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CAPITAL AND PRODUCTIVITY: A NEW VIEW

by

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Abstract

Capital, labor and technical progress are the three principal sources of growth of output. Boskin and Lau (1990c) estimated an aggregate meta-production function relating aggregate real output to capital, labor and time for the Group-of-Five (G-5) countries--France, West Germany, Japan, the U.K. and the U.S.--with post-war data and without maintaining the hypotheses of constant returns to scale, neutrality of technical progress and profit maximization with competitive output and input markets or imposing any restriction on the substitution possibilities between capital and labor. It turns out that all of the traditionally maintained hypotheses as well as the Cobb-Douglas production function hypothesis can be rejected by the empirical data.

The principal new findings of Boskin and Lau (1990c) are that in the post-war period (1) technical progress is capital-augmenting rather than neutral or labor-augmenting, as is often assumed; (2) the elasticity of output with respect to measured capital input is much lower than the usual factor-share estimate based on the assumptions of constant returns to scale and profit maximization; and (3) returns to scale are not fixed but variable and as a consequence of (2) above have been decreasing rather than constant. The rate of augmentation of capital, however, is not uniform across countries. In particular, the rate of augmentation of capital is estimated at between 12 and 15 percent per annum for France, West Germany and Japan, and between 7 and 9 percent per annum for the U.K. and the U.S.

The average productivity of capital (the reciprocal of the capital-output ratio), the marginal productivity of capital, and the output elasticity with respect to capital are all found to be declining over time. The elasticity of substitution between capital and labor is found to be low but statistically significantly different from both zero and unity at the 1970 values of capital and labor for all five countries.

Capital-augmenting technical progress implies that the production function can be written in the form: $Y = F(A(t)K, L)$ where $A(t)$ is an index of the level of technology. Thus, capital and technology are complementary. In fact, together they act as if they were a single input. A growth-accounting exercise based on the estimated aggregate meta-production function shows that capital and technical progress combined accounted for more than 70 percent of the growth in output in the five countries.

The implications of capital-augmenting technical progress on output, capital and labor are explored. In particular, it is found that for the post-war period, in addition to being capital-augmenting, technical progress is also capital-saving rather than labor-saving. Consequently, technical progress is not likely to be a prime cause of structural unemployment for the aggregate economy.

1. Introduction

Enhanced capital, labor and technical progress (or equivalently, total factor productivity) are the three principal sources of the economic growth of nations. The rate of growth of labor is generally constrained by the rate of growth of population. It is seldom, especially for industrialized countries, higher than two percent per annum, even with international migration. Consequently, the rate of growth of capital (physical and human) and technical progress have been found to account for a major proportion of economic growth, especially for countries with high growth rates. For example, Jorgenson, Gollop and Fraumeni (1987) find that between 1948 and 1979, capital formation accounted for 46 percent of the economic growth of the United States, growth of labor input accounted for 31 percent, and technical progress accounted for 24 percent.[2]

The importance of the contribution of capital and technical progress to the growth of output can be readily understood with the help of some simple arithmetic. The elasticity of output with respect to measured labor input can typically be estimated as approximately 0.6 for industrialized countries.[3] Thus, given the rate of growth of measured labor force, which is typically no higher than 2 percent per annum, the maximum rate of growth that can be accounted for by the growth in labor input is 1.2 percent. Any growth in output in excess of 1.2 percent may be attributed to the growth in capital input and to technical progress. For a country that grows at 3 percent per annum, at least 60 percent of the growth in output may be attributed to capital and technical progress.

Capital, especially physical capital, is also important for another reason--it is the only input that can be readily varied in the short and intermediate runs. Human capital and technical progress can be influenced only in the long run.

[2] Jorgenson, Gollop and Fraumeni (1987), p. 21.

[3] See, e.g., Boskin and Lau (1990c).

Most aggregate production function and growth-accounting studies[4] assume one or more of the traditionally maintained hypotheses of constant returns to scale in capital and labor,[5] neutrality of technical progress, and profit maximization with competitive output and input markets. The validity (or lack thereof) of each of these hypotheses affects the estimated aggregate production function and the analysis that follows from it. Boskin and Lau (1990c) develop an alternative approach of estimating the aggregate production function without maintaining these assumptions. In Section 2, the new approach for studying the relationship between output, inputs and technical progress, based on the econometric estimation of an aggregate meta-production function,[6] is presented. This new approach is free of the traditionally maintained assumptions. In Section 3, the major new findings of the meta-production function approach are presented. In Section 4, the implications of capital-augmenting technical progress are explored. Some concluding remarks are made in Section 5. In Appendix 1, there is a brief discussion of the data and the statistical model used.

2. The Meta-Production Function Approach

In Boskin and Lau (1990c), a new framework for the analysis of productivity and technical progress, based on the direct econometric estimation of an aggregate meta-production function, that does not require the traditionally maintained assumptions, is introduced. This new approach enables the separate identification of not only the degree of returns to scale and the rate of technical progress in each

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[4]See, for example, Abramovitz (1956), Griliches and Jorgenson (1966, 1967, 1972) and his associates, Kendrick (1961, 1973), Kuznets (1971, 1973), and Solow (1957).

[5]An exception is Denison (1962, 1967, 1979 and 1985), who assumes that there are three inputs--capital, labor and land--and that the degree of returns to scale is 1.1, i.e., if all three inputs are increased by 1 percent, real output is increased by 1.1 percent.

[6]The term "meta-production function" is due to Hayami and Ruttan (1970, 1985). See also Lau and Yotopoulos (1989) and Boskin and Lau (1990c).

country but also their biases, if any. The estimated aggregate meta-production function is then used as the basis for a new analysis of the relationship between growth in output and growth in capital and labor and technical progress.

The new approach is based on the Lau and Yotopoulos (1989) modification of the concept of the meta-production function, introduced by Hayami and Ruttan (1970, 1985), through the use of time-varying, country- and commodity-specific augmentation factors. The basic assumptions for this approach are:

(1) All countries have access to the same technology, that is, they have the same underlying production function $F(.)$, sometimes referred to as a meta-production function, but may operate on different parts of it. The production function, however, applies to standardized, or "efficiency-equivalent", quantities of outputs and inputs, that is:

$$(2.1) \qquad Y^*_{it} = F(K^*_{it}, L^*_{it}) \ , \quad i = 1,\ldots,n \ ;$$

where Y^*_{it}, K^*_{it} and L^*_{it} are the "efficiency-equivalent" quantities of output, capital and labor respectively of the ith country at time t, and n is the number of countries. The assumption of a single meta-production function implies that $F(.)$ does not depend on i (but may depend on t).

(2) There are differences in the technical efficiencies of production and in the qualities and definitions of measured inputs across countries. However, the measured outputs and inputs of the different countries may be converted into standardized, or "efficiency-equivalent", units of inputs by multiplicative country- and output- and input-specific time-varying augmentation factors. The "efficiency-equivalent" quantities of output and inputs of each country are not directly observable. They are, however, assumed to be linked to the measured quantities of outputs, Y_{it}'s , and inputs, K_{it}'s and L_{it}'s , through time-varying, country- and commodity-specific augmentation factors $A_{ij}(t)$'s , $i = 1,\ldots, n$; $j = K,L$:

(2.2) $$Y^*_{it} = A_{i0}(t)Y_{it} \ ;$$

(2.3) $$K^*_{it} = A_{iK}(t)K_{it} \ ;$$

(2.4) $$L^*_{it} = A_{iL}(t)L_{it} \ ; i = 1, ..., n.$$

These assumption require some explanation. Together they imply that the aggregate production function is the same everywhere in terms of standardized, or "efficiency-equivalent", units of outputs and inputs. Moreover, measured inputs of any country may be converted into equivalent units of measured inputs of another country. For example, one unit of capital in country A may be equivalent to two units of capital in country B; and one unit of labor in country A may be equivalent to one-third of a unit of labor in country B. These conversion ratios may also change over time. In terms of the measured quantities of inputs, the production functions of any two countries are <u>not</u> likely to be the same. However, in terms of "efficiency-equivalent" units, the assumption of a common production function across countries is far more plausible.

It turns out that these commodity augmentation factors can in fact be estimated simultaneously with the parameters of the aggregate meta-production function from pooled inter-country time-series data on the quantities of measured outputs and inputs, subject to a normalization. Thus, it is actually possible to answer the question of how many units of labor in country B is equivalent to 1 unit of labor in country A at some given time t empirically.

We note that in terms of the <u>measured</u> quantities of outputs, the production function may be rewritten as:

(2.5) $$Y_{it} = A_{i0}(t)^{-1}F(K^*_{it},L^*_{it}) \ , \ i = 1,...,n \ ;$$

so that the reciprocal of the output-augmentation factor $A_{i0}(t)$ has the interpretation of the possibly time-varying level of the technical efficiency of production, also referred to as output efficiency, in the ith country at time t.

There are many reasons why these commodity augmentation factors are not likely to be identical across countries. Differences in climate, topography and infrastructure; differences in definitions and measurements; differences in quality; differences in the composition of outputs; and differences in the technical efficiencies of production are some examples. The commodity augmentation factors are introduced precisely to capture these differences across countries. In Boskin and Lau (1990c), the commodity augmentation factors are assumed to have the constant exponential form with respect to time. Thus:

$$Y^*_{it} = A_{i0} \exp(c_{i0}\, t) Y_{it} \; ; \tag{2.6}$$

$$K^*_{it} = A_{iK} \exp(c_{iK}\, t) K_{it} \; : \text{and} \tag{2.7}$$

$$L^*_{it} = A_{iL} \exp(c_{iL}\, t) L_{it} \; ; \; i = 1,\ldots,n; \tag{2.8}$$

where the A_{i0}'s , A_{ij}'s , c_{i0}'s , and c_{ij}'s are constants. We shall refer to the A_{i0}'s and A_{ij}'s as augmentation level parameters and c_{i0}'s and c_{ij}'s as augmentation rate parameters. For at least one country, say the ith, the constants A_{i0} and A_{ij}'s can be set identically at unity (or some other arbitrary constants), reflecting the fact that "efficiency-equivalent" outputs and inputs can be measured only relative to some standard. Econometrically this means that the constants A_{i0}'s and A_{ij}'s cannot be uniquely identified without some normalization. Without loss of generality the constants A_{i0} and A_{ij}'s for the United States are taken to be identically unity. The most important observation, however, is that the augmentation level and rate parameters are all potentially estimable subject to such a normalization--there is thus no need to rely on arbitrary assumptions or extraneous information.[7]

(3) The wide ranges of variation of the inputs resulting from the use of inter-country time-series data necessitate the use of a flexible functional form for F(.) above. In addition, a flexible functional

[7] These country and commodity-specific augmentation level and rate parameters can be used as the basis for an international as well as intertemporal comparison of productive efficiencies. See Boskin and Lau (1990c).

form is also needed in order to allow the possibility of non-neutral returns of scale and technical progress.[8] In this study, the aggregate meta-production function is specified to be the transcendental logarithmic (translog) functional form introduced by Christensen, Jorgenson and Lau (1973). For a production function with two inputs, capital (K) and labor (L), the translog production function, in terms of "efficiency-equivalent" output and inputs, takes the form:

$$(2.9) \qquad \begin{aligned} \ln Y^*_{it} = {} & \ln Y_0 + a_K \ln K^*_{it} + a_L \ln L^*_{it} \\ & + B_{KK}(\ln K^*_{it})^2/2 + B_{LL}(\ln L^*_{it})^2/2 \\ & + B_{KL}(\ln K^*_{it})(\ln L^*_{it}). \end{aligned}$$

