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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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GROWTH IN LEAST DEVELOPED COUNTRIES
An Empirical Analysis of Productivity Change, 1970 - 1992

Helmut Forstner
Anders Isaksson
Thiam Hee Ng

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Statistics and Information Networks Branch of UNIDO

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Abstract *Productivity change over about two decades is measured for 32 Least Developed Countries (LDCs). What we find is an overall decline in total factor productivity (TFP), pointing to technology as a major problem area in LDC growth. Behind such decline, there seems to be best-practice regress, indicating severe problems with the access to as well as the adoption of new technology. At the same time, technical efficiency in the group as a whole appears to have at least not declined to the same extent as LDC best practice, leaving some room for positive developments at individual-country level.*

1. Introduction

The present paper is part of broader-based empirical economic research conducted in the United Nations Industrial Development Organization (UNIDO). This research deals with selected topics from the fields of manufacturing industry, trade and growth[1] where for most of the analyses a cross-country view is adopted. In this connection, efforts at a systematic grouping of countries – resulting in a typology, in particular, of the developing countries – play an important role. The aspect of a country typology is retained in the study presented here, by way of focussing on the group of so-called Least Developed Countries (LDCs) within the large and heterogeneous set of developing countries. The range of issues dealt with by the larger project, however, is drastically narrowed down for the purposes of this presentation: Almost all explicit treatment of or reference to manufacturing industry or trade are left out from the present study, and empirical measurement, analysis and interpretation are concentrated on the subject of growth of aggregate output and of aggregate productivity.

Growth in aggregate output of an economy – when viewed in the traditional general equilibrium framework – can be seen as stemming from three broad sources: growth in inputs of production; improvements in the efficiency of allocation of inputs across activities, as well as in the technical efficiency of using these inputs; and

[1] The three main fields of investigation are the analysis of growth and its sources, with special emphasis on the role of manufacturing industry in this process; the changing structure and altering international location of industrial production; and international specialization and trade in manufactured goods. While each one of these areas is studied on its own, attempts are also being made to explore the relationships among them.

technology, which – in the absence of increasing returns to scale – makes its contribution through technological change, resulting from innovation and bringing about increases in the productivity of inputs. A comprehensive growth analysis has to take into account all three of the above sources, and this is what the present exercise is intended to accomplish, too. However, here the emphasis will be on sources of growth other than growth of factor inputs, or, put in different terms, on changes in productivity and the major components of such changes.

As a point of departure for the intended empirical analysis, some basic facts about aggregate growth of output per capita over the past three decades are presented in aggregate fashion in Figure 1: Population-weighted averages of GDP per capita (expressed in constant 1990 US dollars) are shown for the three groups of industrial countries, the LDCs and 'other' developing countries[2]. The picture is one of dramatic divergence – in the 'naïve' sense of a drifting apart of income levels – between the LDCs and the rest of the world, and of stagnation of per capita income in the former country group.

Hidden behind this simplification of growth patterns are, of course, not only a world of differences among countries in growth performance, but also some general features that can be identified empirically. Such identification will be attempted in the following sections for some such features that have to do with the central issue of productivity and its change over time. In the present context, the productivity theme appears to be a natural choice, not only due to its leading role in all growth analysis, but also on account of the simple fact that per capita output levels, as they are shown in Figure 1, are themselves a crude measure of average aggregate labour productivity. It is from the use of some of the more advanced methods of productivity measurement that a considerable refinement of first impressions about growth and productivity patterns is expected.

This paper reports a number of new results obtained from an application of advanced methods of productivity measurement to data on Least Developed Countries (LDCs). Central among these results is the empirical fact of a steep overall decline in total factor productivity (TFP), which points to technology as one of the major

[2] The choice of weighted averages is deliberate, since only this type of average produces an aggregate picture that can be related to achievements towards the goal of worldwide reduction of poverty – after all it is the number of people affected that counts in such measurement efforts.

problem areas in LDC growth. An analysis of the main components of TFP change shows that within the group of LDCs best-practice techniques of production have been regressing over the period studied here. This indicates severe problems with the access to as well as the adoption of new technology. In contrast, technical efficiency in the group as a whole has at least not declined at the same pace as group-specific best practice, implying that at individual-country level positive developments may have taken place.

The paper is organized in the following way: Section 2 develops, with a fair amount of detail, the analytical tool to be applied here for the purpose of an empirical assessment of changes in aggregate productivity. The data background to the exercise is described in comprehensive fashion in Section 3, which also presents a preview of the underlying empirical information, intended to serve as an introduction to actual measurement and analysis. The latter are the subject of Section 4, which presents the results of a productivity analysis for the LDC sample studied here and also provides some elements of an interpretation. Section 5 points out some directions in which an explanation of the empirical findings reported here may be sought. Finally, the closing section looks to the future of further investigations along the lines drawn in this paper.

2. The method

Changes in productivity at aggregate level can be measured in a number of ways. For the purposes of the present analysis, the choice of method was determined by two considerations. First, the approach taken should not only lead to a reliable assessment of productivity change, but also produce some empirical indications, if possible, of probable sources of such change. Second, the fact that a whole group of countries is being studied also influenced the choice of the approach. More specifically, the method chosen should allow for taking maximum advantage of the multi-country background in an assessment of changes in productivity of each individual country. How the two objectives can be met simultaneously is the subject of most of the discussion in this section[3].

[3] The outline of methods presented here is not one of formal rigour, but rather intends to present clearly the basic ideas behind measurement, be as imaginative as possible in the description of techniques and give the essence of potential interpretations of measurement results. For rigorous and

2.1 Measuring productivity change

There are a considerable number of empirical measures of productivity, which is commonly defined as the ratio of a measure of output to a measure of input use. Which measures are chosen in a specific application depends mainly on the objectives of the research and – in particular, when developing countries are the object of study – on availability of data. That data constraints on the choice of a productivity measure are severe in the present instance of analysing LDCs needs no further elaboration. Regarding the objective of the study, difficulties are somewhat eased due to the focus being on changes in productivity rather than on a comparison of levels of productivity. This implies that, in general, index numbers will be sufficient and that some of the problems of direct comparison of levels across countries can be bypassed in a first round. Furthermore, since the growth of aggregate production, i.e. of GDP, is the object of the present investigations, no particular choice has to be made as how to measure output. Regarding the choice of input measures – in the present case labour and capital - the one overriding consideration is that of data availability. This point will be elaborated and illustrated in the discussion of the data background in the following section.

In productivity measurement, a broad distinction is that between single-factor measures and multi-factor measures[4]. Especially, when the data situation is problematic, one particular version of a single-factor measure appears as a natural choice, namely, that of (average) labour productivity. That measure indicates how productively labour is used to generate output. In the present case, the developments depicted by Figure 1 of the previous section can be interpreted as showing, in proximate fashion, trends in average labour productivity. These trends of GDP per capita – shown as weighted averages for each one of the three country groups – can be assumed to approximate those of the 'correct' measure of GDP per worker quite closely and thus to render a fairly realistic picture of changes in broad aggregates of labour productivity. At the level of maximum aggregation dealt with here, the close link between labour productivity on the one hand and real income per capita – the

formal discussions of the methods used here specialized literature, to which hints are given throughout the present discussion, would need to be consulted.

[4] The terminology as well as part of the present description of methods draw extensively on OECD (2000).

most widely used indicator of living standards – on the other, is obvious. And even with a more accurate measure of actual labour input – obtained through adjustments for labour force participation, unemployment or differences in working hours – this link remains a direct and close one.

There are, of course, intrinsic shortcomings of the output-labour ratio as a measure of the 'productivity', i.e. the quality or intensity of effort, of the single factor labour. For instance, the ratio reflects the joint impact on output of capital, intermediate inputs, technological change, efficiency change, economies of scale and capacity utilization – in other words, of a host of factors other than that of the productive use of labour. This demonstrates, in particular, that the single-factor measure of labour productivity is not geared to distinguish between the combined effects on output of changes in several inputs on the one hand, and of overall productivity change on the other. Therefore, if a clear distinction is sought between the effects of input increase and of a change in productivity (based on technological change or change in technical efficiency), a different approach to productivity measurement – one of the multi-factor type or, to use more conventional terminology, of the total-factor type - has to be adopted.

