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World Productivity Database: a technical description

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Abstract

This paper introduces a new unique database, the World Productivity Database (WPD), which contains information on levels and growth of aggregate total factor productivity (TFP) for as many as 112 countries, covering 1960 to 2000. At its core are numerous measurement methods, variations in functional forms and specifications—including schooling and health—of the production function, constant and variable returns to scale, as well as measures of technical progress and change in technical efficiency. Yet further variation emanates from five labour and four capital stock measures. Another significant feature is TFP forecasts for the period of 2001-2010.

Keywords: total factor productivity; labour productivity; technical progress; technical efficiency; production function; productivity measurement.

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1. Introduction

The purpose of this paper is to describe a new, unique database—the World Productivity Database (WPD)—which contains information on aggregate productivity performance, level and growth, across a large number of countries (112) over a 40-year period (1960-2000).[1] Although it mainly focuses on measures of total factor productivity (TFP), it also includes simpler (partial) measures, such as labour productivity (income per worker) and basic statistics, such as growth of labour productivity and capital deepening.

The interest in productivity performance stems from the fact that it is the ultimate determinant of welfare improvement. It also has a strong bearing on issues and variables, such as competitiveness, interest rates, inflation, profit and wage setting. In the context of developing countries, sustained poverty reduction does not occur without economic growth, in particular, that based on TFP growth. It is productivity growth that allows for sustained expansion of the economy, increased demand for labour and higher real wages.

While many international and national organizations in industrialized countries regularly publish various productivity figures, this is generally not the case in developing countries. WPD bridges this gap by making such data available to policymakers in the latter group of countries. This allows them to keep track of productivity performance and prospects for increased living standards. Naturally, with productivity growth being at the heart of industrial development, UNIDO itself benefits from WPD—both for its programmatic development and its role as source of information on industrial development for the global public. Multilateral institutions, such as the World Bank and other parts of the United Nations, as well as bilateral institutions and non-governmental organizations (NGOs) may, too, find WPD useful.

A third readership is academia—in both developing and industrialized countries—to which WPD provides data for analysis. In particular, WPD caters to the many existing preferences and views among researchers regarding productivity measurement. For example, TFP measures are provided based on more than ten different measurement methods, several approaches to measuring capital and labour input, measures of technical change[2], change in technical efficiency and scale efficiency, and various specifications of the aggregate

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[1] See Table 1 for a list of countries included in WPD. These are sorted based on political and geographical considerations.

[2] Technological change and technical change are related but distinct concepts. The former refers to a change in the set of feasible production possibilities, while the latter describes a change in the amount of output produced from the same amount of inputs. The latter can occur due to several reasons, such as a regulatory change or improved organization, without any technological change. In this paper, the concept mainly referred to is technical change.

production function, including that accounting for schooling and health. Furthermore, many researchers—some of them not experts on productivity measurement—want to link information on productivity to other issues, such as poverty reduction, effects of environmental regulation and wage determination. WPD may considerably shorten the research time needed for data collection and measurement.

Because of the many difficulties involved in the measurement of productivity growth, a wealth of methods and views has developed over the years. Some of these have gained more popularity than others. For example, while standard growth accounting is arguably the most popular measurement method—partly because of its deceptive simplicity—one has to be aware of the implicitly restrictive assumptions involved. Over time, these restrictions have gradually been relaxed and the path to alternative methods laid open, thus providing nearly a plethora of approaches to productivity measurement. The decision as to which of these methods to choose may depend on a host of factors, such as conventions, preferences and suitability. The aim of WPD is to provide as many of these alternatives as possible.

Another debated issue is the measurement of capital stock. It seems that accurate measurement of capital services—and of those of labour as well—requires data of such quality and detail that comparison across a wide set of countries is rendered impermissible. The goal of WPD is to provide as high-quality measures of capital and labour for as many countries and length of time as possible.

The paper is organized into three substantive sections: In Section 2, data sources and data availability are provided, as well as a description of how the input data for productivity measurement were compiled and constructed. Some strengths and weaknesses involved in the choices made are discussed as well. Measurement of TFP level and growth is the focus of Section 3, with a few comments the on merits and disadvantages of different approaches. The approach used for forecasting TFP is also discussed. Although WPD at the moment covers aggregate data only, the aim is to expand it to include manufacturing TFP performance, more countries and longer time series in the near future. Section 4 is devoted to such expansion and other improvements, along with concluding remarks.

2. Data

In this Section, sources, availability and construction of data used in WPD for TFP measurement are discussed. The maximum number of countries covered is 112, which is attained in the simplest specification of production function—one that only includes the primary production factors, labour force and capital. As more refined measures of labour inputs and more elaborate specifications (e.g. those including schooling and health) are employed, the number of available countries decreases, in some cases significantly.

2.1 Data sources

The principal data source is Penn World Tables version 6.1 (PWT, Heston, Summers and Aten, 2002), from which GDP (chain weighted) and investment, both in power purchasing parity 1996 US dollars, are obtained.[3] Real investment is used to compute capital stock in international prices. Albeit with a few considerable changes to the series as described below, labour force has been retrieved from the same source. The combination of output, investment and labour force data from PWT maximizes the number of countries and years covered.