By substituting equations (2.6) through (2.8) into equation (2.9), we obtain equation (2.10), which is written entirely in terms of observable variables:

$$(2.10) \qquad \begin{aligned} \ln Y_{it} = {} & \ln Y_0 - \ln A_{i0} + a_K \ln A_{iK} + a_L \ln A_{iL} \\ & + B_{KK}(\ln A_{iK})^2/2 + B_{LL}(\ln A_{iL})^2/2 + B_{KL}(\ln A_{iK})(\ln A_{iL}) \\ & + (a_K + B_{KK} \ln A_{iK} + B_{KL} \ln A_{iL}) \ln K_{it} \\ & + (a_L + B_{KL} \ln A_{iK} + B_{LL} \ln A_{iL}) \ln L_{it} \\ & + B_{KK}(\ln K_{it})^2/2 + B_{LL}(\ln L_{it})^2/2 + B_{KL}(\ln K_{it})(\ln L_{it}) \\ & + (-c_{i0} + a_K c_{iK} + a_L c_{iL} \\ & + (B_{KK} \ln A_{iK} + B_{KL} \ln A_{iL}) c_{iK} + (B_{KL} \ln A_{iK} + B_{LL} \ln A_{iL}) c_{iL})t \\ & + (B_{KK} c_{iK} + B_{KL} c_{iL})(\ln K_{it})t \\ & + (B_{KL} c_{iK} + B_{LL} c_{iL})(\ln L_{it})t \\ & + (B_{KK}(c_{iK})^2 + B_{LL}(c_{iL})^2 + 2B_{KL} c_{iK} c_{iL})t^2/2, \end{aligned}$$

[8]For example, if the meta-production function $F(\cdot)$ is chosen to be the Cobb-Douglas form, then the returns to scale will be neutral with respect to the inputs. Moreover, the commodity augmentation factors cannot be separately identified and thus the technology will be indistinguishable from one with neutral technical progress. For this last point, see, for example, Lau (1980).

which simplifies into:

$$(2.11) \qquad \ell n\, Y_{it} = \ell n\, Y_0 + \ell n\, A^*_{i0}$$
$$+ a^*_{iK}\, \ell n\, K_{it} + a^*_{iL}\, \ell n\, L_{it}$$
$$+ B_{KK}(\ell n\, K_{it})^2/2 + B_{LL}(\ell n\, L_{it})^2/2 + B_{KL}(\ell n\, K_{it})(\ell n\, L_{it})$$
$$+ c^*_{i0}t$$
$$+ (B_{KK}\, c_{iK} + B_{KL}\, c_{iL})(\ell n\, K_{it})t$$
$$+ (B_{KL}\, c_{iK} + B_{LL}\, c_{iL})(\ell n\, L_{it})t$$
$$+ (B_{KK}(c_{iK})^2 + B_{LL}(c_{iL})^2 + 2B_{KL}\, c_{iK}\, c_{iL})t^2/2,$$

where A^*_{i0}, a^*_{iK}, a^*_{iL} and c^*_{i0} are country-specific constants. We note that the parameters B_{KK}, B_{KL} and B_{LL} are independent of i, i.e., of the particular individual country. They must therefore be identical across countries. This provides the common link among the aggregate production functions of the different countries. Of course, the maintained hypothesis that the parameters B_{KK}, B_{KL} and B_{LL} are identical across countries, i.e., that there is a single aggregate meta-production function that applies for all the countries, can be empirically tested.

We note further that the parameter corresponding to the $t^2/2$ term for each country is not independent but is completely determined given B_{KK}, B_{KL}, B_{LL}, c_{iK} and c_{iL}. This is the consequence of the maintained hypothesis of a constant exponential commodity-augmentation form of technical progress. This hypothesis can also be empirically tested.

Equation (2.11) is the most general specification possible under our maintained hypotheses of a single meta-production function and constant exponential commodity-augmentation representation of technical progress.

In addition to the aggregate meta-production function, we also consider the behavior of the share of labor costs in the value of output: $w_{it}L_{it}/p_{it}Y_{it}$, where w_{it} is the nominal wage rate and p_{it} is the nominal price of output in the ith country at time t. Under competitive output and input markets, the assumption of profit maximization with respect to labor, which is a necessary condition for overall profit maximization, implies that the elasticity of output with respect to labor is equal to the share of labor cost in the value of output:

$$(2.12) \qquad w_{it}L_{it}/p_{it}Y_{it} = \partial \ln Y_{it}/\partial \ln L_{it}$$

$$= a^{*}_{iL} + B_{KL} \ln K_{it} + B_{LL} \ln L_{it} + (B_{KL}\, c_{iK} + B_{LL}\, c_{iL})t.$$

In other words, the parameters in equation (2.12) are identical to the corresponding ones in equation (2.11). If we do not maintain the hypothesis of profit maximization with respect to labor, the parameters in equation (2.12) do not necessarily have to be the same as those in the aggregate meta-production function. Equation (2.12) may be written in the form:

$$(2.13) \qquad w_{it}L_{it}/p_{it}Y_{it}$$

$$= a^{**}_{iL} + B_{KLi} \ln K_{it} + B_{LLi} \ln L_{it} + B^{*}_{Li}\, t\,.$$

Our new approach is applied to pooled inter-country time-series data. By pooling data across countries, the separate effects of economies of scale and technical progress, usually confounded by the simultaneous expansion of scale with time in the data of a single country, can be more readily identified. (At any given point in time, production at different scales is observed. The same scale of production may be observed at different points in time.) In addition, such pooling allows the identification of not only the rates but also the biases of technical progress as well as the biases of the scale economies, if any. Moreover, inter-country data typically have greater variability in the quantities of inputs than intra-country data, thus facilitating the identification and estimation of the aggregate production function. For example, in data from a single country, the quantities of capital and labor are likely to move quite closely together, the consequence of a fairly constant capital-labor ratio, which may in turn be due to fairly stable relative prices. This multicollinearity may make it impossible to identify and estimate the effects of capital and labor separately without imposing some assumption such as constant returns to scale. With inter-country data, there is likely to be greater variability in the capital-labor ratio across countries, thus mitigating the possible effects of multicollinearity.

From a practical point of view, the primary advantage of our approach, which is based on the direct econometric estimation of an aggregate meta-production function, is that it does not depend on the assumptions of constant returns to scale, neutrality of technical progress, and profit maximization with competitive output and input markets, assumptions which underlie most growth accounting exercises. Instead, these assumption are directly tested. Using this approach, we are also able to estimate the rates and patterns of scale economies and technical progress, as well as the relative contributions of the sources of economic growth, all without making any one of the three traditionally maintained assumptions.

3. Summary of the Major New Findings

Tests of Hypotheses[9]

First, the basic maintained hypotheses of the meta-production function approach adopted by Boskin and Lau (1990c) are tested. They consist of (1) the aggregate production functions of all five countries are identical in terms of "efficiency-equivalent" inputs, that is, there is a single aggregate meta-production function for all countries; and (2) technical progress can be represented in the commodity-augmentation form with each augmentation factor being an exponential function of time, conditional on the single meta-production function hypothesis. Neither hypotheses can be rejected at any level of significance. The non-rejection of these two maintained hypotheses lends empirical support to the validity

[9]Readers interested in the details of these statistical tests may consult Boskin and Lau (1990c).

of the aggregate meta-production function with commodity augmentation factors approach.

Next, the three major hypotheses traditionally maintained for aggregate production function or growth accounting studies--constant returns to scale, neutrality of technical progress and profit maximization with competitive output and input markets--conditional on the validity of our maintained hypotheses of a single meta-production function and exponential commodity augmentation factors are separately tested. In addition, the hypothesis of homogeneity of the production function[10] is tested. it is found that all of these hypotheses can be separately rejected at their assigned levels of significance. The results of these series of tests suggest that the traditional assumptions may not be valid, at least for the countries and time periods under study.

After establishing the validity of their assumptions and the lack of validity of the traditional assumptions, Boskin and Lau (1990c) proceed to examine the nature of technical progress. Specifically, Boskin and Lau (1990c) test whether: (1) augmentation level parameters are identical across countries separately for capital and labor; (2) technical progress can be represented by two sets of augmentation rates; and finally (3) technical progress can be represented by a single set of augmentation rates for output or an input. The purpose of these tests is to establish the levels, rates and biases of technical progress as well as to obtain a parsimonious specification. For example, since the hypothesis of neutrality of technical progress has been rejected, technical progress must be biased, but the magnitude and direction of the bias remain to be determined. Moreover, under the commodity-augmentation hypothesis, the number of independent parameters required to represent technical progress is 6 per country--3 augmentation level parameters and 3 augmentation rate parameters. An interesting question is whether a smaller number will suffice.

[10]Note that the restrictions implied by homogeneity are a subset of the restrictions implied by constant returns to scale. If homogeneity is rejected, constant returns to scale will be rejected at the same level of significance.

It is found that the hypotheses of identical capital and labor augmentation level parameters across countries cannot be rejected. This implies that in the base year (1970), the "efficiencies" of capital and labor were not significantly different across countries. However, because the definitions of the capital stocks are the least inclusive for Japan and the United States and the most inclusive for West Germany and U.K., it also implies that the efficiencies of capital are highest in Japan and the United States, followed by France and then West Germany and U.K. in the base year. In any event, the hypothesis of equal augmentation level parameters across countries must be interpreted carefully because differences in definitions and measurements, in addition to differences in the underlying qualities, will also show up as differences in the estimated augmentation level parameters.

The null hypothesis that technical progress can be represented by two (instead of three) sets of augmentation rates, that is, at least one set of augmentation rate parameters are zero, cannot be rejected at the assigned level of significance. The null hypothesis that technical progress can be represented by a single (instead of two) set of augmentation rate parameters is also tested. Technical progress in these "one-rate" models may be identified as Harrod-neutral, Solow-neutral, and Hicks-neutral respectively. Again, at the assigned level of significance, the hypotheses of zero output and capital rates and zero capital and labor rates[11] are rejected. However, the hypothesis of zero output and labor rates cannot be rejected. Boskin and Lau (1990c) conclude that technical progress can be represented by a single set of augmentation rates for capital, that is, <u>technical progress is capital-augmenting</u>.

A final hypothesis on the nature of technical progress is that of identical capital augmentation rate parameters across countries. This hypothesis, conditional on the maintained hypotheses of the study, identical capital and labor augmentation level parameters, and zero output and labor augmentation rate parameters, can be rejected at the assigned level of significance. In fact, the five countries fall into two

[11]This hypothesis is in fact identical to that of neutrality.

groups: France, West Germany and Japan all have capital augmentation rates in the range of 12-15 percent per annum whereas the U.K. and the U.S. have capital augmentation rates in the range of 7-9 percent per annum.

The hypothesis of equal augmentation rate parameters across countries must also be interpreted carefully because they may reflect changes in the definitions, measurements (e.g. depreciation rates, deflators, and their errors, if any), and improvements in the quality of complementary inputs over time, in addition to changes in the underlying quality of the inputs. Moreover, one cannot in general associate an improvement in the quality of an input with an increase in its augmentation factor. For example, an increase in the number of individuals who are computer-literate may show up as an augmentation of capital (an increase in the effective number of computers) rather than labor. Better roads may also show up as an augmentation of capital (an increase in the effective number of vehicles).

Finally, the Cobb-Douglas production function hypothesis is also tested and, as expected, it can be rejected at any level of significance.

The Estimated Aggregate Meta-Production Function

The results of the hypothesis testing are synthesized and a set of restricted estimates are obtained, imposing the restrictions implied by the hypotheses that are not rejected at the assigned levels of significance, namely: identical augmentation level parameters for capital and labor and zero augmentation rate parameters for output and labor. The results are presented in Table 3.1.

The estimated capital augmentation rate parameters are statistically significant and positive for all countries. Japan has the highest rate--14.9 percent per annum--and the United States the lowest--7.4 percent per annum.[12] As mentioned previously, the estimates of augmentation level and rate parameters

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[12]It should be borne in mind that to the extent that there is depreciation it will be reflected in the rate of capital augmentation as a negative contribution.

should be interpreted carefully. It may be further noted that the estimated capital augmentation rates for France, West Germany and Japan are very similar. This similarity is consistent with the hypothesis of convergence of technology among these industrialized countries. The hypothesis that the capital augmentation rates of the three countries are identical cannot be rejected.

The estimated rates of capital augmentation are plotted against the rates of growth of the capital stock for the different countries in Figure 3.1. It is apparent that a positive, but non-linear, relationship exists between the rate of capital augmentation (Solow-neutral technical progress) and the rate of growth of the capital stock. However, there also appears to be an asymptote to the capital augmentation rate so that, beyond a certain point, increases in the rate of growth of the capital stock have no effect on the rate of capital augmentation. One conjecture that is consistent with the scatter-diagram in Figure 3.1 is that at any given time there is only so much new technology ready for immediate exploitation--once this is exhausted, further increases in investment have little effect in raising the current technological level even though they may raise real output.