A measure of total-factor productivity (TFP) can be defined in general terms as the ratio of a (quantity) index of output over a (quantity) index of combined inputs. In the present case, where output is measured in value-added terms, the set of inputs can be confined to that of two types, labour and capital inputs, where the latter would ideally distinguish between physical and human capital. Actual measurement of TFP is usually carried out by one of two broadly defined approaches: parametric or non-parametric.

Parametric measurement rests on the specification of a production function and applies econometric techniques to estimate the parameters of this function. These parameters in turn provide the basis for obtaining direct measures of productivity levels or productivity growth. And for these measures methodological strengths and weaknesses can be identified rather easily. Thus, the regression approach usually taken in this connection allows for a clear formulation of theoretical and statistical assumptions underlying estimation. This advantage of clarity about the nature of estimates at the same time proves helpful for pointing out some of the disadvantages of parametric productivity measurement. The most significant among them seems to lie in the fact that estimation has to start from an explicitly specified form of an aggregate production function. Furthermore, for some crucial parameter values like factor shares, homogeneity across observations has to be postulated. Finally, the problem of endogeneity, plaguing most regression analyses of growth in general, is likely to affect the results of parametric measurement too[5].

Like parametric methods, any non-parametric approach to productivity measurement is rooted in production theory. This implies that certain properties of a production function assume importance for the estimation procedure without, however, creating the need to specify a functional form and to estimate its parameters. Usually, the result of adopting a non-parametric approach is an empirical measure of TFP or TFP change, which can be taken to represent a good approximation to the underlying 'true' value of productivity level or productivity change. The most widely employed non-parametric method of productivity measurement is that of growth accounting, which is applicable both in a times series and a cross section context[6]. Another example of this approach – applied only recently at country level and being of particular interest for the present analysis – is based on the estimation of productivity change with reference to a (world) technology frontier. It has become known under the technical term of data envelopment analysis (DEA).

The two examples of non-parametric measurement outlined above represent another basic distinction among productivity measures, one that relates to the information background: While time series growth accounting is strictly country specific in the sense that it takes into account only data pertaining to the country under study, technology-frontier based productivity measurement has to rely on information at least for a whole (reference) group of countries determining the frontier – even if the task is that of measuring productivity change for one country only. In the remainder of this section, this point will repeatedly be elaborated and also illustrated in some detail.

The specificity of frontier-based measurement of productivity change is best brought out by a comparison with the 'standard' of the (time series) growth accounting approach. The basic idea behind the latter is to relate – in a production function framework – the rate of change of output (of an industry or in the aggregate)

5 A comprehensive discussion of the various approaches to TFP measurement touched upon here is found, for example, in Islam (1999).

6 An ingenious re-interpretation of the growth-accounting approach is given in Harberger (1998).

to the rates of change of the various inputs as a whole. The growth of TFP is then evaluated residually by assessing how much of output growth can be explained by measured input growth and how much of it is left as a 'residual', interpretable as TFP growth. From this it is obvious that the growth accounting method can be applied at country or industry level without reference to other countries or industries. Among the main assumptions that have to be made for the standard time series growth accounting model are the following: The production function, relating (net) output to (primary) inputs of labour and capital, exhibits constant returns to scale. Productivity changes are of the Hicks-neutral type, so that they can be seen as corresponding to a shift of the production function and as being captured by one single parameter. And factor input markets are competitive, so that producers take factor prices as given and purchase input services so as to minimize costs. Although not all of these assumptions necessarily hold in practice, they can be viewed as providing reasonable approximations to many markets and hence a reasonable basis for proximate measures of TFP and its change over time.

Within the growth-accounting framework, the single-country approach can be complemented by a method, which looks at differences among countries instead of changes over time. This country cross-section version of growth accounting thus takes into consideration information on a multitude of countries simultaneously and bases TFP measures on inter-country comparisons[7]. The same view of data also underlies the most recently developed approach to TFP measurement, namely that involving a technology frontier as the main point of reference for changes in productivity. Here, the basic idea is to assess a given country's output with respect to both the amounts of inputs used and a 'world' level of technology, which is represented in 'production space' by the technology frontier. It is with respect to the latter that information on a multitude of countries has to be brought into the picture, in order to be able to claim that the empirically established frontier represents world or best-practice levels of technology. The problem of assessing a technology frontier and determining – with reference to it – changes in productivity is the subject of the remainder of this section.

As was pointed out earlier, the emphasis in this paper is on measuring changes in productivity, more precisely, changes in TFP on an aggregate level. In this case, the

[7] Islam (1999) gives a full-fledged account of this not so widely applied version of the growth-accounting approach and discusses extensively its advantages and disadvantages.

measure generally known as the Malmquist index (M index) appears to be the most appropriate tool, allowing for reference to world technological standards as they are represented in a technology frontier. Figure 2 presents the geometric essentials behind the above index in a model with only two goods and one factor. For the sake of simplicity it is assumed that the technology frontier sketched in the figure is the same in both time periods, i.e., that there is no technological change. The two vectors OP_1 and OP_2 represent the production points of a given country in periods 1 and 2 when there was no change in factor supply. Then TFP change as measured by the M index is the ratio of the length of the second vector over that of the first one where the special feature of the measure consists in the way in which vector length is measured: The 'directional' length p of the vector OP is defined as the ratio of two 'normal' Euclidean vector lengths, namely, that of OP over the length of vector OP^f, where P^f is the point of intersection between the ray of OP and the frontier. From this follows that OP has unit length if and only if P lies on the frontier. This measurement concept is easily generalized to the case of many factors and many goods and needs only a slight modification – to be discussed below - in order to accommodate a shift in the frontier, i.e., technological change[8].

The central task of assessing the technology frontier on the basis of available empirical information can be approached from two different angles. One emphasizes the stochastic nature of the data used and suggests econometric estimation of a so-called stochastic frontier production function. The parameters of this frontier function are common for all observations, with the only exception of levels of efficiency, while technological change is given by a time trend. In contrast, the alternative view disregards stochastic elements and instead employs a non-stochastic and non-parametric approach to determining the technology frontier common to all countries in the sample. Put in geometric terms, this method of data envelopment analysis (DEA) amounts to 'enveloping' all the observed production points and thereby generates a piecewise linear surface which can be taken as an approximation of the

[8] What has been said above about giving intuition preference over rigour in the present methodological discussion especially applies to the present passages on the concept of the M index. The intention here is to bring across the central idea of a directional measure of relative output on which this type of index is based. For a rigorous and compact outline of this and related concepts the methodological portions of Faere et al (1994) may be consulted.

'true' technology frontier inside which all production takes place[9]. The next paragraphs will expand on some of the details of this estimation method.

2.2 *Data envelopment analysis*

Data envelopment as a method to trace out in proximate fashion a technology frontier that is in accordance with a given set of observations on countries' input-output combinations is no doubt intuitively appealing[10]. Figure 3 – based on the same two-goods-one-factor production model as Figure 2, however, with the additional assumption of a constant-returns-to-scale technology – brings out the main idea behind the DEA approach: For a given set of country-specific points, representing outputs per unit of input in this two-dimensional 'product space', an enveloping piecewise-linear curve is constructed in a stepwise procedure where corners are given by undominated 'extreme' production points P_1, P_2 and P_3. Countries corresponding to these three points are technological leaders who employ best practices in the process of transforming the given single factor into the two types of output.

This illustration at once points to the fact that a single country observation may have a significant impact on the location and shape of the technology frontier whenever one individual country 'pushes' the enveloping polygonal curve along its ray of output composition. But this may just be what happens in reality in the context of localized technological innovation, which takes time to spread to other locations. Thus, the apparent disadvantage that this way of assessing the frontier might be 'driven' by individual observations may not be all that harmful. And, in addition, the advantage of the method's being parameter-free and thus not imposing on the relationship a specific functional form is likely to outweigh the neglect of stochastic elements.