Refined labour measures and more intricate specifications require additional data. From the Groningen Growth and Development Centre (GGDC, 2005) and Asian Development Bank (ADB, various issues), data on employment and hours worked (only GGDC) have been obtained, while unemployment rates have been collected from the International Labour Organization (ILO) *Yearbook 2003* (ILO, 2003a), KILM (ILO, 2003b) and ADB (various issues). Barro and Lee (2000) is the source for schooling data, while the health indicators used here—life expectancy and adult mortality rates—come from World Development Indicators (World Bank, 2004). Finally, in some cases data have been checked against national sources and, occasionally, adjusted.

2.2 Data availability and construction

The main intention here is to report on adjustments that have been made to original data. In addition, the different fashions with which input variables are allowed to enter the production function are discussed. While output (GDP) and, in particular, capital, represent general limitations to data availability, in that data for a maximum of 112 countries from 1960 to 2000 are available, indicators of labour, schooling and health define data availability for production functions going beyond the most basic specification, i.e., one based on labour and capital.

There are two underlying datasets used for TFP measurement. First, an unbalanced, which is the main input data and secondly, a balanced (meaning that all countries included are observed for the same years) because some measurement methods, such as data

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[3] PWT version 6.1 has data running from 1950 to 2000, which should, thus, be understood as the limiting factor of WPD in terms of time coverage.

envelopment analysis (DEA) require data to be balanced. The decisive advantage of the former is that of superior country coverage. On the other hand, the main disadvantage is that some countries carry less weight than others since they are observed for fewer years. This disadvantage is, for example, relevant for parametric estimation of TFP. Table 2, which is sorted by various categories of labour input, summarizes for which countries data are available. All countries marked with at least one dot have data, while countries marked with two dots are only available in the unbalanced dataset.

An example is the comparison of Rwanda, Taiwan, Province of China (hereinafter, Taiwan) and United Republic of Tanzania (hereinafter, Tanzania). Common to Rwanda and Tanzania is that only TFP estimates based on labour force can be obtained. But, whereas Tanzania appears in both the balanced and unbalanced datasets—and, hence, for all measurement methods—when health is included in the production function, TFP data on Rwanda are only available for measurement methods that do not require balanced data, because data for health are unavailable for all years. In the case of Taiwan, more versions of labour data are available. Hence, TFP growth estimates can be obtained for all specifications based on labour force, employment, derived employment and hours worked for those two employment categories, as well as for specifications including schooling in addition to labour indicators. However, when health is involved in measuring TFP, for Taiwan such measures are no longer available.

2.2.1 Output

Output is measured as chain-weighted real GDP in constant 1996 prices adjusted for purchasing power parity. Tables 3 and 4 list the countries that did not have full coverage of output data, the missing-years problem and how this was resolved. The most common problem is that, for some countries, one or a few of the end years are missing. The general solution is to use information on the growth of real GDP, as obtained from the World Development Indicators (World Bank, 2004). To enable the capital stock series to start in 1960, both GDP and investment are "back cast". The next Section describes how this was done, with pre-1960 missing years referring to this exercise. When GDP is missing for the middle of the series (for example, Haiti in 1966), it is interpolated by taking the average between two years.

2.2.2 Investment

Tables 3 and 4 list cases where investment data are either missing or data series are shorter than needed and, as in the case of output, describe how these issues are treated. If investment, but not output, data are missing, backward extrapolation based on a moving-average mechanism is applied. For example, if the average investment rate of a country between 1960 and 1964 is 20 per cent, this is assumed to be the value for 1959 as well. Thereafter, a new average investment rate for 1959 to 1963 is calculated and applied to 1958 and so on until sufficient data has been derived to allow for calculation of initial capital stock.[4] The consequence is that business cycles are "smoothed away" for the missing years. But this does not necessarily have a profound negative impact on K_0 and subsequent TFP measurement. In case output data, too, are missing, a similar moving-average mechanism is first used to extrapolate output before repeating the above procedure as for investment.

At this stage, it is possible to rank the capital stocks based on the extent and way output and investment series are extrapolated. The most reliable capital stocks are those based on time series dating sufficiently back so as to avoid manipulation. This generally includes capital stocks for industrialized countries. Next are capital stocks that require extrapolation of the investment series. Fairly advanced developing countries belong to this category, for example, those from Latin America and East Asia. The third best cases are those where both output and investment data have to be extrapolated, typically low-income countries. Although the impact of such data manipulation is only detectable early in the output and capital series, the user should be aware of this. For qualitative purposes, the impact nonetheless appears quite insignificant.[5] For international comparison of TFP levels, it might, therefore, be advisable to avoid using the first decade of TFP data, where the impact of initial capital is the largest; over time, this impact dwindles.

2.2.3 Capital

Capital is arguably the most difficult production factor to measure.[6] For that reason, WPD includes TFP estimates based on four approaches to capital stock measurement (K06, K13,

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[4] This implies that data are extrapolated back to 1946, 1950 and 1954 for K_0 based on 15, 10 and 5 years, respectively.