In Figure 3.2, the real output per unit of measured capital stock, also known as the average productivity of capital (or equivalently the reciprocal of the capital-output ratio) is plotted against time for each of the five countries. The average productivity of capital showed a generally declining trend. What this implies is that the capital-output ratio must have been rising over time. In terms of "efficiency-equivalent" units of capital, the average productivity of capital would have shown a even steeper decline.

In Table 3.2 we present estimates of selected parameters of the aggregate production functions of interest for the five countries, including the production elasticities of capital and labor, the degree of local returns to scale, the rate of local technical progress, the effect of technical progress on the capital-labor ratio, and the elasticity of substitution at the 1970 values of the capital and labor inputs. For the purpose of comparison the actual share of labor in 1970 is also included. We discuss these parameters in turn.

(1) Marginal Productivity of Capital

We compute and plot the estimated marginal productivity of capital against time for each country in Figure 3.3. Figure 3.3 shows that Japan had an extremely high marginal productivity of capital in the 1950's and 1960's. However, it declined continuously since the mid-1960's and reached levels comparable to the United States by the mid-1980's. (Could this have partially explained the large capital flows between Japan and the United States in the 1980's?). The marginal productivity of capital of the United States, gross of depreciation, also declined steadily throughout the period, reaching 8.5 percent in 1985. Assuming an average rate of depreciation of capital (equipment and structures) of 5 percent per annum, this implies a real (before tax) rate of return to capital of approximately 3.5 percent in 1985. The marginal productivity of measured capital also declined over time for all of the other countries. This decline is primarily a consequence of diminishing marginal returns to capital, caused partly by the low rate of growth in the other inputs--labor and possibly land and natural resources. The estimated marginal productivities of capital also show a tendency of gradual equalization across countries over time.

(2) Production Elasticity of Capital

The estimates of the production elasticities of capital in Table 3.2 range between 0.19 for W. Germany to 0.27 for Japan in 1970 and are much lower than those estimated from the more conventional factor-share method under the assumptions of constant returns to scale and profit maximization with competitive markets. For the year 1970, our estimates of the production elasticities of labor are somewhat higher than the actual shares of labor costs in total output for France, West Germany, and Japan and somewhat lower for the United Kingdom and the United States. (This finding suggests that labor may possibly be paid more than its marginal product in both the U.K. and the U.S.) On the whole, our estimated production elasticities of labor do not differ substantially from the actual labor shares. Given the values of the actual labor shares, the factor-share estimates of the production elasticities of capital would have been between 0.4 and 0.5, approximately twice our estimated production elasticities.

Moreover, in theory, for a concave production function, the production elasticity of capital can be increasing as well as decreasing with respect to capital, depending on the nature of the production technology. For the five countries under study, however, the elasticities of capital turn out to be decreasing with respect to both capital intensity and time (see Figures 3.4 and 3.5). If the production functions were Cobb-Douglas, the graphs would have been horizontal straight lines.

However, a low production elasticity of capital does not necessarily imply a low capital share. Given decreasing returns to scale (see below) and that the labor elasticity is close to the actual labor share, there is actually a surplus that accrues to capital as the residual claimant to output. Thus, capital is probably also paid more than its marginal product in all five countries.

(3) Degree of Returns to Scale

As the hypotheses of homogeneity and constant returns to scale in production have both been rejected, not only is the degree of returns to scale not unity but it is also not a fixed constant--it depends on the quantities of capital and labor and time. At the 1970 values of the measured inputs of each country, statistically significant decreasing returns to scale are found for all five countries.[13] The estimated degrees of returns to scale range between approximately 0.74 and 0.81 (see Table 3.2).

The estimated degree of local returns to scale for the ith country may be simply calculated as the sum of the estimated production elasticities of capital and labor. For the period under study, the degree of local returns to scale is significantly less than unity, that is, returns to scale are sharply decreasing,

[13]The t-ratios for the null hypothesis that the degree of returns to scale is equal to unity, that is, the null hypothesis of constant returns to scale, are 2.373 for France, 3.648 for West Germany, 2.508 for Japan, 3.207 for the United Kingdom and 2.892 for the United States. The critical values are 2.58, 2.81 and 3.29 for levels of significance equal to 0.01, 0.005 and 0.001 respectively.

principally on account of the low estimated production elasticity of physical capital. The finding of decreasing returns to scale may possibly be attributed to omitted factors of production such as land, public capital stock (in the case of Japan and the United States), human capital, R&D capital stock, natural resources and the environment. The degrees of local returns to scale are plotted against time for each country in Figure 3.6. One may note that locally, for every country, the degree of returns to scale is less than unity and declines over time. (In fact, given the estimated parameters of the aggregate meta-production function, the degree of local returns to scale is expected to decrease with the quantities of capital, labor and time.)

(4) Elasticity of Substitution

In the last column of Table 3.2, the estimated elasticities of substitution between capital and labor for the five countries at the 1970 values of capital and labor are presented. Our estimates of the elasticities of substitution are quite low. They range between 0.23 and 0.46 in absolute value, indicating relatively low substitutability between capital and labor. These estimates are statistically significantly different from both unity and zero. They indicate how far away we are from a Cobb-Douglas world.

(5) Technical Progress

In Table 3.3, we present our estimates of the average annual rates of technical progress, defined as the average annual rate of growth in output, holding inputs constant, and compare them with estimates obtained using the conventional method under the assumptions of constant returns to scale, neutrality of technical progress and profit maximization with competitive output and input markets. We note significant differences between the two alternative sets of estimates of technical progress. Our estimates are much higher, partially reflecting our finding of a lower capital elasticity and hence decreasing returns to scale for the five countries, and show somewhat greater dispersion. However, the rankings of the countries by the rate of (realized) technical progress change only marginally, with France and Japan trading first and second places.

Since technical progress is found to be non-neutral, the rate of technical progress realized in each period, that is, the local technical progress, depends on the quantities of capital and labor, and time. It may be computed as:

$$
\begin{aligned}
\tau_i(K,L,t) &= \partial \ln F(e^{c_{iK}t}K,L)/\partial t \\
&= (\partial \ln F(e^{c_{iK}t}K,L)/\partial \ln K)\, c_{iK} \\
&= (a_K + B_{KK} \ln K + B_{KL} \ln L + B_{KK}\, c_{iK}\, t)\, c_{iK} \qquad (3.1)\\
&= (0.199 - 0.047 \ln K + 0.015 \ln L - 0.047\, c_{iK}\, t)\, c_{iK}. \\
&\quad\ (4.685)(-4.085) \qquad (0.893) \qquad (-4.085)
\end{aligned}
$$

What equation (3.1) says is that the rate of local technical progress is given by the product of the production elasticity of capital and the rate of capital augmentation. It declines with the level of capital and time but rises with the level of labor. Thus, even though the rates of capital augmentation are exogenous, the rates of technical progress realized depend on the quantities of capital and labor and to that extent may be regarded as endogenous. The rates of local technical progress are plotted against time for each country in Figure 3.7. It is interesting to note that, for every country, the local rate of technical progress declines with time, just like the production elasticity of capital. In fact, the rates of local technical progress show strong signs of equalization, over time, despite significant differences in the rates of growth of the inputs and in the rates of capital augmentation across countries. This decline in the rates of local technical progress may be largely attributed to the diminishing marginal productivity of capital due to increases in both capital and time. However, the equalization in the local rates of technical progress realized, which depend on the quantities of inputs as well as time, should be carefully distinguished from the possible equality of the rates of capital augmentation, which are assumed fixed and exogenous in this study.

Alternative Accounts of Economic Growth

The estimated aggregate meta-production function is used to assess the relative contributions of the three sources of growth--capital, labor and technical progress--without relying on the assumptions of constant returns to scale, neutrality of technical progress and profit maximization. In Table 3.4, we present a summary of the data on the outputs and inputs of the five countries over the sample periods. It shows that Japan had the highest average annual rate of growth of real GDP and the United Kingdom the lowest. Japan also had the highest average annual rate of growth of capital stock and U.K. the lowest. The United States had the highest rate of growth of the labor force and West Germany the lowest.

In Table 3.5, we present two alternative sets of estimates of the relative contributions of the different sources of growth for each of the five countries, first using the estimated aggregate meta-production function of Boskin and Lau (1990c) and secondly using the conventional approach of subtracting the factor-share weighted sum of rates of growth of the inputs from the rate of growth of output, again based on the same data. Table 3.5 shows, according to the meta-production function, that over the period under study, technical progress is by far the most important source of economic growth, accounting for more than 50 percent (more than 75 percent for the European countries), and capital is the second most important source of economic growth (except for the U.S.). Labor accounts for less than 5 percent except for the United States. These results may be contrasted to those of the conventional approach which identify capital as the most important source of economic growth (more than 45 percent), followed by technical progress (between 23 and 52 percent).

Our estimated contribution of capital of 23 percent for the United States may also be compared to the 19 percent estimated by Denison (1985) and the 47 percent estimated by Jorgenson, Gollop and Fraumeni (1987). Jorgenson, Gollop and Fraumeni (1987) adjust the quantity of the capital input for improvements in quality. If, however, the contribution of the improvements in the quality of the capital input is attributed to technical progress, the Jorgenson, Gollop and Fraumeni (1987) estimate of the contribution of capital is reduced to only 12 percent. Our estimated contribution of technical progress of 50 percent may also be compared to the 26 percent estimated by Denison (1985) and the 24 percent estimated by Jorgenson, Gollop and Fraumeni (1987). If, however, the contributions of the improvements in the quality of inputs are attributed to technical progress, Denison's estimate is increased to 46 percent and the Jorgenson, Gollop and Fraumeni (1987) estimate to 69 percent. Thus, once the adjustments to the quality of inputs are taken into account, our results of the growth accounting exercises, using the new method, are not qualitatively different from those of others, even though the conventional method under the traditional assumptions may have been expected to attribute a higher proportion of economic growth to capital and a correspondingly lower proportion to technical progress.

It is interesting to note that the estimated combined contributions of capital and technical progress are virtually the same under both approaches as are the contributions due to labor. By either the new or the conventional method, capital and technical progress combined account for more than 95 percent of the economic growth of France, West Germany, Japan and the United Kingdom. In the United States, where the labor force grew more rapidly than in other countries during this period, they still account for 70 percent of the economic growth. The comparable estimates (estimates without the adjustment of the quality of inputs) of the combined contributions of capital and technical progress for the United States, from other studies, range between 59 and 91 percent.[14] Thus, despite the differences in the underlying assumptions, the estimates of the combined contribution of capital and technical progress are not qualitatively different.

The reason why the estimates of the combined contributions of capital and technical progress are so similar is because the contributions of labor are very similar by either approach--our estimated output

[14]See the studies surveyed in Boskin and Lau (1990b).

elasticities with respect to labor are not that different from those obtained via the factor share method. However, our approach yields much lower output elasticities with respect to capital than those obtained by the factor share method under the constant returns to scale assumption. Thus, our estimated contributions of the remaining factor, technical progress, or the "residual", must be correspondingly higher. Another way of understanding our results is to observe that our low estimated production elasticities of capital imply decreasing rather than constant returns to scale and thus the estimated rates of technical progress must be higher to be consistent with the same rates of growth of real output and inputs.

4. Implications of Capital-Augmenting Technical Progress

What are some of the implications of our finding of capital-augmenting technical progress? It means capital is essential for the realization of the benefits of technical progress. It restores capital formation to its central place in economic growth. If technical progress is in fact capital-augmenting, rather than labor-augmenting, or equivalently Harrod-neutral, as is often assumed, a steady state may fail to exist (unless technical progress also happens to be labor-augmenting).[15]

Output and Capital-Technology Complementarity

In Figure 4.1, the outputs of an hypothetical economy in period 0 and period 1, holding labor constant, are plotted as a function of the physical capital stock at a high and a low rate of capital augmentation. It is apparent that the increase in the level of output in period 1 resulting from a higher rate of capital augmentation is higher the higher the level of the capital stock, illustrating the capital-technology complementarity implied by capital-augmenting technical progress.

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[15]Capital-augmenting technical progress is also labor-augmenting if the production function is Cobb-Douglas in capital and labor or is a transformation of a Cobb-Douglas production function.