So far, in order to exhibit the DEA approach a two-by-one model was used in which each country produced two goods by utilizing one factor only. This model serves perfectly well the purpose of outlining in geometric terms the so-called output-orientated version of the method. Its alternative, the input-orientated DEA, which will

[9] Some more details on the distinction between the stochastic and the non-stochastic approaches to frontier estimation are found in Krueger et al. (2000).

[10] Full accounts of data envelopment analysis, its theoretical background, the computational techniques involved and some guidance towards an interpretation of its results are contained in Coelli et al. (1998) as well as in Cooper et al. (2000).

prove relevant for the empirical application presented in this paper, is best illustrated at the case of a one-by-two model: One (aggregate) output, namely GDP, is 'produced' by use of two primary factors, e.g., labour and (physical) capital. Under the assumption of a constant-returns-to-scale technology, the amounts of inputs per unit of output can be determined and plotted in 'factor-input' space. Figure 4, which is drawn in schematic fashion, shows the result of this procedure, where each point represents a given country's requirements of factors to produce one (value) unit of GDP. If all countries were technically efficient, all points would trace out a so-called unit-value isoquant in factor-input space, which would have to be convex to the origin. The fact that two points lie outside the indicated isoquant indicates that the countries corresponding to these points are technically inefficient in view of given technological possibilities. Overall, the technology frontier of the output-orientated version - where inefficiency was indicated by a point lying inside the frontier - in the input-orientated version is replaced by a unit-value isoquant, with inefficient input points lying to its northeast.

As was the case for output orientation, for input orientation, too, a piecewise-linear curve, enveloping a set of observed points, can be determined. Under the assumptions stated previously, this envelope is the equivalent of the proximate technology frontier assessed in output space and can be obtained by the same method of DEA. The curve inscribed in Figure 4 is the result of such an enveloping procedure, applied to imaginary data. The computational technique utilized in both cases is that of linear programming, which allows to find those production (input) points that are undominated in simultaneous comparisons of each one of the observed points with each other. This procedure produces a piecewise-linear envelope, which can be visualized for models of low dimensionality like the present ones. It is not constrained, however, in its application by the number of goods and factors involved in a production model, although of course the possibilities of visual geometric representation vanish with higher dimensionality .

The last restriction on the expository model to be lifted in order to make it useful for the purpose of measuring productivity change concerns changes in technology. So far it was assumed that the technology frontier (or its input equivalent, the unit-value isoquant) was frozen into one position all the time and that all change in productivity was due to change in technical efficiency of factor use. If in addition technology is allowed to change too, the frontier will move – in the 'normal' case of technological progress outward in output space and inward in input space. This raises the question for the Malmquist method of measuring a change in productivity of which frontier to take as representing the reference technology. A plausible answer is 'both', in the form of a geometric mean of the two possible indexes. And this answer proves immensely fruitful in respect of the further analysis of productivity change.

As can be shown quite easily, the M index measuring a change in productivity can be rewritten in such a way as to represent the product of two factors, each one of which can be given a most interesting and useful economic interpretation. The first one of these factors measures change in technical efficiency as it was defined previously in the context of the output-orientated version of DEA and the M index based on it. The difference to Figure 2, where this concept was introduced, is only that distance has to be measured with respect to the first frontier in the first period and the second frontier in the second. The measurement concept remains the same as outlined above: a change in the relative distance of the output (input) point from the respective frontier indicates a change in technical efficiency.

What is left of the M index of productivity change after 'factoring out' the change-in-technical-efficiency component can justifiably be viewed as a measure of technological change. Geometry-inspired considerations show that this 'factor' indeed measures the extent of a shift of the technology frontier between two points in time. As an overall result, the M index – written as a geometric mean of two indexes referring to the two reference technologies – represents a multiplicative composite of a measure of change in technical efficiency and one of technological change. Thus, productivity change becomes decomposable into these two components as a result of the use of an M index based on a DEA assessment of technology frontiers. Which further economic interpretation the index and its constituents can be given is to become the subject of much of the discussion below[11].

[11] A detailed technical description of the present decomposition of the productivity index, as well as extensions to the case of a variable-returns-to-scale technology and the attendant differentiation between a pure-efficiency and a scale-efficiency component can be found in Faere et al. (1994).

3. The data

The present paper presents an attempt at estimating the change of economy-wide productivity, taken to be total factor productivity, for about two-thirds of the Least Developed Countries. In a technical sense – using the concepts outlined in the previous section - the exercise can be characterized as an application of the Malmquist-approach to measuring productivity change, where in addition the non-parametric method of data envelopment analysis is employed for determining a reference technology. The underlying model is the one of minimum dimensionality outlined above: its one-by-two framework is set up to analyse the production of one output, that of gross domestic product (Y), by use of two primary inputs, which are labour (L), aggregated over all skill categories, and the services of physical capital (K). Hence, in terms of the number of variables involved, data requirements are also minimal; however, in view of the country sample chosen, these requirements are far from easy to meet. The actual choice, for the purposes of the present analysis, of a sample of 32 countries out of the 48 LDCs (as they had been defined by the United Nations in 1997) is already to be seen as a consequence of the difficulties encountered with the compilation of information even for the smallest set of variables.

3.1 Estimating capital stocks

For the 32 LDCs analysed here[12] time series on both GDP, expressed in constant US dollars at 1990 prices, and on labour, measured in this context in terms of labour force, are available from the UNIDO Statistics Database. Difficulties, as usual, arose with the required time series on capital stock for the same country sample. Here the approach taken to derive estimates from available information was the use of data on investment[13], available in the above database, for the construction of country time series of capital stock, expressed – like the GDP figures - in constant US dollars at 1990 prices. The method employed in this exercise of capital stock estimation is the

[12] The 32 LDCs included in the present sample are: Angola, Bangladesh, Benin, Bhutan, Burkina-Faso, Burundi, Cape Verde, Chad, Democratic Republic of Congo, Equatorial Guinea, The Gambia, Guinea, Guinea-Bisseau, Haiti, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Myanmar, Nepal, Niger, Rwanda, Sierra Leone, Solomon Islands, Somalia, Sudan, Tanzania, Togo, Uganda, Zambia.

[13] Investment is measured in terms of gross fixed capital formation for which the UNIDO Statistics Database contains time series compiled from data of various international and national sources.

so-called perpetual inventory-method, with fairly standard assumptions regarding the rate of depreciation applied, as well as with respect to determining the capital stock in the initial year of the time series constructed.

The perpetual inventory method derives, in iterative fashion, the capital stock of a given year by adding to the stock of the previous year the depreciated value of real investment. In the ideal case, a rate of depreciation would be used that is specific both to a given country and to the type or component of capital stock dealt with. The latter consideration is not relevant in this context, since it is time series of economy-wide aggregates of capital that are to be constructed. The former consideration should be taken into account, if only there was a chance to obtain the requisite information. Given the lack of such information, especially with regard to LDCs, a uniform rate of depreciation has to be applied, which in the present case is assumed to equal 10 percent[14].

In order to determine a starting value of the capital stock time series to be constructed, the broad alternatives are that of using a geometric series of accumulated investment reaching back infinitely long into the past or of deriving such initial value from the assumption of steady-state growth and the capital-output ratio associated with this mode of growth. In the present case the latter method was applied on the basis of some additional assumptions. These assumptions concern parameters, which are involved in determining the steady-state value of a country's capital-output ratio from which the initial capital stock can be derived. One of these parameters is again the depreciation rate, which, like before, is assumed to equal 10 percent. Another one is the steady-state growth rate itself, which is constructed as a weighted average of the country's average growth rate during those ten years prior to the initial year chosen and the growth rate of world output[15]. Finally, the steady-state investment rate is

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[14] With this choice the present study follows Krueger et al. (2000). Alternative choices of depreciation rates of 5, 7 and 15 percent did not significantly alter the results of productivity measurement reported in Section 4.