[5] An example here is the comparison of poor and rich countries. The described data manipulation does not affect country rankings but may have an impact on whether the gap between two countries is 15 or 16 per cent. Isaksson, Ng and Robyn (2005) provide country rankings based on TFP.

[6] Flow of capital services is actually what needs to be measured. As this cannot be easily carried out for many of the countries in the WPD sample, it is conventional to assume that capital services are proportional to the stock of capital.

Ks and Keff).[7] These differ in how the initial capital stock is computed, the rate at which capital is assumed to depreciate, whether that rate is constant or varies over time and whether the lifetime of an asset should be explicitly accounted for.[8]

The perpetual inventory method provides a standard way of formulating how capital evolves:

$$K_{t+1} = (1-\delta)K_t + I_t, \qquad (1)$$

where I_t is the investment undertaken year t, K_t is the capital stock at the end of year t and δ is the depreciation rate. Substituting back in time to some initial period leads to equation (2):

$$K_t = (1-\delta)^t K_0 + \sum_{i=1}^{t}(1-\delta)^{t-i} I_i. \qquad (2)$$

where K_0 represents the initial capital stock. In (2), δ and K_0 are unknowns and have to be estimated or assumed. Since the correct values of these two unknowns can be debated, WPD offers capital measures based on alternative estimates or assumptions of these, leading to three different capital stocks (K06, K13 and Ks). Common for the three is that capital is assumed to depreciate at a constant rate over time.

For two of these, K06 and K13, it is assumed that ten years of investment serve as an adequate proxy for the initial capital stock K_0. For example, for investment data starting in 1950, investments from 1950 to 1959 are used to construct K_0 for 1960. Underlying the 39 versions of each capital stock measure, among several other considerations, is experimentation using three different initialization lengths, namely five, ten and 15 years.[9]

The two capital stocks only differ in terms of their assumed depreciation rates, which are six and 13.3 percent, respectively (hence, K06 and K13). The latter measure is based on Leamer (1988) and assumes an unusually rapid depreciation rate, implying an emphasis on relatively recent investments and less impact of K_0. It should be noted that the chosen δ is a number matching the double-declining balance method, implicitly assuming a lifetime of 15 years for K13. By contrast, K06 places relatively less emphasis on recent investments and the

[7] There are 39 alternative assumptions for each of the four capital stock versions, implying a total of 156 capital stocks. Variations in assumptions include parameters, such as number of years back cast, numbers of years used for the moving-average mechanism and numbers of years used for computing K_0.
[8] The effect of different ways of calculating capital is most readily seen when comparing TFP levels, while for comparison of TFP growth it is much less discernible.
[9] However, note the exception of capital based on the efficiency method (Keff).

effect of initial capital lingers longer.[10] The implied lifetime for K06 goes beyond the end of the sample period.

Another common way of computing the initial capital stock is to assume that the country is at its steady state capital-output ratio, leading to what is called here steady-state capital stock (Ks). The major advantage compared to K06 and K13 is that ten years of data do not have to be lost in the calculation of K_0. The key equation is:

$$k = i/(g + \delta), \tag{3}$$

where k, g, i and δ are the capital-output ratio (K/Y), growth rate of real GDP (Y), investment rate (I/Y) and depreciation rate, respectively. Hence, (3) requires estimates of steady-state values of i, g and δ.

The depreciation rate is set at six per cent. Following Easterly and Levine (2002), g is a weighted average of all countries' average growth rate and world growth rate of output (for the first ten years, the time period here equals 1960-1969). The weights are set to 0.75 and 0.25 for the world and country growth rates, respectively, leading to country-specific estimates of the steady state growth rate. The average investment rate for the first ten years (1960-1969) serves as a proxy for the investment rate i. Inserting these numbers into equation (3) leads to a solution for k. Finally, the initial capital stock is computed as initial Y (i.e., the 1960 value) times k.

A drastically different way of measuring capital introduces the concept of asset lifetime, which implies the use of a time-varying depreciation rate. The physical efficiency method (leading to Keff) starts from the notion that an asset's productivity is a function of the depreciation rate δ, which, in turn, depends on the age of the asset. At year one, the productivity of the asset is unity (i.e., 100 per cent). As the asset ages, its productivity declines at an increasing rate. After some time, the asset's lifetime L is considered over or, at least, the asset's productivity is too low, so the asset is scrapped. Following Crego *et al.* (1998), the relative productivity of an asset S at age j, Sj, can be expressed as:

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[10] Individual countries may have different depreciation rates due to different compositions of capital. For example, more developed countries tend to have a larger share of IT-related assets, which have relatively high depreciation rates, while developing countries' capital stocks contain a relatively large share of buildings and machines, which have a slower rate of depreciation

$$S_j = (L - j)/(L - \beta_j),\ 0 \le j < L$$
$$S_j = 0,\ j \ge L \quad . \tag{4}$$

In (4), β is the curvature parameter and crucially determines the rate of deprecation as the asset ages. If β is positive but less than unity, depreciation accelerates over time leading to a concave asset productivity curve. Figure 1 illustrates this idea for two fictitious assets, A and B, with different lifetime and decay parameters.