In Figure 4.2, the outputs of a hypothetical economy in periods 1 and 5 are plotted as a function of the saving rate (assumed to be constant over time) at a high and a low rate of capital augmentation. It is also apparent that the increase in the level of output resulting from a higher rate of capital augmentation is higher the higher the saving rate, providing an illustration of another dimension of capital-technology complementarity.

In Figure 4.3, the difference between neutral technical progress and capital-augmenting technical progress, holding labor constant, is illustrated. Given output as a function of capital in period 0, the shifted production functions in period 1, assuming neutral and capital-augmenting technical progress respectively, are also plotted. The two shifted production functions are calibrated so that they produce the same output at K = 0.5 in period 1, which is assumed to correspond to the observed input-output combination in period 1. We see that even with the same data points, neutral and capital-augmenting technical progress yield different estimates for the shifted production functions. Figure 4.3 also shows how the rate of local technical progress depends on the quantity of capital if technical progress is non-neutral.

Is Capital-Augmenting Technical Progress Capital- or Labor-Saving?

One interesting question is whether capital-augmenting technical progress is also capital-saving, in the sense that the (cost-minimizing) demand for capital relative to labor,[16] at a given quantity of output and prices of capital and labor, is reduced as a result of the technical progress. It can be shown that capital-augmenting technical progress is capital-saving if and only if the elasticity of substitution between capital and labor is less than unity in absolute value. In the next to the last column of Table 3.2, we present estimates of $\partial \ln (K/L)/\partial \ln A_K(t)$, which are all negative, indicating that technical progress has been capital-saving rather than labor-saving in all of the countries. One important consequence of

[16]Recall that the hypothesis of profit maximization has been rejected.

the capital-saving nature of technical progress is that structural unemployment in the aggregate economy is unlikely to be technologically induced. Instead, new technology makes a given quantity of capital go further as a complementary input to labor.

The Share of Labor

A final question that will be addressed is what happens to the share of labor in total output over time. In the long run, given competitive output and input markets, the share of labor is unlikely to deviate very much from the production elasticity of labor.[17] Even if they are not equal because of failure in profit maximization or imperfectly competitive markets, the trends of their movements are not likely to diverge. In Figure 4.4, the estimated production elasticities of labor are plotted against time. It is apparent that the production elasticities of labor have been rising over time for all five countries, but at varying rates. Given the low elasticity of substitution between capital and labor, the relatively high rates of growth of the capital input and its augmentation, and the low rate of growth of the labor input, it should come as no surprise that the share of labor will rise over time.

5. Concluding Remarks

We have introduced and implemented a new method of analyzing productivity and technical progress, based on the concept of an aggregate meta-production function, using pooled time series data from the Group-of-Five countries for the post-war period. We have found that the empirical data are inconsistent with the hypothesis of constant returns to scale, at the aggregate, national level. In fact, there are sharply decreasing local returns to scale. Moreover, we have found that technical progress is non-neutral. In fact, it is capital-augmenting. We have also found that the empirical data are inconsistent

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[17] The production elasticity of labor increases with capital and time and decreases with labor.

with the hypothesis of profit maximization with respect to labor under competitive conditions. One or more of these hypotheses are, however, often maintained in the study of productivity and technical progress.

With our new approach, we have obtained alternative estimates of the production elasticities of the inputs and of technical progress as well as alternative decompositions of economic growth into its sources--capital, labor and technical progress--that are independent of the traditional assumptions. We have found much lower estimate for the production elasticity of measured capital input but similar estimates for the production elasticity of measured labor input than are customary. We have also found much higher and somewhat more dispersed rates of realized technical progress.

We have not made explicit adjustments for the quality of capital or labor, as were done by Denison (1962, 1967, 1979, 1985) and Jorgenson, Gollop and Fraumeni (1987). Instead, we allow any trend of improving input quality to be captured by the rates of capital and labor augmentation themselves. Thus, what we attribute to technical progress include what others may attribute to the improvement in the qualities of the inputs.

We have also found that technical progress is capital-augmenting rather than labor-augmenting, as is more frequently assumed. Capital-augmenting technical progress implies that the aggregate production function can be written in the form:

(5.1) $Y = F(A(t)K, L).$

Thus, the benefits of technical progress are higher the higher the level of the capital stock. A country with a low level of capital stock relative to labor will not benefit as much from technical progress as a country with a high level of capital relative to labor. Capital and technical progress are thus complementary.

The consequence of this capital-technology complementarity can be readily appreciated from our empirical results. Consider France, West Germany and Japan. They have almost the same estimated rate of capital augmentation of between 12 and 15 percent per annum. However, according to our estimates, Japan has the highest average annual rate of (realized) technical progress, followed by France and then West Germany, in the same order as their respective rates of growth of capital stock (See Tables 3.3 and 3.4). This is precisely the complementarity of capital and technical progress at work. We have shown how the benefit of a higher capital augmentation rate is higher the higher the level of capital. We have also presented evidence that an increase in the saving rate which results in a higher level of capital formation may also bring about an acceleration in the rate of economic growth in the short and intermediate runs.

However, we should emphasize that our finding of capital-augmenting technical progress does not necessarily mean that the quality of labor has not improved over time, or that all the investments in human capital have gone to waste. As mentioned earlier, improvements in the quality of labor may manifest themselves in the form of capital-augmenting technical progress.

A further implication of capital-augmenting technical progress, given that the elasticity of substitution between capital and labor has been found to be less than unity, is that technical progress is capital-saving rather than labor-saving, in the sense that the desired capital-labor ratio for given prices of capital and labor and quantity of output declines with technical progress. Technical progress is thus less likely to cause structural unemployment through the technological displacement of workers.[18]

We have also found from our growth-accounting exercises that technical progress is by far the most important source of economic growth of the industrialized countries in our sample, accounting for more than 50 percent, in contrast to the growth accounting studies of Denison and Griliches and

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[18]In fact, given that F_{KL}, the cross-partial derivative of output with respect to capital and labor, is positive (see Boskin and Lau (1990c)), capital-augmenting technical progress is likely to enhance employment, in the intermediate and long runs.

Jorgenson and his associates. However, even though this finding may be reminiscent of the findings of a large unexplained "residual" in early studies of economic growth,[19] they are, in fact, quite different on at least two counts. First, the early studies typically assume constant returns to scale, neutrality of technical progress, and profit maximization with competitive markets. Second, while technical progress is, in the form of capital augmentation, assumed to be exogenous in our model, as in the early studies, we have found it to be complementary to capital so that it does a country with a low level of capital stock much less good than a country with a high level. This capital-technology complementarity, which implies a positive interactive effect of capital and technical progress, distinguishes our results from others. Thus, it would be wrong to interpret our finding to mean that capital is not an important source of economic growth. Capital and technical progress work together as if they were a single input. Their contributions depend on each other and are inextricably intertwined. They are both indispensable ingredients for economic growth.

Technical progress (specifically the rates of commodity augmentation) is taken to be exogenous in this study. Moreover, the rates of augmentation are assumed to be constant over time. It is, however, remarkable that the rates of augmentation of capital turn out to be almost identical for France, West Germany and Japan, indicating that the three countries have nearly the same access to advances in technology. It will be of interest to explore why the rates of capital augmentation are much lower for the U.K. and the U.S. and more generally to investigate the determinants of the observed variations in the rate and pattern of commodity augmentation. Can they be satisfactorily explained by capital accumulation, education, R&D expenditures, the ratio of public to private investment, the composition of aggregate output (among primary, secondary and tertiary), or other factors? We have already seen some evidence that the rates of capital augmentation appear to be related to the rates of growth of

[19]See the references in Boskin and Lau (1990b).

physical capital (Figure 3.1). It may well be the case that they are related to the rates of growth of human capital as well. It will also be interesting to allow the possibility of augmentation rates that vary over time.

Appendix 1:

The Data and the Statistical Model

Data

We use data from the Group-of-Five (G-5) countries: France, Federal Republic of Germany, Japan, the United Kingdom, and the United States. The period covered is from 1957 to 1985 except for West Germany and the United States, data for which begin in 1960 and 1948 respectively. What follows is a brief description of the variables and the data sources.

(1) Real Output (Y)

The aggregate real output of the economy is measured as the real Gross Domestic Product (GDP) in 1980 prices. Data on real GDP of the five countries are taken from National Accounts, 1953-1982 and 1960-1985, published by the Organization for Economic Cooperation and Development (OECD), except for the immediately postwar period of 1948-1952, for the United States, data for which are obtained from Historical Statistics of the United States: Colonial Times to 1970, published by the U.S. Department of Commerce. The data for France, West Germany, Japan, and U.K. are converted into 1980 U.S. dollars using the exchange rates between the currencies of the respective countries and the U.S. dollar prevailing in 1980, period average of market rate (line rf), published in International Financial Statistics by the International Monetary Fund.

(2) Labor (L)

Labor is measured as the number of person-hours worked. The labor supply of the economy is measured by the civilian labor force. The data are taken from Labor Force Statistics, 1956-1967, 1958-1969, and 1965-1985, published by the OECD except for the period of 1948-1955 for the United States, data for which are estimated by splicing the published data on civilian labor force from the U.S. Department of Commerce, Historical Statistics of the United States, Colonial Times to 1970 to those of

Labor Force Statistics. Unemployment rates are obtained from the same sources. Employment is estimated as the labor force times one minus the unemployment rate. It is then multiplied to the average number of hours worked per year to obtain labor hours. Data for hours worked are obtained from OECD, Main Economic Indicators: Historical Statistics, 1955-1971, 1960-1979 and 1964-1983 and Main Economic Indicators, 1987, except for the U.S., data for which are obtained from U.S. Department of Labor, Bureau of Labor Statistics, Labor Force Statistics Derived from the Current Population Survey, 1948-1987.

The share of labor in the value of output is estimated by dividing the current labor income (compensation of employees paid by resident producers) by the current GDP of each country, data for which are obtained from the same sources as those for real GDP, except for the period 1948-1952 for the United States. Current labor income data for the United States for this period are obtained from National Income and Product Accounts of the United States, U.S. Department of Commerce and GDP in current prices are obtained from Survey of Current Business, December, 1980. The compensation of employees paid by resident producers includes "all payments by resident producers of wages and salaries to their employees, in kind and in cash, and of contributions, paid or imputed, in respect of their employees to social security schemes and to private pension, family allowance, casualty insurance, life insurance and similar schemes."

(3) Capital (K)

Capital is measured as utilized capital. Gross fixed capital stock at the beginning of the year is used as a measure of capital supply. The data in 1980 prices are taken from OECD, Flows and Stocks of Fixed Capital, 1955-80 and 1960-85 except for U.S. (1948-55) and Japan (1957-65); the former is taken from the Bureau of Economic Analysis, Survey of Current Business, January, 1986, while the latter is based on Table 1-2 from Denison and Chung (1976). For Japan and the United States, the gross fixed capital stock data include only private non-residential capital. For France, the data include private non-residential and public capital.[20] For West Germany and the United Kingdom, the data include private non-residential, private residential and public capital. These data are converted into U.S. dollars using 1980 exchange rates. The data on capacity utilization are also taken from OECD, Main Economic Indicators: Historical Statistics 1960-1979 and 1964-1983 and Main Economic Indicators (1986) with the exception of U.S., U.K., Japan (1957-59) and France (1957-61). For Japan and France, the missing data are estimated by backward extrapolation. Capacity utilization rates for the U.S. are obtained from the Economic Report of the President, 1989. Capacity utilization rates for the U.K. are constructed by the peak-to-peak method. The estimated utilization rates for U.K. (average of 98.81 percent) are much higher than those for the other countries (average of 81.13 percent), because of the different methodologies used. In order to maintain comparability of the data, the estimated utilization rates for U.K. are multiplied by the ratio 81.13/98.81. Utilized capital is estimated as the capital stock at the beginning of the year times the capacity utilization rate. It is assumed that the capacity utilization rates apply to the whole economy and not just the manufacturing sector.[21]

(4) Time (t)

Time is measured in years chronologically with the year 1970 being set equal to zero.