[15] Following the procedure outlined in Easterly and Levine (2000), the weights chosen in the above average were 0.75 for the world growth rate an 0.25 for the country rate. With the estimates of parameters thus obtained, the steady-state value of the capital-output ratio is given as the ratio between the investment rate on the one hand and the sum of steady-state country growth rate and depreciation rate on the other. Applying this capital-output ratio to observed output in the initial year yields an estimate of the initial capital stock.

approximated by the average investment rate during those of the ten years indicated above for which there are data. By use of these three parameters, estimates of the aggregate capital stock for each country are obtained for the initial year 1970. And on this initial value the K-time series were built in perpetual-inventory fashion up to the year 1992.

3.2 A data preview

Table 1 presents a preview of the data used in the following analysis of aggregate productivity change. It presents average annual growth rates of output, labour and capital. The growth rates, calculated from the time series on the three variables described above, are for aggregates over the whole sample of LDCs and thus represent weighted averages of individual country growth rates of output as well as input supplies. The overall message conveyed by these growth rates is abundantly clear: Over the whole period and for those LDCs surveyed here the growth of factor supplies exceeded output growth, substantially in the case of capital. With regard to the latter comparison, this pattern obtained also in all the sub-periods shown in the table where differences of growth rates were particularly large in the early 1970s. By and large, these growth rate comparisons provide a first if rough indication of productivity decline in the group of developing countries analysed here. They also create sufficient motivation for taking a closer look at what happened to LDC productivity and some of its components.

Taking up the discussion of the previous section and looking ahead to the following one, another piece of evidence on the data assembled for this analysis is presented in Figure 5. The design of this figure follows closely the concepts and arguments used for introducing the DEA view of input-output relationships above and can therefore be seen first of all as an illustration of these concepts in terms of real-life data. The graphic takes the form of a scatter plot of what can briefly be called the surveyed countries' GDP production techniques. In this plot, which adopts the 'input-orientated' perspective of production technology, the aggregate-production technique of a given country is represented by the pair of its labour-output and capital-output ratios[16]. This produces an overall picture – drawn in factor-input space – of the

[16] For the plot shown in Figure 5 to make sense, again the assumption of constant returns to scale is essential. This assumption is retained throughout the rest of the paper.

immensely wide variation across countries of such techniques, indicated by the wide spread of 'technique points' over this space.

In particular, Figure 5 invites a comparison between the 32 LDCs in the present sample on the one hand and 22 industrial countries, for which the same kind of data have been compiled, on the other[17]. The striking impression left by this comparison is that of a clearly visible gulf that separates LDC techniques of producing aggregate output from those used by the industrial countries. And a glance at the graphic suffices to realize that it is the vastly higher capital-intensity of industrial-country production compared to that of the LDCs, which opens this gulf. Almost equally striking appears to be the fact brought out by Figure 5 that among the LDCs themselves techniques vary enormously, an observation that almost seems to militate against the notion of these countries forming a fairly homogeneous group. However large the spread of techniques within the LDC group may be, the technical divide between this group and the industrialized world remains the defining characteristic of the scatter plot of factor-output ratios.

The above observation may be given the interpretation that a techniques-gap of this size puts industrial-country methods of production almost out of sight for the LDCs. And if this interpretation was to be extended, the graphic could be taken to suggest that two country groups so radically different in their production techniques cannot be viewed as sharing one technology. The assertion following from this would be that, for whatever reason, the two groups might actually be using different technologies that would have to be represented by two different frontier curves. In other words, empirically established facts about production techniques could be taken as an indication that in reality it is not one 'world technology frontier' that provides the reference for assessing productivity change, but several such frontiers, each one being specific to a 'technologically homogeneous' group of countries.

The suggestion of breaking up a hypothetical world technology into a number of different frontiers is a radical one that goes against much of the modelling underlying empirical work, e.g., in the analysis of international specialization and trade. In the present context, there is no need to go that far, if the empirical procedure

[17] The 22 'Industrial countries' covered here are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States.

is recalled, which leads to assessing a proximate technology frontier. This procedure actually amounts to identifying those technique points, which represent best-practice methods of production and 'drawing' the frontier in such a way as to connect these best-practice techniques. Therefore, Figure 5 could also be seen as providing a rationale for the following approach: Estimates of productivity change in LDCs are obtained by use of the Malmquist method, where the technology frontier referred to is not some 'world frontier', but rather that frontier, which is determined by *best-practice techniques in the LDCs* themselves[18]. This approach will be pursued in the rest of the paper and the implications, which it holds, in particular, for any interpretation of the results thus obtained, will be taken into account throughout the discussion of the following sections.

4. The results

This section presents the results of applying the method of productivity analysis outlined in Section 1 to the data described in Section 2. The outcome is summarized in the most compact form possible in Table 2. This table presents – in index number form – measures of productivity change over the period 1970 to 1992, considered as a whole as well as broken up into four consecutive sub-periods, for the 32 LDCs comprising the present sample. In addition to these measures of TFP change, it gives – also expressed as index numbers – estimates of the two major components associated with such change: the change in (LDC) best-practice on the one side and the change in (technical) efficiency on the other. The index numbers shown in the table refer to the aggregate of the whole sample and represent annual change, averaged over the years of the time periods indicated, as well as over the countries in the sample[19].

The central achievement of the exercise reflected in Table 2 is that it attaches well-reasoned numbers to the overall impression of negative growth (over 1970 to 1992) of LDC average productivity, and traces developments over four sub-periods

[18] A similar exercise of estimating a technology frontier and interpreting it from a best-practice point of view is contained in Krueger *et al* (2000).

[19] All DEA calculations were carried out with the help the computer program DEAP Version 2.1 (as described in Coelli, 1996), the free use of which is herewith gratefully acknowledged. The basic results on the 32 individual countries are presented in Table 3.

within the whole period studied here. With reference to the discussion of Section 2 it can be claimed that the numbers of Table 2 are based both on the most general notion of overall productivity change and on an advanced method of estimation. Similar estimates for industrial countries, as they can be found in the relevant literature, reveal the opposite trend for that group. Thus, it emerges as a first general result that 'divergence' in per-capita GDP levels between the two groups, as it has been rendered visible by Figure 1, is rooted in divergence of productivity. Thus, the first impression of overall productivity decline, gathered from rough comparisons of the aggregate growth rates of Table 1, is confirmed by the still aggregate, but considerably more refined results of Table 2 which were obtained as unweighted averages from country-specific year-to-year changes in TFP.

4.1 Changes in LDC best practice

What the results of Table 2 have to offer in terms of a quantitative characterization of the way in which TFP declined appears to be as interesting as the overall assessment of change. With respect to the two components of productivity change investigated here, the table draws a clear distinction. Thus, the second column of Table 2 conveys an unmistakable message: best-practice change in LDCs over the studied time period has meant *regress* instead of much desired and much needed *progress.* A vivid illustration of what lies behind the numbers of the second column in the table is provided by Figure 6. This figure traces the changing positions of the LDC best-practice frontier in the years 1970, 1980 and 1992, respectively, and thereby gives visible substance to the diagnosis of shifts in the wrong direction, in other words, of best-practice regress. Observations such as these may be called striking, indeed, and they seem to deserve some explanatory remarks, also in view of the special approach to measurement taken here.

As was indicated in Section 1, the M-index method of measuring productivity change for its 'technological' component usually invokes some form of estimation of the world technology frontier. And although the method of tracing out such a frontier relies on those points representing best-practice techniques, a shift of the frontier can reasonably be ascribed to technological *innovation* as its source. This is not necessarily the case, however, when frontier estimation is based on a restricted country sample, like the 32 LDCs surveyed here. In such a case, the reason for a shift of the frontier may in some rare cases be innovation, expanding world technological possibilities. Normally, however, will it be a change (positive or negative) in the *group-specific* best-practice of *adoption* of new technology created elsewhere. Following this line of argument, shifts of the LDC-specific frontier identified in this exercise are taken as representing technology adoption within the group as a whole. Accordingly, that component in LDC productivity change, which is ascribed to shifts of the frontier, is termed best-practice (rather than technological) change in the present context. Thus, the results of Table 2 have to be interpreted as providing a clear indication of regress in LDC best-practice of technology adoption.