In addition to β, the lifetime of the asset also affects the depreciation path. According to Crego *et al*. (1998), when the different assets—which have different lifetimes—are translated into aggregate investment, the aggregate service life turns out to be 20 years with a decay parameter of 0.70 (β). WPD adopts 20 years of service life for each year's investment. As a consequence, it also uses 20 years for the calculation of initial capital stock for this particular capital stock. The implication is that the capital stock and TFP series based on this method starts in 1969, as compared to the standard of 1960, used in WPD.

2.2.4 Labour[11]

Standard in empirical literature of cross-country nature is to measure labour input by labour force. The advantage of this labour measure is its superior availability and, possibly, quality compared to alternative labour measures. The main disadvantage is that it leads to underestimation of measured productivity level because of under-utilization, or unemployment. The effect on productivity growth is uncertain, since it depends on the behaviour of growth in both the labour force and its components.

WPD offers productivity estimates based on five labour input measures: labour force, employment, derived employment, hours worked based on employment and hours worked based on derived employment. There are two kinds of labour utilization rates for which labour force should be adjusted: variations in numbers employed and in hours worked. The first two alternatives to labour force (LF) are employment (EMP), which is obtained either as a direct measure of employment or derived by applying unemployment rates to LF data, leading to derived employment (DEMP). Both of these labour measures are then adjusted to account for variation in hours worked, giving rise to two additional labour measures (HEMP and HDEMP). While productivity measures based on HEMP and HDEMP are considered

[11] Here, labour is understood as raw labour. This distinguishes it from cases when adjustments for its quality are made (see the discussions on schooling and health).

superior to those based on, for example, LF, the trade-off is significantly reduced country coverage.

The labour force (LF) data underpinning the different labour measures used were obtained from PWT 6.1.[12] In several cases, unusually rapid LF growth periods were observed, possibly due to changing measurement methods or population coverage. In Argentina, for example, average annual labour force growth rate is some one per cent. In 1991, that number exceeded five per cent, a rate that lasted until 1995. Thereafter, it returned to some one per cent. The jump in growth may mark some administrative change in coverage, such as inclusion of rural areas, in addition to urban or women, in addition to men.

Large increases in the growth rate of LF are considered incredible and are, therefore, smoothed. The adjustments made to LF are based on the assumption that relatively recent measurement methods are superior, in particular, in terms of coverage, to relatively older ones. The implications of these adjustments are clear in the case of the Argentinean example. The LF growth rate of 1991-1995 is aligned to the rest of the series by, first, adjusting the five per cent growth rate down to the average annual post-1995 growth rate of some one per cent. Secondly, the pre-1991 LF levels are adjusted to align with that of 1996. These adjustments do not affect TFP growth but have implications for TFP level. Continuing with this example, because pre-1996 LF levels are adjusted upwards, TFP levels are correspondingly adjusted downward. Table 5 shows the countries and years for which this kind of adjustment is made.

As can be expected, data on EMP are more difficult to obtain. Consequently, the country coverage is reduced by some 50 per cent compared to that for LF. The source of EMP for countries in the Organization for Economic Co-operation and Development (OECD) is OECD itself, while GGDC provides information for Latin America. Data for Asian countries come from various issues of ADB's *Key Indicators of Developing Asian and Pacific Countries*. Contrary to the case of LF, these data are not adjusted and are used for TFP calculations as they are.[13]

Derived employment (DEMP) is arrived at by adjusting LF according to unemployment rates obtained from OECD, ILO and ADB. Compared with EMP, country coverage differs because countries that have information on unemployment may not have data on

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[12] A few cases of simply erroneous labour data were found in PWT. For those cases, after having cross-checked against national sources, data from the World Bank were used instead of PWT. Table 5 provides a list of countries for which this is the case.

[13] GGDC employment data give the impression that, between census years (normally undertaken once a decade), they have been linearly interpolated.

employment, and vice versa (see Table 2 for country coverage).[14] In cases where unemployment series are shorter than the employment series described above, the unemployment series are extrapolated based on growth of derived unemployment resulting from subtracting employment from labour force. Table 5 indicates for which countries and periods extrapolation is undertaken.

Based on EMP and DEMP, labour input measured as hours worked (HEMP and HDEMP) is computed. In addition to correct labour input for variations in numbers employed, hours worked adjust labour for the utilization rate with respect to the intensity with which employees work, for example, part-time and overtime. These measures thus account for two adjustment mechanisms available to employers in case of shifts in demand. Data on average hours worked come from GGDC. The number of countries reporting on hours worked for a sufficient time period decreases significantly, and country coverage only includes OECD and a few others (see Table 2).

Methods of labour data collection can have an important impact on productivity measurement. Luxembourg is a particularly important case, since the country ranks first in terms of TFP. While the measured labour force is small, there is a large group of employees commuting from neighbouring countries, leading to an understatement of actual labour input and, thus, overstatement of TFP. In fact, the sum of unemployment and employment turns out larger than the (derived) labour force. Because of its implausibility, unemployment is set to zero for the few years in which this phenomenon occurs.