(5) Instrumental Variables

The instrumental variables used in the estimation include: real output lagged one and two periods; lagged capital stock; lagged labor force; country dummies; world population; female life expectancy; male life expectancy; female population; male population; arable land; land under permanent crops; world

[20]The original data for 1957-1965 include only private non-residential capital but have been adjusted so that they are comparable to data including both private non-residential capital and public capital.

[21]To the extent that this assumption is not true there will be measurement errors in our data on utilized capital.

prices of cotton, oil and iron ore relative to the world price of wheat; lagged relative prices of cotton, oil and iron ore; and time. For the first-differenced model, the actual instrumental variables employed consist of first differences of the natural logarithms of the continuous variables listed above as well as the dummy variables listed above. Data on world population are obtained from United Nations, Statistical Yearbook. Data on female and male populations are obtained from the same sources as those for civilian labor force. Female and male life expectancy are taken from United Nations, Demographic Yearbook. Data for land are obtained from Food and Agriculture Organization, Production Yearbook. The prices of cotton (Egypt Long Staple), oil (Venezuela-Tia Juana), iron ore (Brazil North Sea Ports), and wheat (Australia-Sydney) are obtained from International Monetary Fund, International Financial Statistics Yearbook (1979, 1989).

The Statistical Model

We introduce stochastic disturbance terms ε_{1it}'s and ε_{2it}'s into the first-differenced forms of the natural logarithm of the aggregate production function and the labor share equation, respectively.[22] We assume:

(A1.1) $$E \begin{pmatrix} \varepsilon_{1it} \\ \varepsilon_{1it} \end{pmatrix} = 0\ , \forall i\ , t\ ;$$

and

(A1.2) $$V \begin{pmatrix} \varepsilon_{1it} \\ \varepsilon_{1it} \end{pmatrix} = \Sigma \quad \text{, a constant, non-singular matrix, } \forall i,\ t;$$

and the stochastic disturbance terms are uncorrelated across countries and over time. In the first-

[22]It turns out that the model without first-differencing yields a Durbin-Watson statistic that is close to unity for the labor share equation, indicating serious mis-specification. The model with first-differencing yield reasonable values for the Durbin-Watson statistics. We therefore adopt the first-differenced model.

differenced form, our stochastic assumptions amount to saying that the influence of the stochastic disturbance terms is permanent--they raise or lower the production function and the labor share permanently until further changes caused by future stochastic disturbance terms.

Under the further assumption of joint normality of the stochastic disturbance terms, we can estimate the system of two equations consisting of the production function and the labor share equation, first differenced, and its various specializations under the different null hypotheses by the method of nonlinear instrumental variables.[23]

[23]See, e.g., Gallant and Jorgenson (1979).

Table 3.1

Estimated Parameters of the Aggregate Production Function and the Labor Share Equation (First-Differenced Form)

Parameter	Estimate	T-ratio
<u>Aggregate Production Function</u>		
a_k	0.199	4.685
a_1	0.622	2.479
B_{kk}	-0.047	-4.085
B_{11}	-0.034	-0.289
B_{k1}	0.015	0.893
c_{FK}	0.128	5.471
c_{GK}	0.146	6.169
c_{JK}	0.149	4.664
c_{UKK}	0.089	5.246
c_{USK}	0.074	5.474
$\bar{R}^2$	0.838	
D.W.	2.018	
<u>Labor Share Equation</u>		
B_{k1F}	-0.140	-1.965
B_{K1G}	-0.173	-1.823
B_{K1J}	-0.054	-1.491
B_{k1UK}	0.387	1.288
B_{K1US}	-0.043	-0.722
B_{11F}	0.241	1.163
B_{11G}	0.276	1.852
B_{11J}	-0.405	-4.429
B_{11UK}	0.242	2.282
B_{11US}	0.093	0.598
B^*_{F1t}	0.010	2.519
B^*_{G1t}	0.012	2.274
B^*_{J1t}	0.012	3.165
B^*_{UK1t}	-0.012	-1.257
B^*_{US1t}	0.002	0.687
$\bar{R}^2$	0.231	
D.W.	1.893	

Table 3.2

Estimated Parameters of the Aggregate Production Functions
(at 1970 Values of the Independent Variables)

	Capital Elasticity	Labor Elasticity	Degree of Local Returns to Scale	Rate of Local Tech. Progress	Actual Labor Share	$\frac{\partial \ln(K/L)}{\partial \ln A_K(t)}$	Elasticity of Substitution
France	0.243	0.562	0.805	0.031	0.489	-0.709	0.291
	(7.731)	(6.670)	(9.789)	(12.642)		(-5.237)	(2.145)
W. Germany	0.193	0.572	0.764	0.028	0.532	-0.562	0.438
	(10.026)	(8.562)	(11.832)	(10.621)		(-4.881)	(3.804)
Japan	0.269	0.528	0.797	0.040	0.435	-0.649	0.351
	(7.804)	(6.553)	(9.823)	(10.273)		(-8.347)	(4.517)
U. K.	0.208	0.570	0.777	0.018	0.597	-0.769	0.231
	(9.117)	(7.918)	(11.163)	(8.099)		(-12.008)	(3.599)
U. S.	0.196	0.542	0.738	0.015	0.614	-0.538	0.462
	(9.386)	(5.726)	(8.132)	(7.153)		(-6.742)	(5.801)

Note: Numbers in parentheses are t-ratios.

Table 3.3

Alternative Estimates of Average Annual Rates of Technical Progress

Country	Conventional Estimates	Our Estimates
France	.018	.030
W. Germany	.014	.027
Japan	.016	.040
U.K.	.012	.018
U.S.	.008	.016

Table 3.4

Average Annual Rates of Growth of Real GDP, Capital and Labor

	Period	GDP	Capital Stock	Utilized Capital	Labor Force	Employment	Labor Hours
France	57-85	0.039	0.045	0.044	0.007	0.004	-0.003
W. Germany	60-85	0.029	0.041	0.039	0.001	-0.002	-0.005
Japan	57-85	0.068	0.092	0.093	0.011	0.011	0.007
U.K.	57-85	0.024	0.031	0.031	0.005	0.001	-0.002
U.S.	48-85	0.031	0.032	0.034	0.018	0.017	0.016

Table 3.5

Relative Contributions of the Sources of Growth

	Capital	Labor	Technical Progress
		This Study	
FRANCE	27	-5	78
W. GERMANY	23	-10	87
JAPAN	36	5	59
UK	27	-5	78
US	23	27	50
		Conventional Estimates	
FRANCE	57	-5	48
W. GERMANY	65	-11	46
JAPAN	72	5	23
UK	54	-6	52
US	45	29	26