4.2 Technical-efficiency change

A wholly different picture is drawn by the figures of the third column in Table 2. In stark contrast to what is perceived as the broad trend of LDC best-practice change, developments in overall *technical efficiency* of these countries seem to indicate improvement throughout. Unlike productivity and best-practice change, the index of technical-efficiency change from 1970 to 1992 has a value greater than one and likewise for each one of the sub-periods studied here. An interpretation of these findings may start from the conventional view of changes in technical efficiency, but this view has to be modified due to the special features of the present application of the DEA method.

Normally, technical efficiency is related to, among other things, technology diffusion from the (world) frontier to the interior of the technology set. And it is for this reason that improvements in technical efficiency are often labelled as 'catching-up'. In the present case, a similar description may be applied, though with strong qualifications. First, any catching-up of individual countries as well as of the group as a whole is with reference to the group's own examples of best-practice technology adoption and not necessarily to pace setters of world technology. Second, efficiency gains can only be seen in relative terms: In times of best-practice regress, such relative gains are spurious unless they outpace best-practice decline, resulting in an overall productivity rise. What is observed in the present case is that on average over the 32 countries technical efficiency – gauged by their own best-practice standards – has increased. A realistic reading of this result is that of an improvement relative to a declining best-practice performance, meaning that on average LDCs have not slipped in technical efficiency to the extent they have in best practice within their group.

4.3 *Individual-country performance*

The aggregate results shown and discussed here have been obtained as unweighted averages of country-specific measures of productivity change, which are found in Table 3. While it is not the objective of this paper to analyse individual-country performance, a few remarks seem to be in place on the variation of such performance within the LDC sample studied presently. First, the overall decline of TFP corresponds to developments in about three-quarters of the countries in the sample where the steepest fall by far in aggregate productivity was recorded for Somalia, amounting to over seven percent annually. Five other countries – among them the Democratic Republic of Congo – also experienced formidable productivity losses of about five percent annually. On the other hand, productivity gains of over half-a-dozen countries remained moderate – amounting to less than one percent annually for most countries – with the only exception of annual TFP growth around three percent measured for Chad.

For obvious reasons, the contribution of best-practice change to the change in productivity was negative throughout, ranging from an annual decline of over six percent (again in the case of Somalia) to one of less than two percent for five of the LDCs surveyed here. In stark contrast to the technological-change component, relative change in technical efficiency was indeed positive for three-quarters of the countries in the sample, providing a detailed illustration of the aggregate results shown in Table 2. According to Table 3, gains relative to LDC best-practice decline amounted to as much as six-and-a-half percent annually in the case once more of Chad and were not much below this value for five other countries, including, for example, Uganda. On the other end of a ranking of countries by technical-efficiency change, losses were contained – with only one exception – to less than two percent annually.

By and large, Table 3 appears to produce a good substantiation and also illustration of the results obtained on average for the whole sample[20]. And without attempting interpretations of individual country results, it may be said that the assessment of country-specific performance provides a rough quantitative indication

[20] A number of tests were carried out to examine the sensitivity of results with respect to the design of the country sample. They showed that exclusion of countries with 'extreme' indes values does not visibly affect the numbers shown in Tables 2 and 3.

of a fairly wide range of growth experience among LDCs, involving not only broad variation in TFP change, but also substantial differences as to the role of the major sources of such change.

5. Hints at an explanation

Any explanation of the results reported above would first and foremost have to be guided by the fact that the underlying analysis is one conducted at the highest levels of aggregation in two respects: First, the subject of the investigations is the growth of aggregate output (GDP) at country level and its relationship to increases in aggregate factor supplies, and second, most of the numbers derived from such aggregate information are further subjected to an averaging process, so that in the end they reflect developments in a group of 32 countries, viewed as a whole. Bearing in mind these features of the analysis, what can be given is only some broad indications of or speculations about some of the reasons behind the observations outlined above.

To begin with, the documented *decline* in LDC (total factor) *productivity*, viewed in conjunction with the group's poor growth performance, seems to reinforce the point that factor accumulation – in particular, the accumulation of physical capital – is not enough to achieve satisfactory LDC growth[21]. The other substantial growth ingredient, namely, new technology from abroad needs to be provided in sufficient quantity and quality on the one hand, and adopted at reasonable breadth, depth and speed on the other. In addition, the formation of human capital - a factor not included in explicit form in the present framework - may be as important, both in its own right and as a prerequisite for satisfactory levels of technology adoption and diffusion throughout an LDC economy[22].

Furthermore, the *regress* in LDC *best-practice* is likely to have at least two reasons. First, access for these countries to new technology seems to be insufficient, a conjecture that is supported, for example, by figures on capital goods imports, which must be seen as a major source of (embodied) new technology. According to trade shares compiled from detailed information on trade flows contained in the United

[21] Easterly and Levine (2000) make this point much more strongly and in a considerably broader perspective. They build on it a plea for the all-important role of technology for growth.

[22] Lucas (1992) still provides one of the most lucidly stated observations also on this point.

Nations Commodity Trade Statistics, the share of LDCs in world imports of this type has dropped from 1.6 percent in 1970 to less than 0.4 percent in 1998[23]. This could be taken as another hint at the fact that, by and large, globalization of technology flows, which to a large extent are embodied in trade flows involving certain goods, appears to bypass the countries analysed here. Secondly and equally importantly, adoption of new technology from abroad is likely to be hindered by relative scarcity of human capital. And this effect is most probably aggravated by the nature of technological change, which seems to keep raising skilled labour-requirements, not only in the industrialized countries where still most technology is created but also in the developing countries where such technology needs to be adopted, adapted and put to use[24].

Finally, the mostly spurious positive impression of relative *progress* in LDC *technical efficiency* can at least be given a descriptive meaning. If best practice within the group has declined dramatically, LDC technical efficiency on the whole has fallen at a slower pace. Such limited relative 'success' may be seen as squaring with the intentions and maybe with part of the achievements of structural adjustment programmes too. Reforms, such as trade liberalization and price deregulation, are deemed to have enforced adjustments at micro level. As a result, for example, of the less efficient firms exiting and the more or increasingly efficient ones staying in business, some rise in technical efficiency might be expected. The backdrop to these positive elements regarding effort and achievement at micro level, however, is the one outlined in the previous paragraph: stagnation or even regress as far as best-practice standards within the group are concerned. Therefore, whatever might have been achieved in terms of relative gains in technical efficiency should not be overestimated, since it did not have to meet the enhanced and steadily increasing demands that are usually associated with technological progress.

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[23] This figure is taken from Robyn (2001) where some other empirical evidence on growth-relevant developments in LDC (manufactured) trade is produced.

[24] A brief yet fairly comprehensive account of what the skill-bias in today's technological change may mean for developing countries is given in Machin (2000).

6. The next steps

Viewing the group of LDCs as a starting point – and one, which poses the greatest difficulties in terms of data availability - other country groups might be analysed, taking advantage of a much improved data situation. However, in any application of the present approach of relating productivity change to within-group best practice, some effort will have to be spent on the systematic design of country groups that can justify the notion of a group-specific reference technology.

Another straightforward extension of the exercise presented here relates to attempts at increasing the number of factors of production considered and at improving the data on the related variables. On the basis of information improved in this way, country-specific calculations of productivity change and its determinants would be carried out and their results linked to what is known about individual countries. Finally and on a point of method, an attempt might be made to base future assessments of aggregate productivity change and its major components on a refined model of higher dimensionality than that of the one-by-two example reported in this paper. This would be a modification of the measurement approach that could link aggregate productivity analysis of the kind discussed here with the more detailed assessments at sector or industry level that have recently been proposed in the literature as promising subjects for future research in this field[25].

[25] Recent references on this point are Harberger (1998), and Jorgenson and Stiroh (2000).