2.2.5 Schooling

Going beyond production functions with only primary inputs, WPD allows for schooling (S) as one of two additional (secondary) inputs.[15] Schooling is measured by attainments levels for the population 15 years and older, as obtained from Barro and Lee (2000). As Table 2 suggests, country coverage is reasonably good. Preferences as to how to include schooling in the production function differ among economists. WPD allows for two common ways. Either schooling enters as a separate regressor, or, if it enters as an augmentation to labour, labour can be said to be quality-adjusted instead of just raw labour.

First, schooling is treated as a separate regressor. A common issue encountered in production function estimation, when schooling enters as a separate input, is that it has a

[14] This concerns Costa Rica, Ghana, Kenya and Malawi.
[15] Health is the second.

tendency not to be statistically significant. Jones (1996) argues that the root of the problem is that it usually enters in logarithmic form, implying an investigation into the effect of a percentage change in schooling. This, however, is not commensurate to realistic changes in schooling. As an alternative, he proposes that schooling enters in actual school years. WPD adopts this line of thought when the production function is of Cobb-Douglas form. In the case of translog production functions, the logarithmic form of necessity is maintained throughout.[16]

Secondly, schooling may also enter as an augmentation to labour, for example, along the lines of Hall and Jones (1999). In their work, it is assumed that returns to schooling differ according to the development stage of countries, such that, in less advanced countries returns to education are higher. Countries are divided into three groups, and labour is adjusted for quality according to (5):

$$h = e^{\varphi(s)} L \qquad (5)$$

where L is raw labour, s average years of schooling and the function $\varphi(s)$ is piecewise linear with the following slopes: $\varphi(s) = 0.134*s$ if $s \leq 4$, $\varphi(s) = 0.134*4 + 0.101*(s\text{-}4)$ if $s < 4 \leq 8$ and $\varphi(s) = 0.134*4 + 0.101*4 + 0.068*(s\text{-}8)$ if $8 < s$.[17] The three numbers—0.134, 0.101 and 0.068—reflect Mincerian (Mincer, 1974) education-wage profiles for sub-Saharan Africa, world average and OECD, respectively. The idea of (5) is that $\varphi(s)$ reflects the relative efficiency of a unit of labour with s years of education compared with a unit with no schooling. Another year of schooling is assumed to increase a worker's efficiency in a proportional fashion. Equation (5) is thereafter inserted in the production function instead of simply labour L.

2.2.6 Health

Another quality characteristic of labour to consider is health (see Table 2 for data coverage). Following the work of Weil (2001), it is hypothesized that differing levels of nutrition and health status impact significantly on energy and capacity to work across countries. WPD employs two measures of health, both from World Development Indicators (World Bank,

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[16] It may be noted that schooling is always statistically significant in non-log form, thus lending support to Jones's assertion.

[17] These are, of course, country-specific measures; country indicators have been omitted for expository purposes.

2004). Life expectancy (H1) is used when health enters the production function as a separate input, because it has very good country coverage. However, adult mortality rate (H2)—the fraction of current 15 year-olds expected to die before the age of 60—is the preferred measure when labour is adjusted for health. This is partly owing to how Weil accounts for health, but further explanation is provided below. In the case of H2, it is implicitly assumed that, in the future, age-specific death rates remain constant at current levels. It should be noted that the correlation between H1 and H2 is very high.

Health is only included together with schooling. Inclusion of health in WPD reflects recent empirical literature, which has only now seriously started accounting for it (see, for example, Shastry and Weil, 2002). As in the case of schooling, when health enters the production function as an additional regressor, it does so in absolute values (years) instead of in logarithmic form. Again, an exception is made for the translog production function.

When labour is adjusted for health, in addition to schooling, an extension of equation (5) is employed. For this to work, we need an idea of what the return to health is. Weil (2001) reports one for H2 but not for H1, which explains why H2 is used in this case. Equation (6) describes the labour adjustment for schooling and health:

$$h = e^{\varphi(s)+\lambda(H2)} L \,. \tag{6}$$

where $\lambda < 0$, which implies that workers become less energetic as H2 increases. Following Weil (2001), the value of $-\lambda$ *(*100)* has been set to 1.68.[18]

Finally, a special experimental case is reported. Mankiw, Romer and Weil (1992) estimate the output elasticity to human capital, as measured with schooling, to be one-third. This value becomes useful when attempting to account for health in growth accounting calculations, for which otherwise no obvious income share is available. In WPD, an income share of a third is assumed for the composite of schooling and health.[19] The, admittedly ad hoc experimental formula used in WPD to make health operational in growth accounting—while maintaining that it can only enter together with schooling—is:

[18] Caselli (2003) calculates that a reduction of AMR by six percentage points has the same impact on wages as one extra year of schooling, which seems excessive. He, therefore, suggests 1.68 as an upper limit. However, since no other value is available, 1.68 is used throughout in WPD, as this is currently the best information available.