FIG 3.1: CAPITAL AUGMENTATION RATE

VS.CAPITAL GROWTH RATE

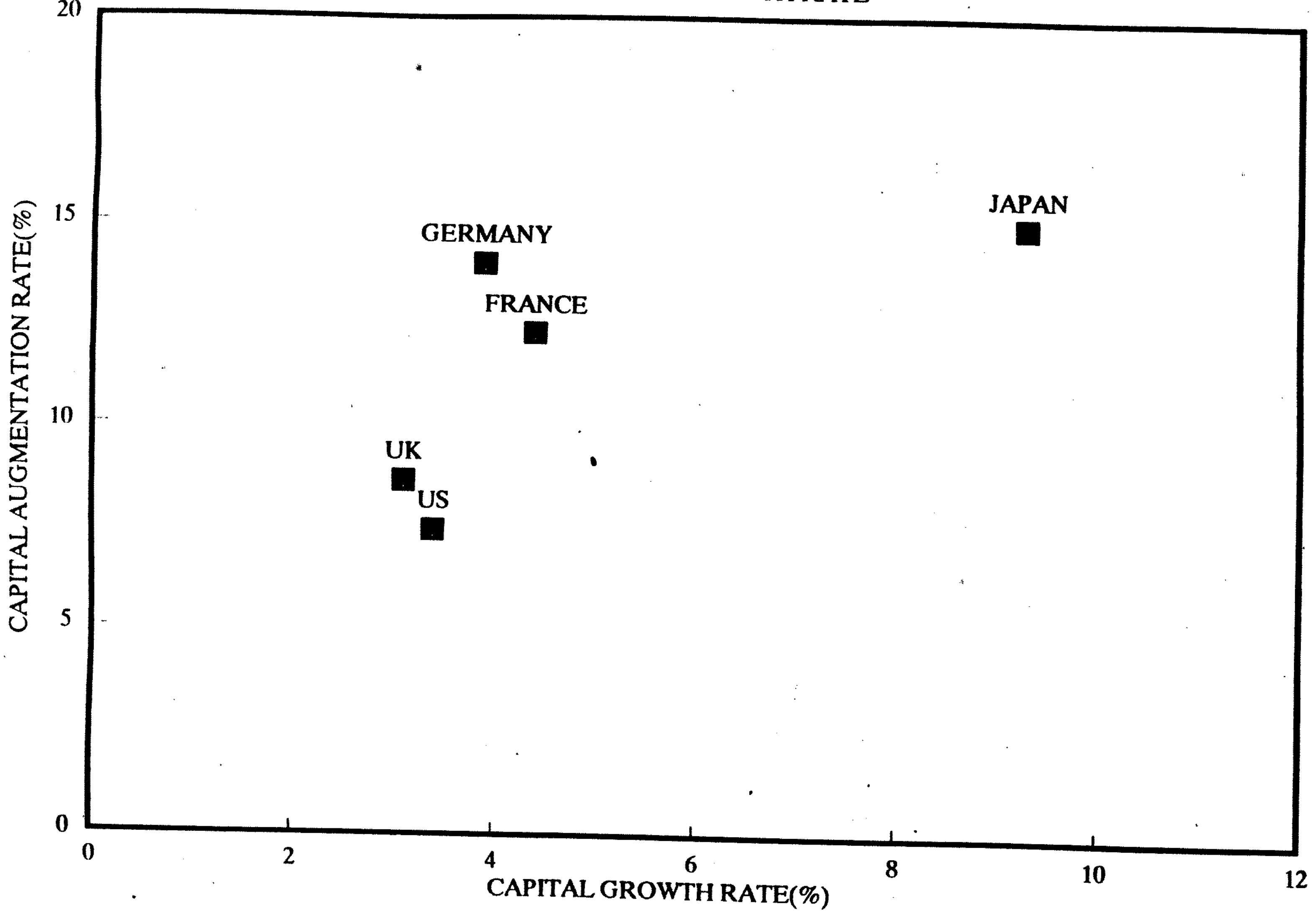


FIG 3.2: REAL OUTPUT

PER UNIT CAPITAL STOCK

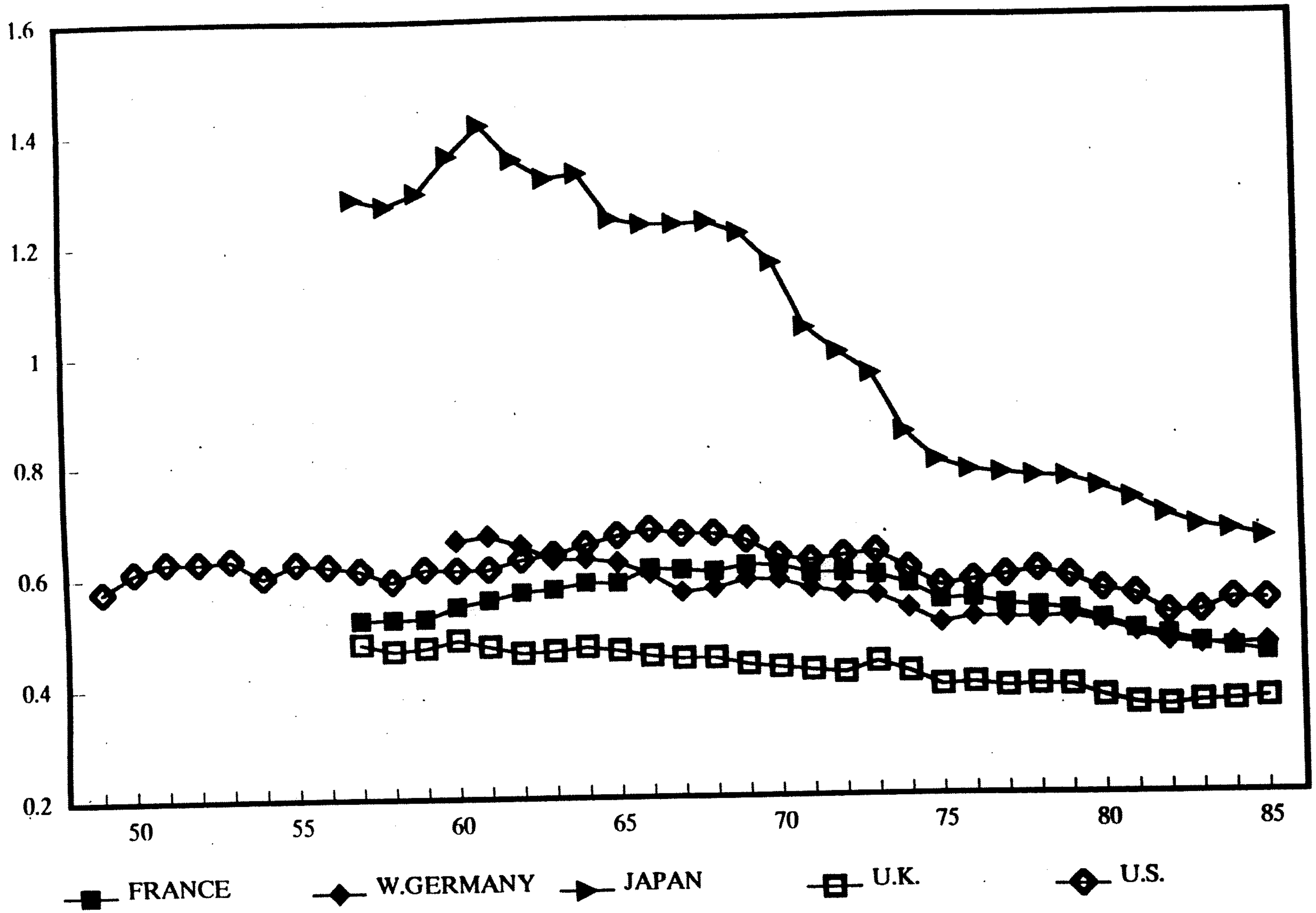


FIG 3.3:ESTIMATED MARGINAL PRODUCTIVITY
OF CAPITAL

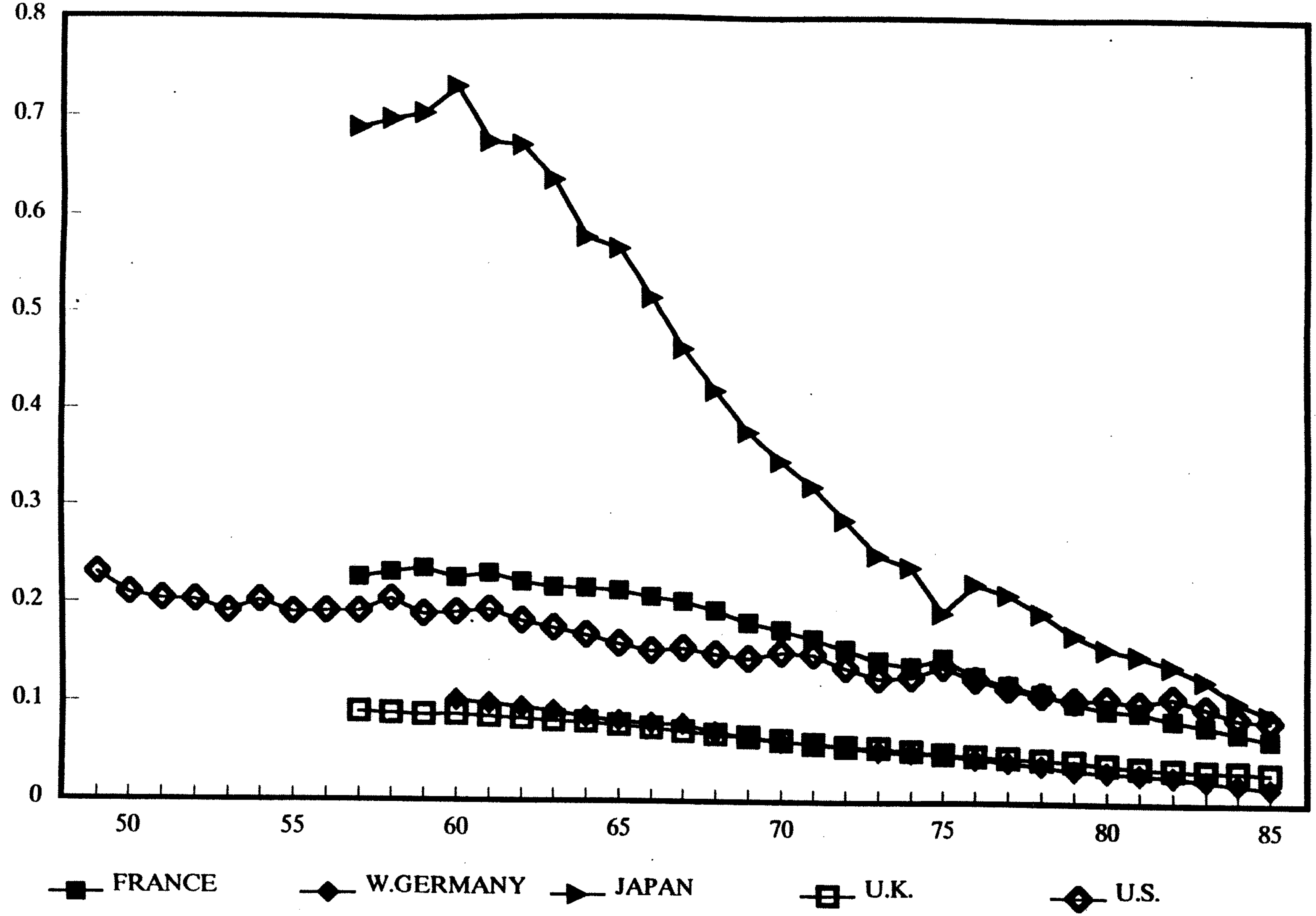


FIG 3.4: PRODUCTION ELASTICITY OF CAPITAL AND CAPITAL INTENSITY