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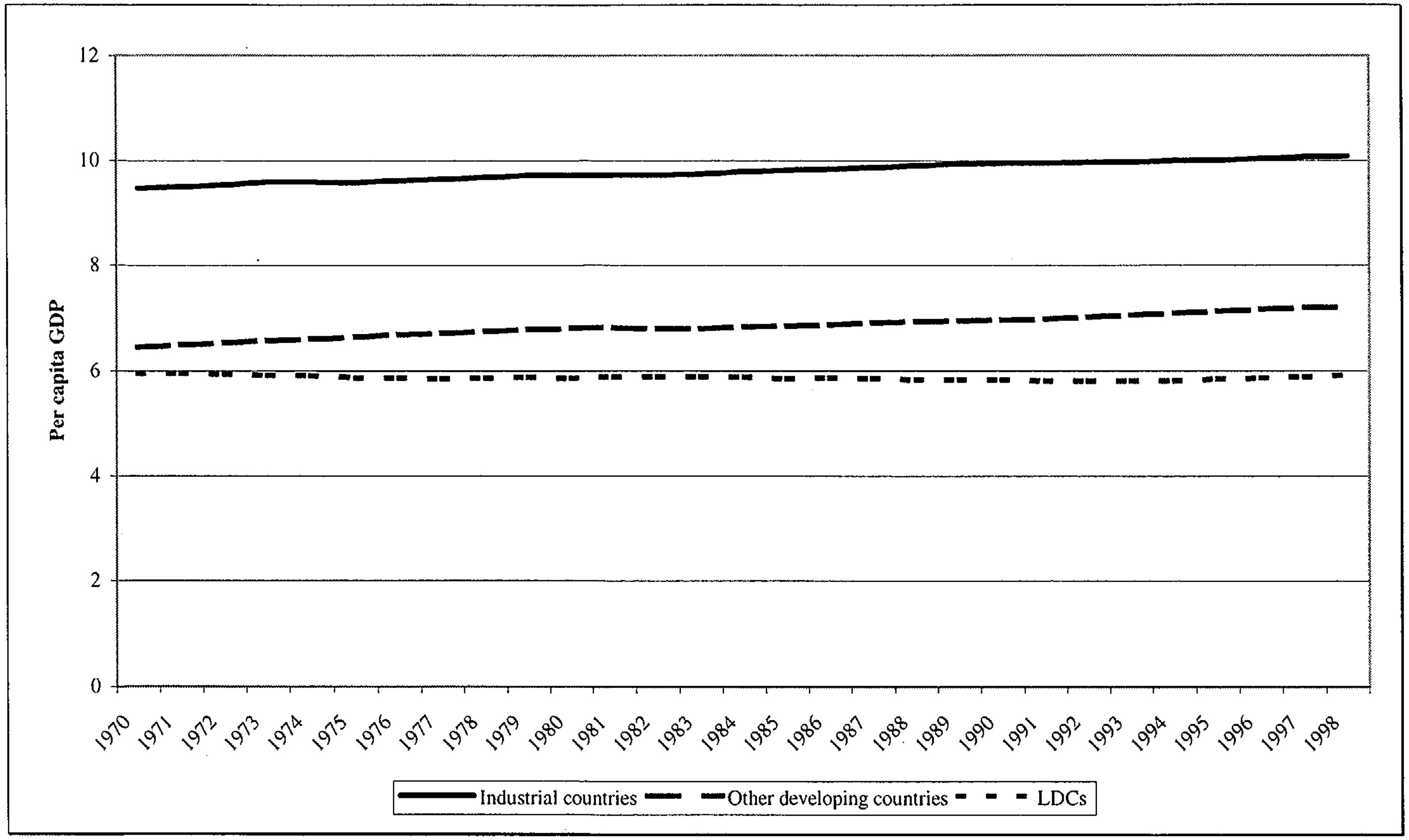
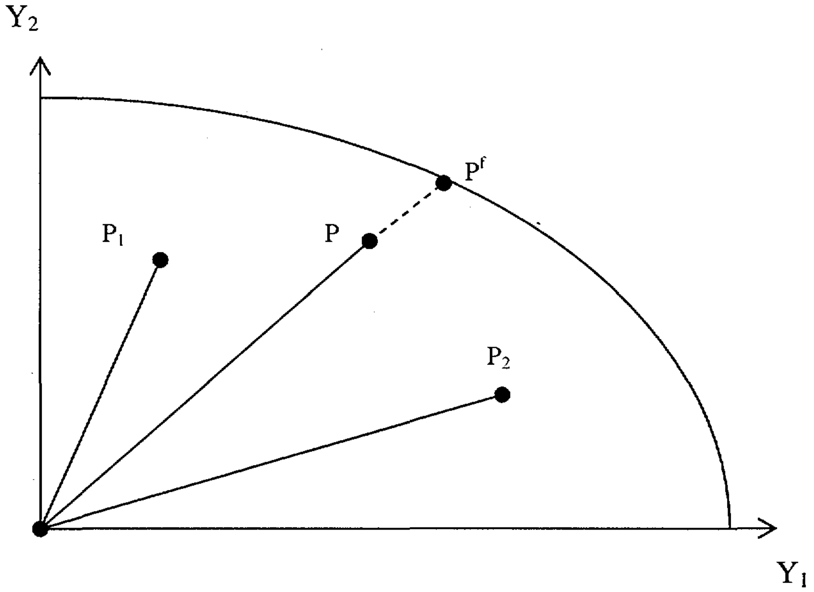
Figure 1 Gross domestic product (GDP) per capita, by country group, 1970 to 1998



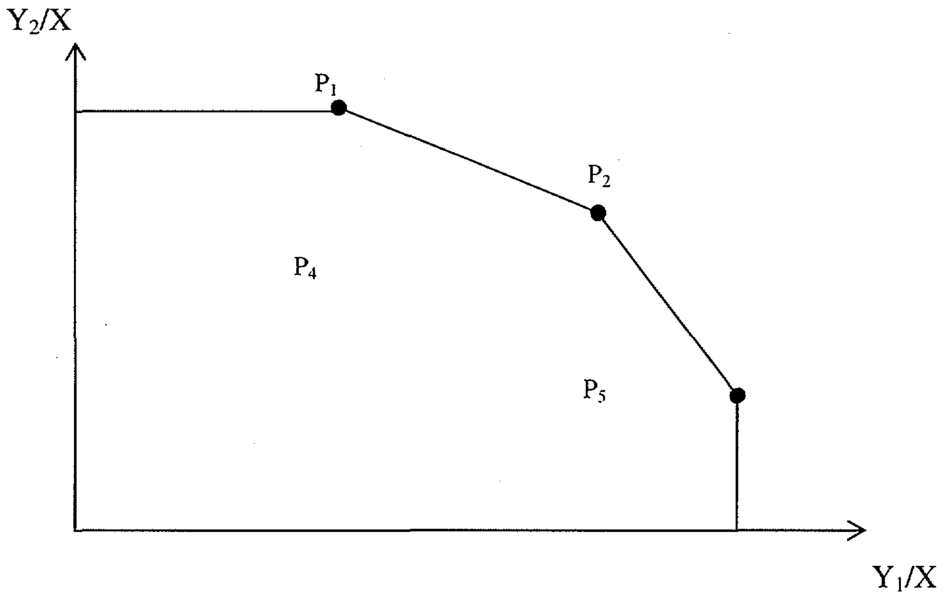
Source: UNIDO calculations based on data from the UNIDO Statistics Database.
Note: The figure shows weighted group averages of real levels of per capita GDP with population as the weighting variable. Values are in 1990 US dollars per person and are plotted on a natural-logarithmic scale. The data cover 41 LDCs.