[19] The income share of raw labour is reduced by the same amount.

$$h = e^{\gamma(s+H3)}L \tag{7}$$

where $H3 = H1/(\hat{\beta}_1 + 2 * \hat{\beta}_2 * s)$. The parameters, $\hat{\beta}$, are estimated from the simple regression $H1 = \alpha + \beta_1 s + \beta_2 s^2 + \varepsilon$, where ε is the error term. The reason for undertaking this operation is that schooling, in terms of scale, is only some tenth of life expectancy in terms of years (for example, eight years of schooling and 80 years life expectancy). To simply add schooling and health would not do justice to schooling, since variation in the composite would almost entirely be due to variations in health. Therefore, a relation first had to be established by way of statistical estimation. This relation turned out to be non-linear, which explains the first derivative in (7).[20]

3. Measurement methods[21]

The main purpose of this section is to present the measurement methods used in WPD for, successively, TFP level, TFP growth and TFP forecasts. The section is divided into three major parts: levels, growth and forecasting of productivity. The discussion on measuring TFP levels is short, as it involves relatively few complications. By contrast, the second part constitutes the bulk of the section and is fairly technical, although an attempt is made to discuss only the key equations involved. The final part concerns how forecasting of TFP was carried out. This was done based on TFP growth series rather than components of the production function and, therefore, the difficulties normally involved in forecasting were drastically reduced. In turn, this leads to a relatively short third part.

Before proceeding, some general guidelines may be useful. First, it is advisable to analyze TFP growth together with TFP levels.[22] For example, rapid growth tends to occur at relatively low levels, while at high levels, growth tends to be slower. Secondly, one should try to understand the underlying assumptions—implicit or explicit—behind different measurement methods. For example, is it reasonable to assume perfect competition in the case one is examining? Thirdly, because different methods are based on different restrictions and assumptions, and have different strengths and weaknesses, employment of more than one measurement method may uncover information otherwise concealed. Fourthly, one may also want to consider the extent to which countries are comparable.[23]

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[20] Details of the estimations can be obtained from the author upon request.
[21] The discussion in this section draws from Isaksson (2006b).
[22] Hulten and Isaksson (2007) is an example of such an analysis.
[23] For example, analysis of relatively homogenous industrialized countries appears less demanding than comparisons of heterogenous countries, such as Burundi, Egypt, Guatemala and Japan.

3.1 Measuring TFP levels[24]

Productivity measurement at the total economy level—implicitly or explicitly—starts from the notion of an aggregate production function. Such an assumption is almost unavoidable when measuring TFP, but it should be borne in mind that it is only a metaphor, since it is unlikely that the true shape and properties of such a function can be accurately deciphered.[25] However, the use of it is justified as a useful means to organize the data in a way that makes economic sense, and as a framework for interpreting empirical results.

An alternative is to disregard the production function, restricting the analysis to partial productivity measures, such as labour and capital productivity. Labour productivity is an interesting statistic in that it provides an overall view of productivity performance based on both TFP and capital deepening. However, for policy purposes, it is less useful, since it is silent on the relative importance of its components, i.e., should policy concentrate on inputs or TFP and with what weights?

WPD, therefore, makes of the notion of the aggregate production function. For the levels measurement, the following standard Cobb-Douglas, in logarithmic form, with Hick-neutral technical change is assumed:

$$ln Y_t = ln A_t + \alpha * ln K_t + \beta * ln L_t , \qquad (8)$$

where Y is output, K and L are capital and labour, respectively, and A is a measure of the level of technology, i.e. TFP. Parameters α and β are the capital's and labour's shares in output, which, when perfect competition in factor markets prevails, equal the respective marginal products. As is standard at the aggregate level, constant returns to scale (that is, $\alpha+\beta=1$) are assumed.[26]

The level of TFP is, then, measured as

$$ln A_t = ln Y_t - \alpha * ln K_t - \beta * ln L_t , \qquad (9)$$

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[24] All level measures discussed are PPP-adjusted.

[25] The technical conditions for consistent aggregation are too restrictive as to be intuitively implausible. See, however, Jones (2005).

[26] More is said about and alternatives provided to this functional form in the discussion on TFP growth.

and, then, computed relative to the TFP level of the United States. Note that equation (9) is only permissible because it is assumed that α and β are country- and time-invariant. Although Gollin (2002) strongly argues for this indeed to be the case, Hulten and Isaksson (2007), for example, are less convinced of the validity of this assumption. If α and β vary across countries, TFP ranking based on (9) is no longer immune to the choice of base-country, so the formula provided by Caves, Christensen and Diewert (CCD, 1982) is preferable. With common income shares, CCD produces the same results as those obtained by applying equation (9).

As the concept of TFP or TFP level estimates are not universally accepted, WPD also offers simple income, relative to the United States, and capital per worker measures.[27] Although they serve as reasonable starting points for productivity analysis, they should not be seen as equivalent alternatives to TFP. Ten-year forecasts of TFP levels are provided, but discussion of that is deferred to Section 3.3.

3.2 Measuring TFP growth[28]

WPD offers numerous alternatives to TFP growth measurement, including relaxations of assumptions, as, for example, constant and variable returns to scale. To those not favouring measures of TFP growth, data on growth of income and capital per worker are available as well. Before turning to the rather lengthy discussion on measurement methods, some general features applicable to most methods are presented.