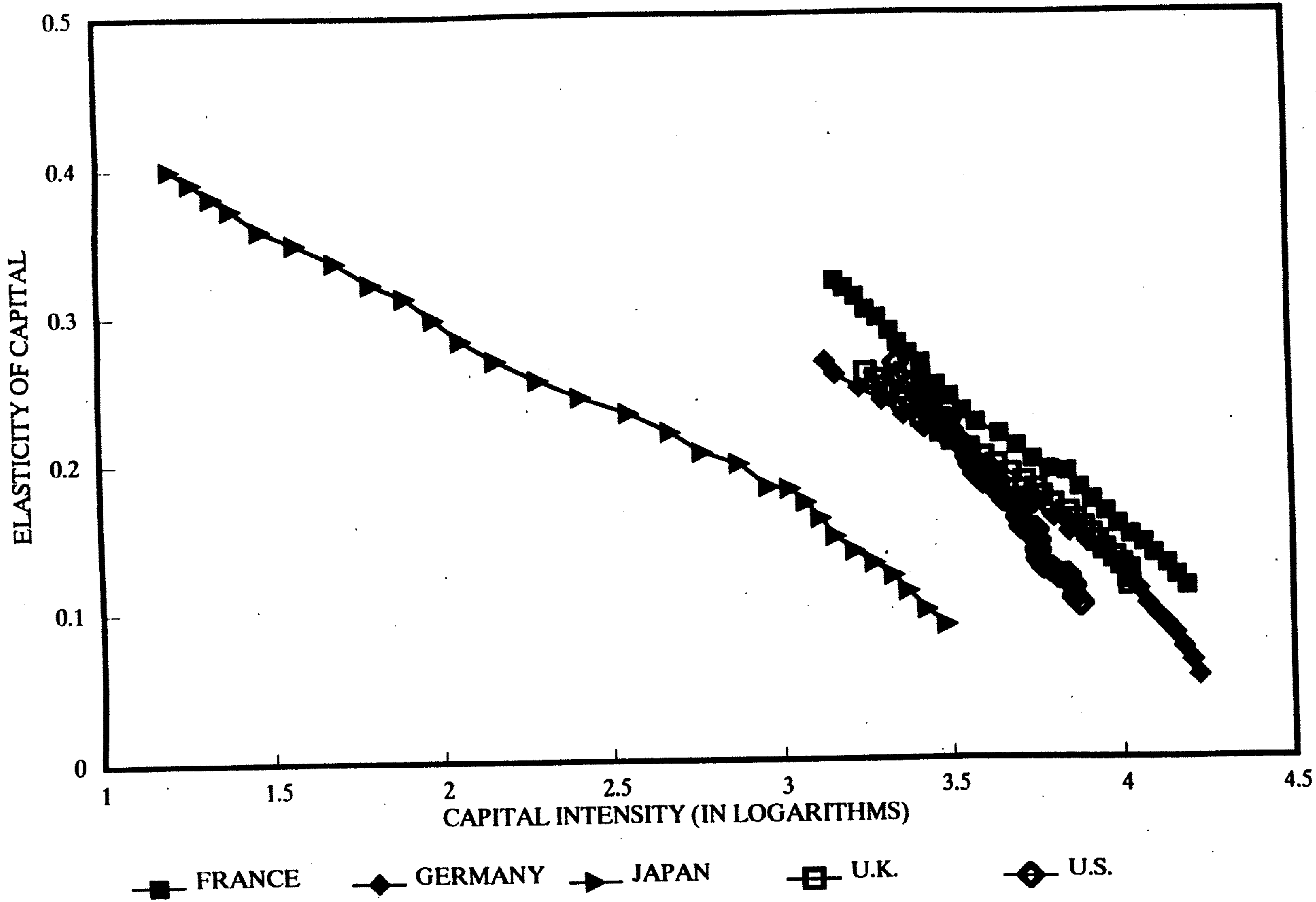


FIG 3.5: PRODUCTION ELASTICITY
OF CAPITAL

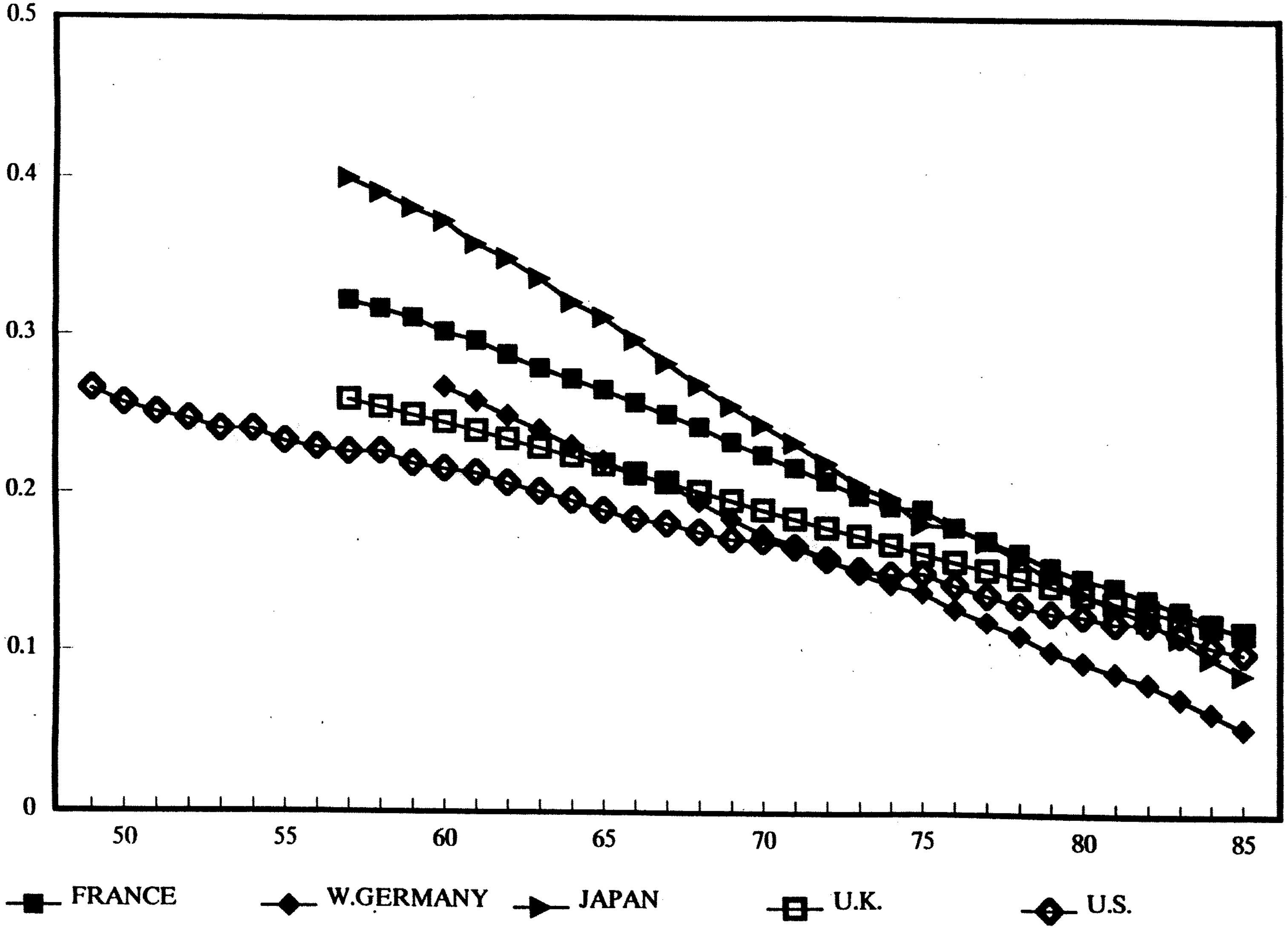


FIG 3.6: LOCAL RETURNS TO SCALE

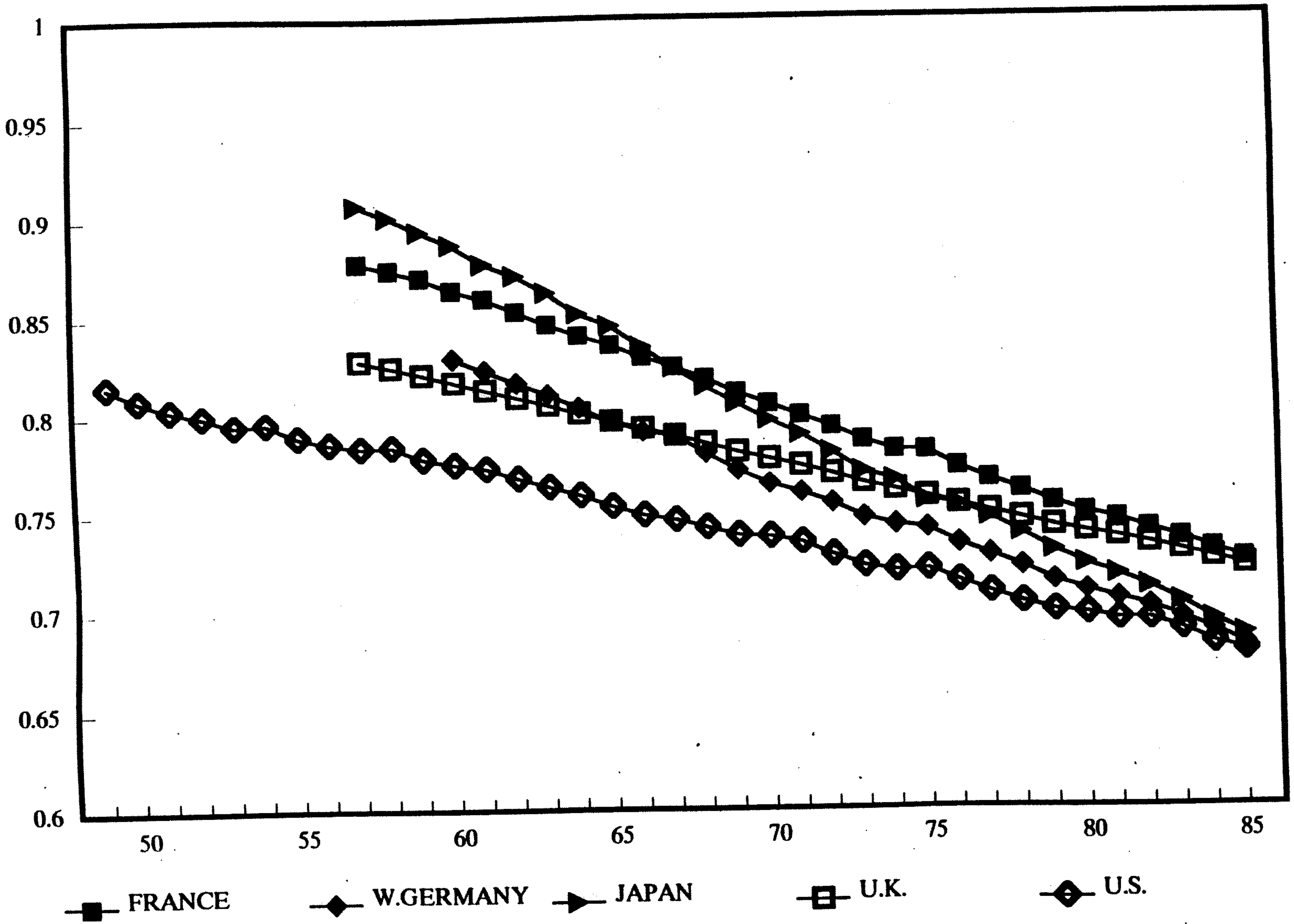


FIG 3.7: LOCAL TECHNICAL PROGRESS

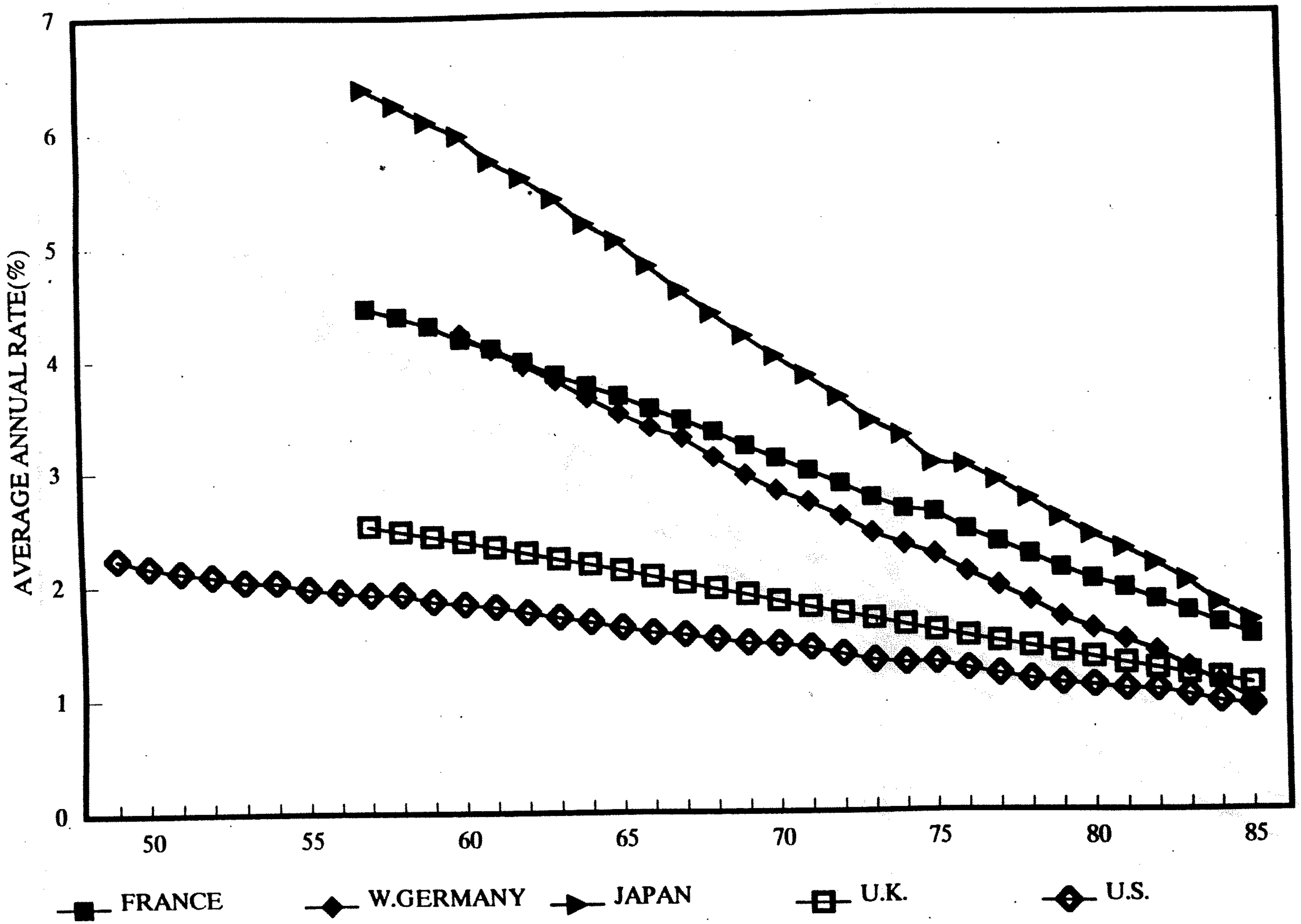


FIG4.1: RELATIONSHIP BETWEEN OUTPUT, INITIAL K STOCK AND K AUG. RATE

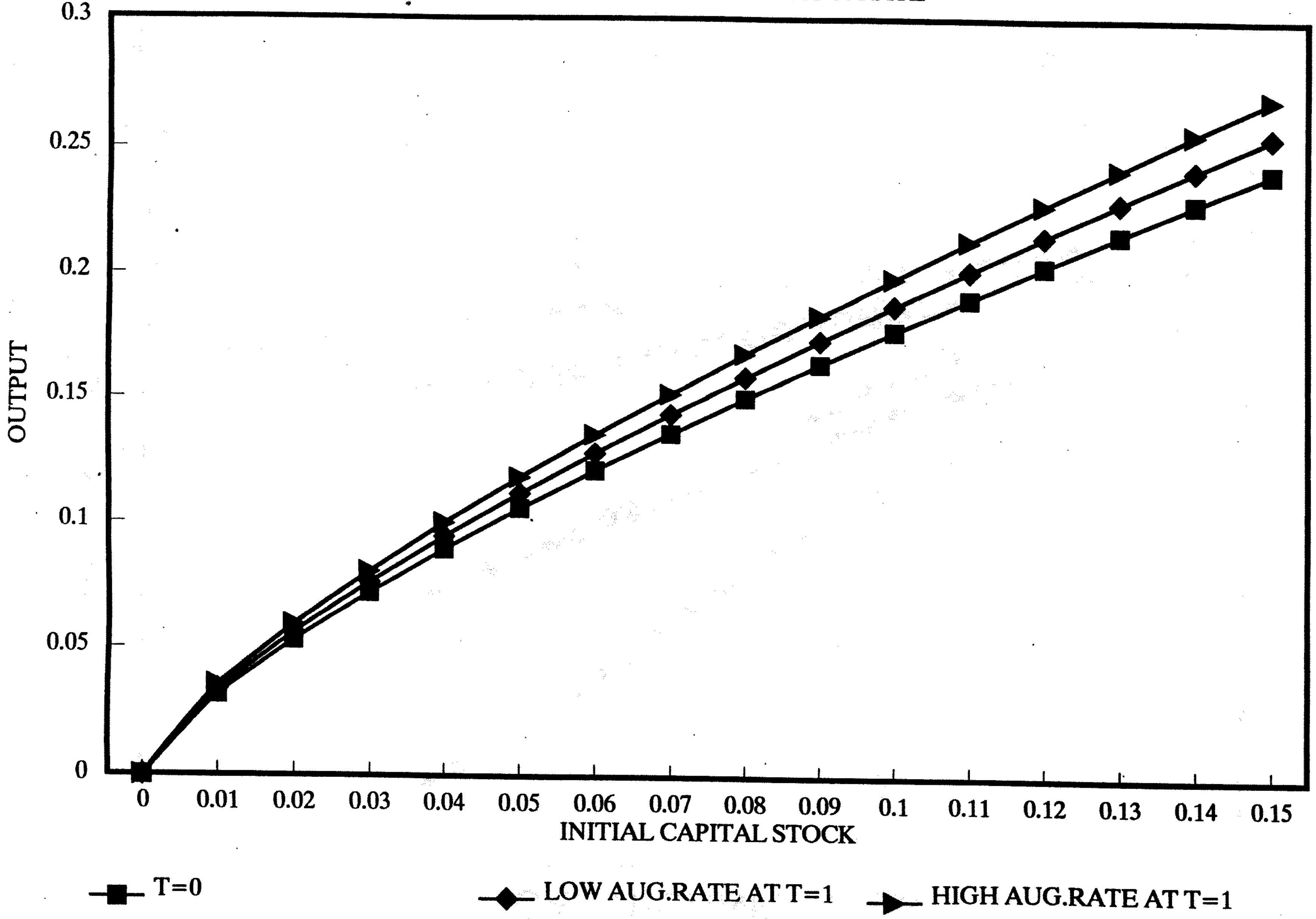


