This view of the society as a speculator trying to outguess the vagaries of the exogeneous rate of technological change is not very satisfying. Nevertheless, the analysis is clearly correct if exogeneously given rate of technological change is assumed. But our results contradict this assumption. Technology is largely a function of cumulated K/L. Hence private return on investment may, or may not be adversely affected by an advance of technology and obsolescence - it depends on how their own investment will affect their technology and to what extent their technology is a function of other investments. Similarly, social and private returns on investment are not identical - social returns are almost certain to be much higher with the exception of perhaps such investments as in some product developments and advertising where private returns may be higher. This, of course, is not to say that Solow's argument is not applicable to a possibly very large area where investment in productive activities has little, or no effect on technology applicable to those activities. There private (but almost cerainly not social) rates of return will be lowered by obsolescence caused by advances of exogenously determined technology.

The trend of a number of recent investigations was towards discounting the importance of capital input in favor of quality variables such as quality of labor input, age of capital, etc. This study suggests a wider framework of a self-contained theory of endogeneous technological change which is mainly a function of changes in cumulated K/L. Capital input, in this form, is vry important indeed when given sufficient time to work itself out fully. The quality variables of technical experience, knowledge acquired through R&D, and possibly other quality variables as well, seem to have been mainly serving as carriers of K/L's influence over time.

Thus what has been usually measured as technological change consisted in fact mainly of technical experience and, most likely, of R&D output, the two variables being almost entirely determined by distributed lag effects of capital per man-hour. Whatever remained could have been probably explained to a large extent by the long-run effects of changes in the educational level.

Limitations

But this argument must not be carried too far. Firstly, we chose a highly aggregative approach which can be severely criticized in connection with the rigourous meaning of such a production function. Other considerations may well offset this disadvantage. In any case, the results, if accepted, will have very wide applicability. Because of this very fact, however, they will also be subject to possibly important additions and modifications when applied at the national or sectoral levels.

Secondly, technical experience is not the only determinant of technology. Education is also a factor of some consequence and even though its short-run effects on output seem to be very small, in the long-run, steady growth models, and perhaps especially for fast growing economies, education may be an input of very considerable importance. Moreover, we had to construct a composite measure of the level of formal level of education of labor. Even though it seems to be a good measure it may contain errors which could have had some effect on the estimates of the coefficient of this variable.

Thrdly, finding a unifying link of the cumulated K/L variable does not mean that the variables which carry its influence over time are of no consequence. It is very important to know how changes in cumulated K/L are worked out through technical experience, probably R&D, and possibly other variables, into final increases in output. The economic process in which this variable determines output is no less important than the knowledge of the extent of its influence.

Summary Comment

This study reverses the trend of a number of recent studies towards discounting the importance of capital in favor of labor input, time trend, some quality variables, etc. It seems that capital input, in its K/L form, is very important indeed when given sufficient time to work itself out fully. The quality variable of technical experience, and probably other quality variables as well, seem to have been mainly serving as carriers of K/L's influence over time.

Thus what has been frequently measured as technological change consisted in fact mainly of technical experience and, most likely, of R&D output, the two variables being almost entirely determined by distributed lag effects of K/L, and, probably to a much smaller extent, of changes in the educational level. In addition, in the case of time-series studies, those indeces of technological change might have well also included increases in the rate of capital utilization (due to inadequate measures of capital input).

The final results of this study seem to imply that there exists, in a very broad context, a basic variable of cumulated capital per man-hour which, when supported by a variable measuring the level of eduction, can be offered as a basis for a self-contained theory of endogeneously determined technological change.

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Abreviations

AER American Economic Review
Em Econometrica
EJ Economic Journal
JEH Journal of Economic History
JFE Journal of Farm Economics
JPE Journal of Political Economy
OECD Organisation for Economic Cooperation and Development
QJE Quarterly Journal of Economics
RES Review of Economics and Statistics
RESt Review of Economic Studies
UN United Nations

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