Begin by reproducing (9), but this time in discrete growth form:

$$\Delta \ln A_t = \Delta \ln Y_t - \alpha * \Delta \ln K_t - \beta * \Delta \ln L_t \qquad (10)$$

where Δ symbolizes change between two years. The many measurement methods for TFP growth are variants of each other. In trying to measure TFP growth, they relax restrictions or estimate what another method might simply assume. Income shares, for example, are estimated by parametric methods but assumed in growth accounting. Three major groups of measurement methods can be discerned: growth accounting, regression analysis and frontier methods.

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[27] These cover all labour and capital measures available in WPD.

[28] All growth measures are PPP-adjusted. Note that for most measurement methods, however, this is actually unnecessary.

Equation (10) is characteristic of growth accounting. Common for such analysis is the assumption of constant—both in time and space—income shares, α and β. That constancy is relaxed, i.e., $\alpha_i \neq \alpha_j$ and $\beta_i \neq \beta_j$, where i and j could, for example, denote different countries, by way of parametric estimation. This is the main benefit brought about by regression compared to growth accounting analysis. Also DEA and LMDEA, which are non-parametric frontier methods, let the question of income shares be answered in the process of computing TFP growth.

Although at the aggregate economy level constant returns to scale, that is $\alpha + \beta = 1$, is conventionally assumed, one can easily imagine circumstances when it is not applicable. For example, the astonishingly rapid growth of the so-called Asian Tigers most likely had periods characterized by increasing returns to scale, i.e., $\alpha + \beta > 1$. To allow for maximum flexibility, in WPD all parametric and frontier-based measurement methods estimate TFP growth under constant and variable returns to scale. When variable returns to scale are allowed, WPD offers an estimate of the scale effect. Growth accounting, on the other hand, assumes constant returns to scale.

Technical change and TFP growth are different concepts, with analysts tending to pay attention to both. Therefore, in WPD all methods except growth accounting also provide estimates of technical change. One advantage of frontier methods is that change in technical efficiency is measured as well. Such change is assumed away in growth accounting and regression analysis.

Although (10) is a very convenient functional form, it is also quite restrictive. For example, it assumes perfect substitutability between inputs and assumes away the possibility of quadratic growth or non-neutral technical change. A flexible functional form of the production function is the transcendental logarithmic form or, in short, the translog. For every parametric estimation measurement method, WPD offers both Cobb-Douglas and translog functional forms, where the former can be understood as a restricted version of the latter.[29] TFP growth based on the translog, in logs, is computed as follows:

$$\begin{aligned}\Delta \ln A_t = \Delta \ln Y_t - \beta_K \Delta \ln K_t - \beta_L \Delta \ln L_t - \beta_{KK} \Delta \ln K_t^2 - \beta_{LL} \Delta \ln L_t^2 \\ - 2\beta_{KL} \Delta \ln K_t \Delta \ln L_t\end{aligned} \quad . \qquad (11)$$

[29] According to statistical tests undertaken, the translog is invariably favoured over Cobb-Douglas.

All measurement methods can include schooling and health, in addition to labour and capital. Whereas this appears fairly uncomplicated when a production function is estimated, with the respective factor shares simply estimated, it is less straightforward in the case of growth accounting, since the relevant factor shares are unknown. As stated earlier, following Mankiw, Romer and Weil (1992), a factor share of one-third is assumed for both schooling and schooling combined with health. It is worth repeating that in WPD it is also possible to include schooling, or schooling and health, as adjustments to labour. In that case, there is no change with respect to the income shares assumed with only primary inputs, i.e., labour has the same income share as labour augmented with schooling and schooling and health.

3.2.1 Measurement based on growth accounting

This group of measurement methods contains three variants of the standard growth accounting approach. These methods differ in their assumptions regarding the type of technical change and whether endogeneity of capital accumulation with respect to TFP growth is allowed for.[30] The basic notion is that TFP growth is the remaining GDP growth after factor growth has been accounted for, i.e., it is derived as residual growth.

Equation (10) is the standard Hicksian growth accounting equation, repeated here for convenience:

$$\Delta ln\, A_t = \Delta ln\, Y_t - \alpha * \Delta ln\, K_t - \beta * \Delta ln\, L_t \,.$$

For simplicity, cases including schooling and/or health are not shown, as equation (10) suffices for the demonstrative purposes of this paper. It assumes that technical change is *Hicks-neutral*, which means that the shift of the production function, from A to B in Figure 2, due to TFP growth occurs along a constant capital-labour ratio, in other words, the shift is proportional. Output growth is decomposed into growth of the capital-labour ratio and TFP growth.

The standard approach is extended to allow for labour-augmenting, or labour-saving, technical change, implying a disproportionate shift of the production function (again, from A to B). In this case, technical change is said to be *Harrod-neutral*, as illustrated by Figure 3,

[30] Such endogeneity can be said to be similar to that occurring in parametric estimation of production functions, in which case capital is endogenously determined in a larger system of equations (Hulten and Isaksson, 2007).

with the production function shifting along a constant capital-output ratio, instead of a constant capital-labour ratio.