FIG4.2: RELATIONSHIP BETWEEN OUTPUT,
SAVING RATE AND CAPITAL AUG. RATE

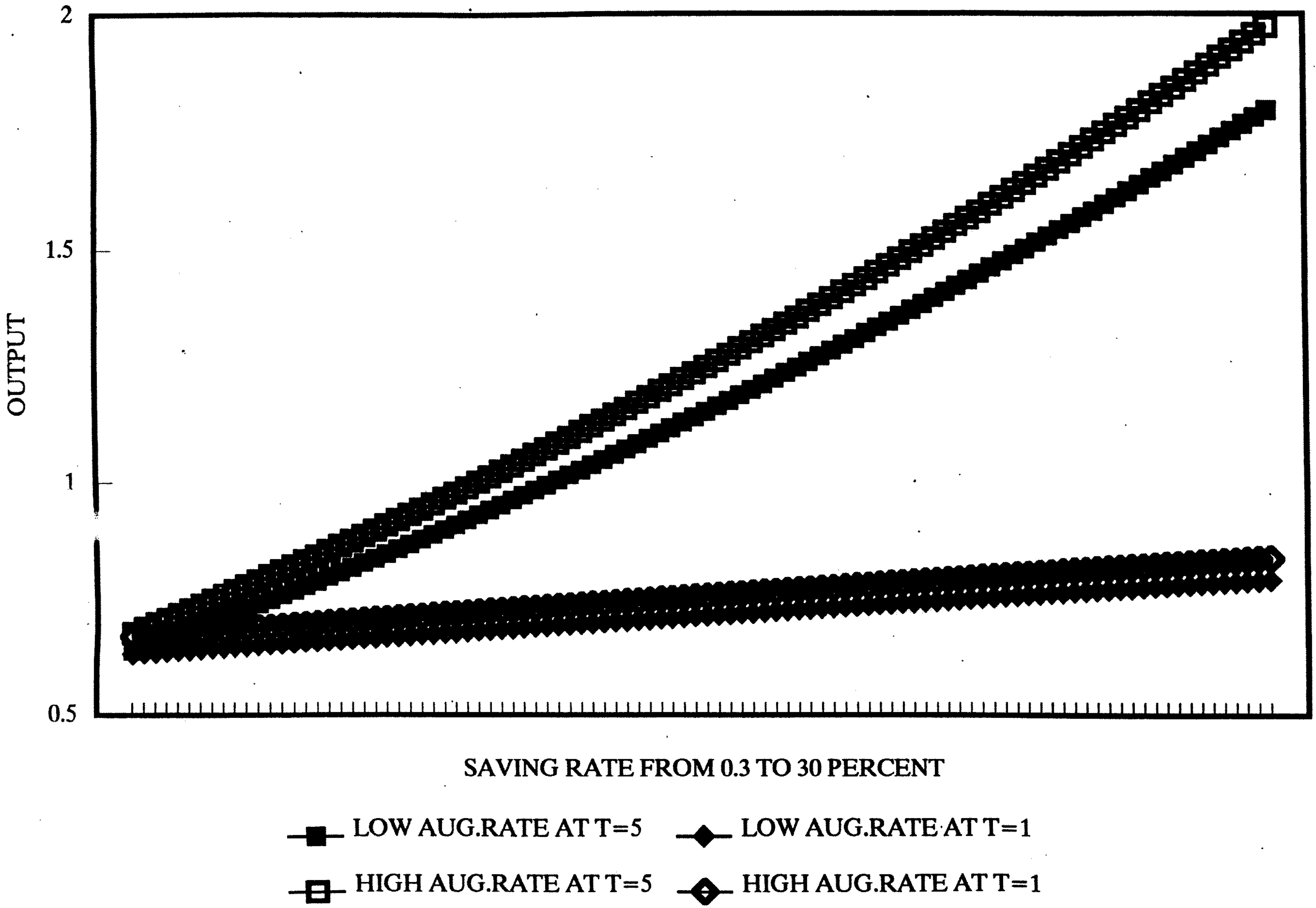


Fig. 4.3 Comparison of
Hicks-Neutral and Solow-Neutral Technical Progress

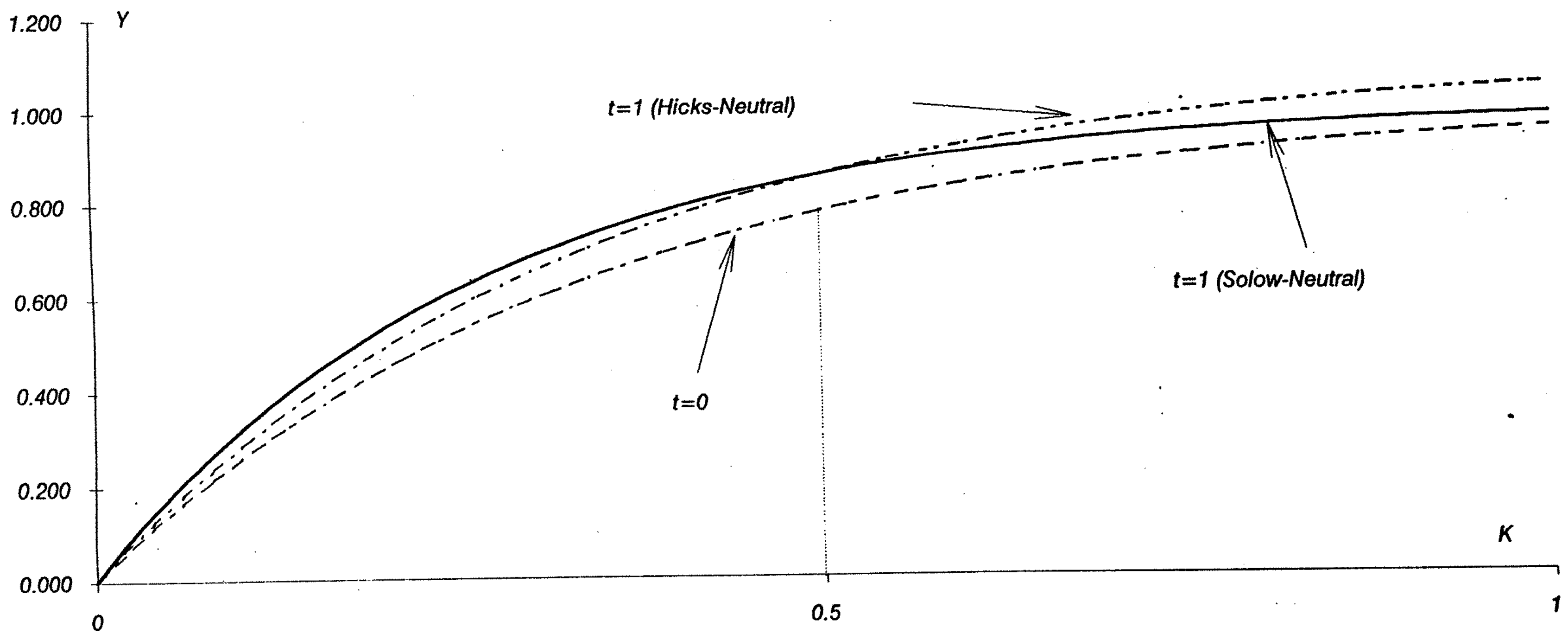
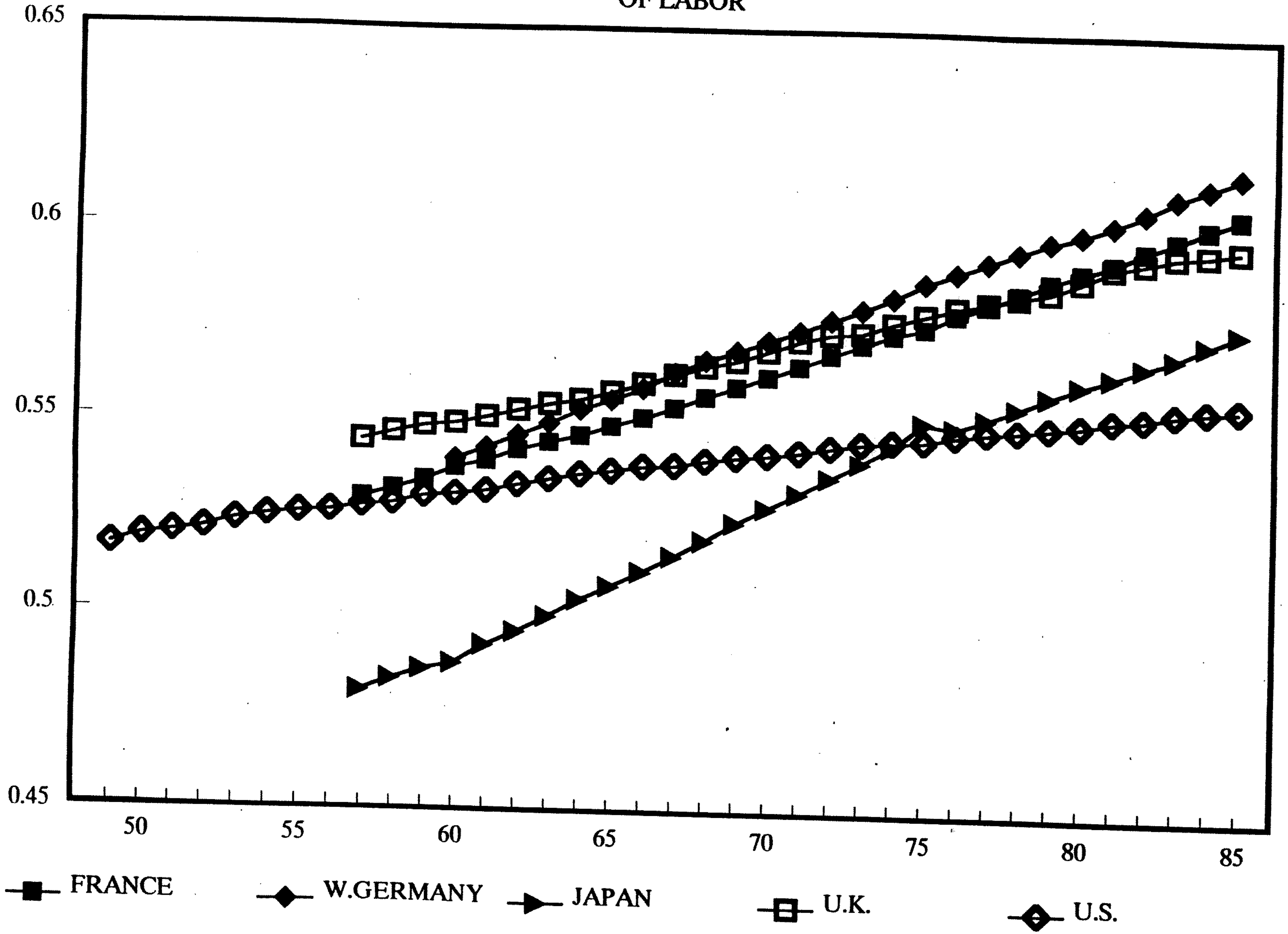


FIG 4.4: PRODUCTION ELASTICITY
OF LABOR



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