Figure 2 Directional output distance



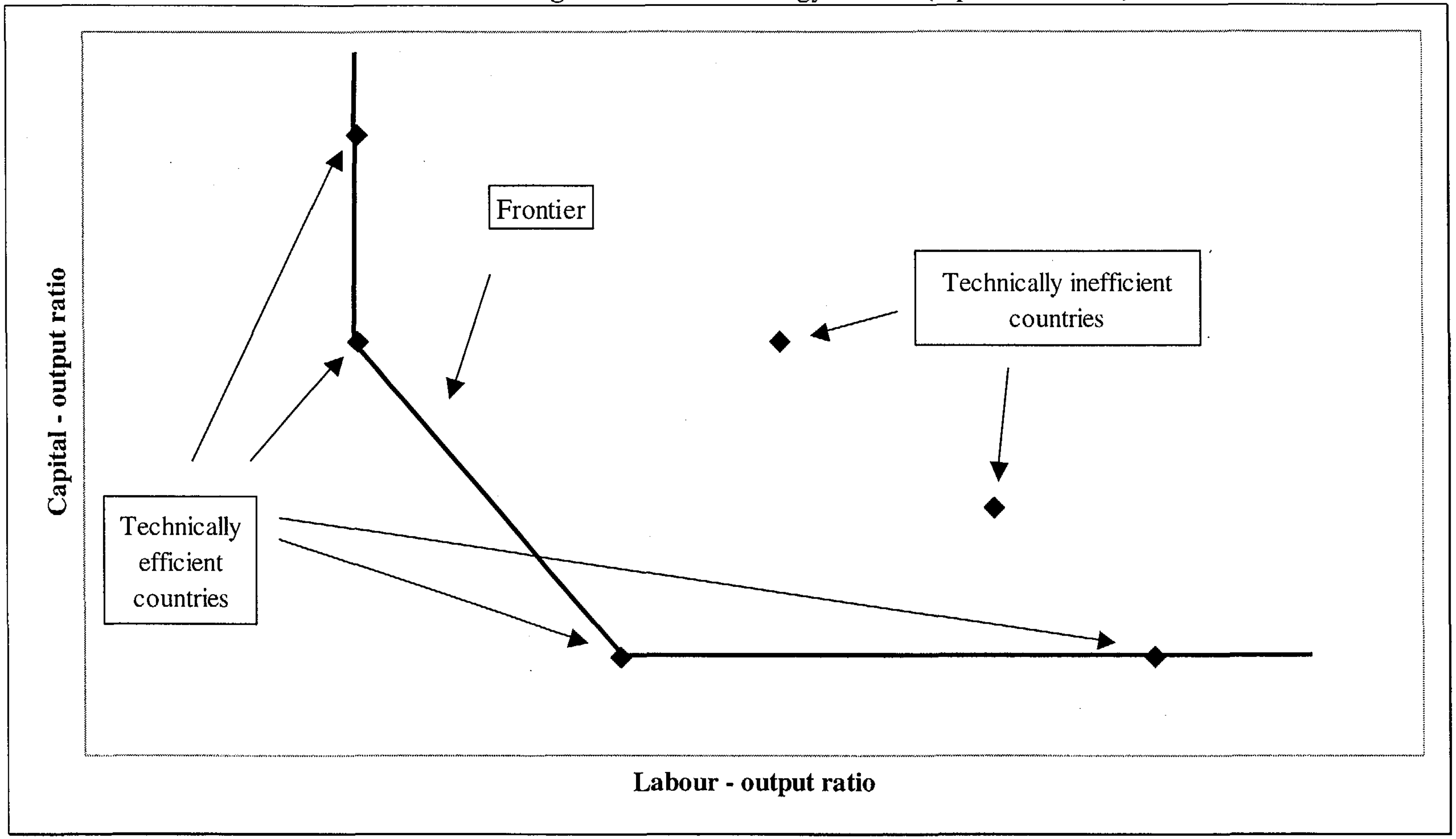
Note: Y_i denotes output of good i (i = 1,2)

Figure 3 The technology frontier (output orientation)



Note: Y_i denotes output of good i (i = 1, 2) and X input; technology is assumed to be of the constant-returns-to-scale (CRS) type.

Figure 4 The technology frontier (input orientation)



Note: The present 'input-orientated' representation of production builds on the assumption of constant returns to scale. The technology frontier is traced out by the most technically efficient countries. Countries to the north-east of the frontier are technically inefficient, i.e., they could reduce at least one of the inputs needed to produce one unit of output.

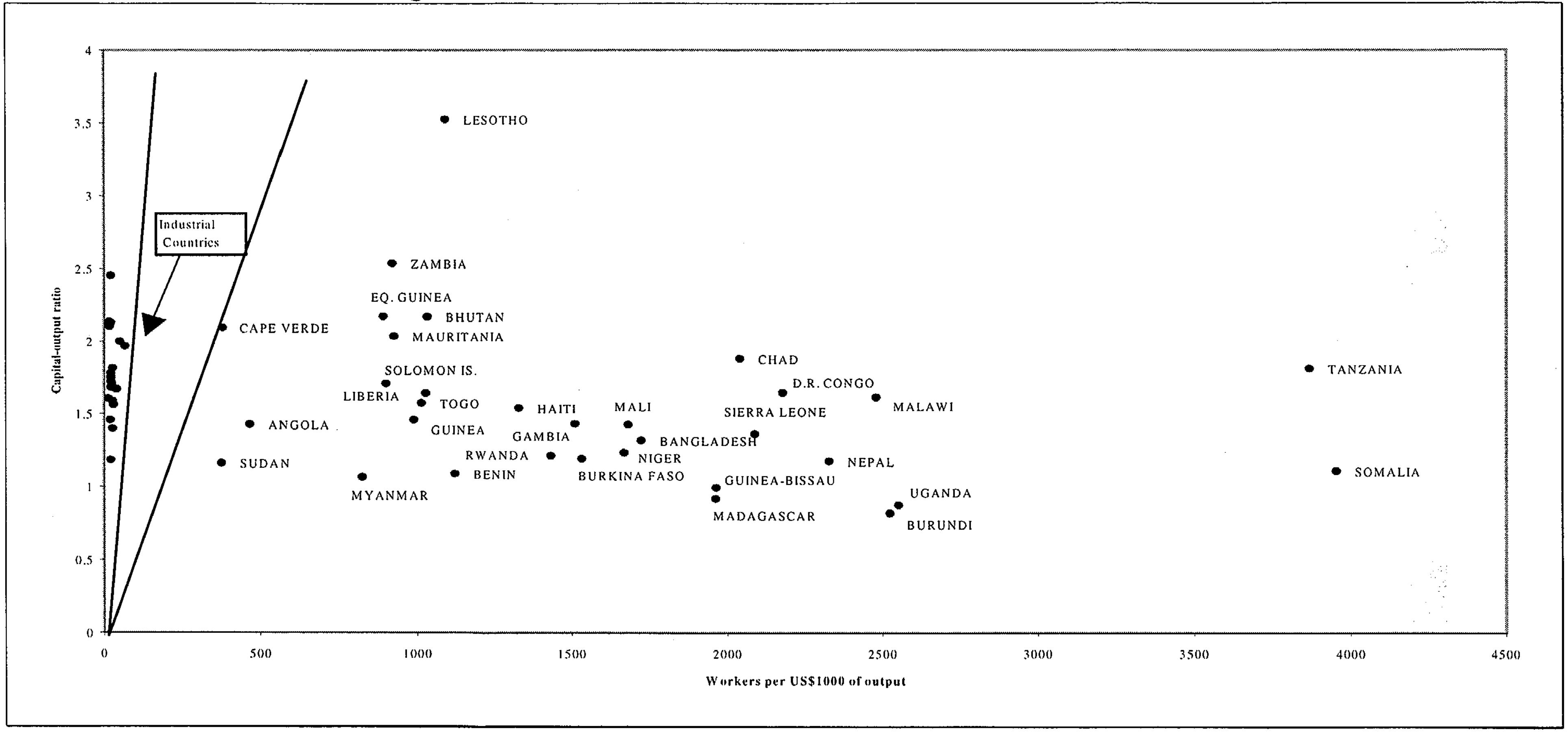
Table 1 – Aggregate output, labour and capital of LDCs:
Average annual growth rates, 1970-1992
(percent)

Period	Output	Labour	Capital
1970-75	0.8	2.2	3.4
1975-80	3.0	2.2	3.5
1980-85	2.8	2.4	4.3
1985-92	1.6	2.4	2.3
1970-92	***2.0***	***2.3***	***3.2***

Source: UNIDO estimates based on data from the UNIDO Statistics Database.

Note: Growth rates are compound growth rates. Underlying real output values (GDP) as well as real values of capital stocks are expressed in 1990 US dollars. The LDC sample described here covers those 32 countries (listed in endnote vii) for which data were available consistently for the time period 1970 to 1992.

Figure 5 The technical divide: LDCs versus industrial countries, 1992



Source: UNIDO estimates and calculations based on data from the UNIDO Statistics Database.
Note: Each point in the plot represents a GDP-production technique, which is characteristic of a particular country. All value data involved in the calculations are in constant US dollars at 1990 prices. Country samples are as described in endnotes vii and xi. The two straight lines drawn into the scatter plot delimit a factor-proportions cone that separates LDC from industrial-country production techniques.

Table 2 - Productivity, best-practice and technical efficiency of LDCs: Average annual change, 1970-1992

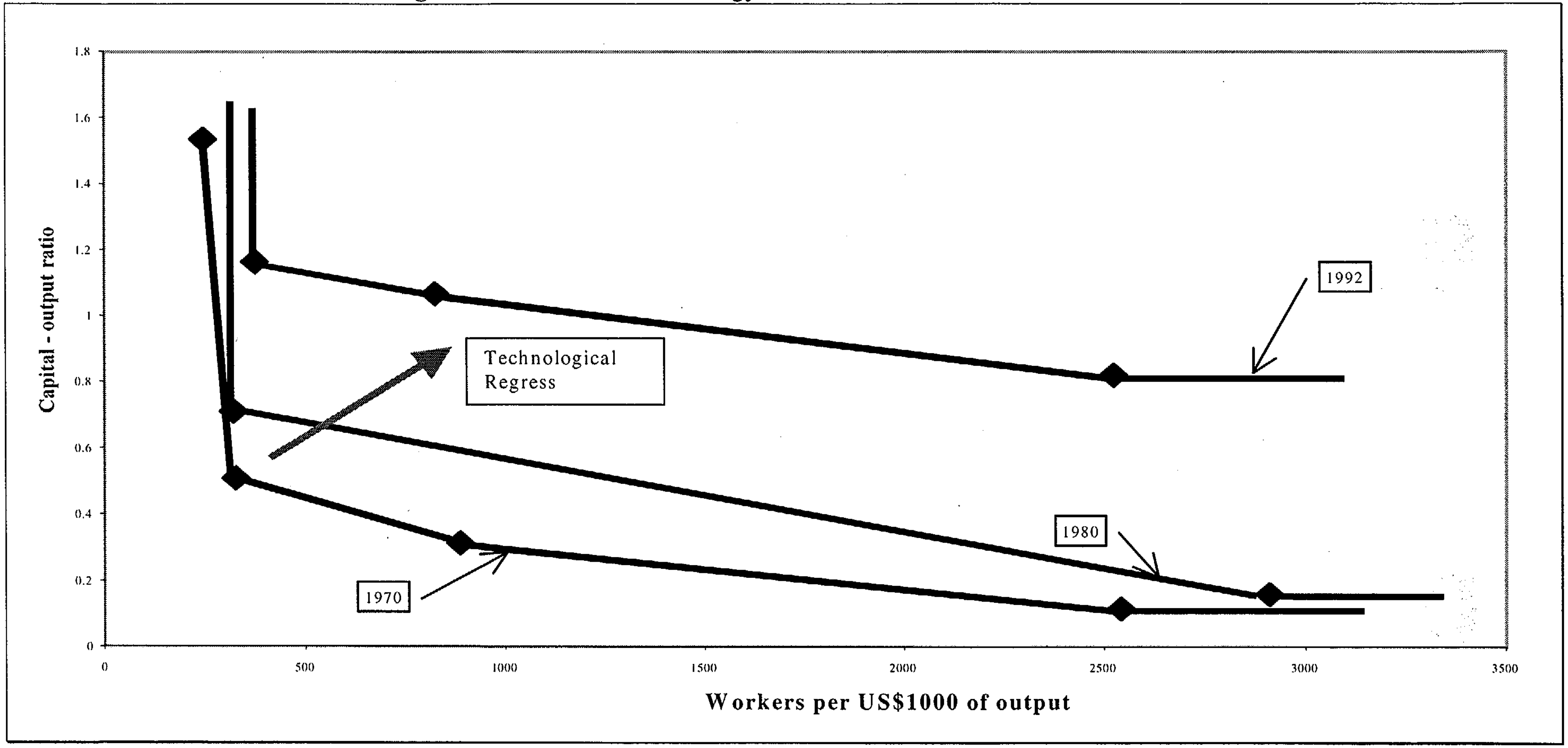
(Index numbers)

Period	Productivity	Best-practice	Technical efficiency
1970-75	0.983	0.967	1.016
1975-80	0.976	0.968	1.008
1980-85	0.977	0.949	1.030
1985-92	0.990	0.972	1.019
1970-92	***0.982***	***0.965***	***1.018***

Source: UNIDO estimates based on data from the UNIDO Statistics Database.

Note: All numbers in the table are index numbers. An index value larger (smaller) than unity indicates a positive (negative) change, whereas an index value of 1 indicates no change. Productivity is measured by the Malmquist index, which is decomposed into two components: one of them reflects the contribution of change in LDC best-practice and the other that of change in technical efficiency. Calculations were carried out on a year-to-year-change basis, and all averaging over years was in terms of geometric means of index values. The LDC sample used here covers those 32 countries (listed in endnote vii) for which data were available consistently for the time period 1970-1992.

Figure 6 Shifts of the technology frontier: 32 LDCs, 1970–1980–1992



Source: UNIDO estimates based on data from the UNIDO Statistics Database.

Note: Each one of the technology frontiers shown here is not only typical for a given year, but also characteristic of 'best-practice' methods of production within the country sample under purview. (The 32 countries of the present sample are listed in endnote v.) Here too, constant returns to scale are assumed.

Table 3: Average annual changes in productivity, best practice and technical efficiency: 32 LDCs, 1970-1992

Country	Productivity	Best practice	Technical efficiency
Angola	0.973	0.982	0.991
Bangladesh	0.977	0.961	1.017
Benin	1.010	0.964	1.048
Bhutan	1.006	0.963	1.045
Burkina-Faso	0.970	0.965	1.005
Burundi	0.982	0.965	1.018
Cape Verde	1.006	0.983	1.023
Chad	1.029	0.967	1.064
Dem.Rep. of Congo	0.958	0.961	0.998
Eq. Guinea	0.953	0.978	0.975
Gambia	0.971	0.961	1.010
Guinea	1.003	0.965	1.039
Guinea-Bissau	1.006	0.961	1.048
Haiti	0.967	0.960	1.007
Lesotho	0.956	0.960	0.996
Liberia	0.992	0.984	1.008
Madagascar	0.985	0.959	1.027
Malawi	1.003	0.961	1.044
Mali	0.992	0.961	1.033
Mauritania	0.954	0.964	0.990
Myanmar	0.993	0.964	1.029
Nepal	0.986	0.962	1.025
Niger	0.949	0.959	0.990
Rwanda	0.965	0.962	1.003
Sierra Leone	1.007	0.963	1.045
Solomon	0.993	0.965	1.029
Somalia	0.926	0.938	0.986
Sudan	0.980	0.980	1.000
Tanzania	0.993	0.958	1.036
Togo	0.964	0.963	1.002
Uganda	1.007	0.958	1.051
Zambia	0.989	0.982	1.007
Mean	**0.982**	**0.965**	**1.018**

Source: UNIDO estimates based on data from the UNIDO Statistics Database

Note: See the note of Table 2