Thus, Harrodian technical change not only involves a shift, but also a tilt of the production function, implying an alteration of the marginal product of capital.[31] Equation (10) is replaced by (12)

$$\Delta ln\, A_t = \Delta ln Y_t - \frac{\alpha}{\beta} * (\Delta ln\, \kappa_t - \Delta ln\, \kappa_{t-1}), \tag{12}$$

where κ = *K/Y*. This means that output growth is decomposed into TFP growth and change in the capital-output ratio.

Although it is, in principle, possible to include a term to represent increasing returns to scale, this is seldom done.[32] In WPD, only growth accounting under the assumption of constant returns to scale is provided. Another issue with growth accounting, as well as several other methods, is that it neglects induced capital accumulation due to TFP growth. In other words, there may be important dynamic effects to account for and failing to do so could lead to understatement (overstatement) of the role of TFP growth (capital accumulation).

Hulten (1979) has taken issue with this matter and developed a method that accounts for such effects, termed dynamic growth accounting, in WPD.[33] The method derives a dynamic residual, which is a weighted sum of the standard growth accounting residual over a period of *T* consecutive years and an expansion of the intertemporal production possibilities frontier. This frontier defines efficient combinations of consumption—within a growth accounting framework production and consumption are indistinguishable—and terminal capital obtainable from endowments of initial capital and labour (and other inputs if they appear in the production function), as well as levels of input efficiency.

The interpretation of the dynamic residual differs from that obtained from standard (atemporal) growth accounting. While the standard static residual relates to the shift in the aggregate production function, the dynamic counterpart involves an expansion of the

[31] Although technical change is normally assumed to be positive, the change in marginal product of capital could go either way depending on whether technical change is positive or negative.
[32] See, for example, Hall (1989) for a case where this is done.
[33] Dynamic growth accounting does not lend itself well to year-on-year comparisons, since each annual figure is an average of year *t* and all previous years. The implication, then, is that a comparison between TFP growth obtained from dynamic growth accounting is best compared to the period average TFP growth obtained from, for example, standard static growth accounting.

intertemporal consumption possibility set due to technical progress.[34] TFP growth from dynamic growth accounting is, then, a linear combination of these two residuals

$$\Delta A_D(0,T) = \sum_{t}^{T} \frac{p_t Y_t}{W_T} \Delta A_t , \tag{13}$$

where p_tY_t is nominal output, ΔA_t the standard residual from equation (10), ΔA_D the dynamic residual and W_T the accumulated wealth over the relevant period. W_T is measured as

$$W_T = \sum_{t=1}^{T} p_t C_t + p_T K_T - p_0 K_0 . \tag{14}$$

where p_tC_t is nominal consumption and the remaining part is the difference between terminal and initial nominal capital. Equation (13) can, thus, be interpreted as an average rate for the relevant period as a whole.

To underscore the difference, the standard residual is understood as the average rate at which the production function shifts, while the dynamic residual measures the importance of productivity change for output growth. WPD offers dynamic growth accounting for both Hicks- and Harrod-neutral technical change.

3.2.2 Measurement based on regression analysis

Regression analysis involves parametric estimation of the income shares α and β, instead of assuming them. In addition, the assumption of returns to scale can be relaxed and an estimate of technical change obtained. Those being the main advantages, on the negative side, parametric estimation introduces such thorny issues as choice of functional form and uncertainties about statistical properties. Based on regression analysis, WPD provides TFP growth based on two functional forms, constant and variable returns to scale and estimation with and without trend.

The unconstrained pooled Cobb-Douglas, with and without an explicit measure of technical change, takes the following log-linearized form

[34] See Hulten (1979) or Isaksson (2006b) for a more thorough explanation and derivation.

$$ln\,Y_t = ln\,A_t + \hat{\alpha}\,ln\,K_t + \hat{\beta}\,ln\,L_t + \hat{\varepsilon}_t\,, \tag{15}$$

where the "^" indicates that they have been estimated, and ε_t is the residual assumed to be i.i.d. Equation (16) changes to

$$ln\,Y_t = ln\,A_t + \hat{\alpha}\,ln\,K_t + \hat{\beta}\,ln\,L_t + \sum_{m+1}^{M} \hat{\gamma}_m T_m + \hat{\varepsilon}_t\,, \quad m=1, 2,..., M \tag{16}$$

with technical change represented by T and measured by $\hat{\gamma}$. In (16), to obtain annual values instead of an average for the entire time period, time dummy variables replace the trend. For the case when the functional form is translog, annual variation derives from interaction between inputs and the time trend. Time dummy variables would make the functional form unnecessarily complicated and the production function over-parameterized.[35]

With constant returns to scale imposed, (15) and (16) can be expressed as:

$$ln\,Y_t - ln\,L_t = ln\,A_t + \hat{\alpha}(ln\,K_t - ln\,L_t) + \hat{\varepsilon}_t\,, \tag{15'}$$

$$ln\,Y_t - ln\,L_t = ln\,A_t + \hat{\alpha}(ln\,K_t - ln\,L_t) + \sum_{m+1}^{M} \hat{\gamma}_m T_m + \hat{\varepsilon}_t\,. \quad m=1, 2,..., M \tag{16'}$$

TFP growth, for all cases, is measured as:

$$\Delta\,\hat{A}_t = \hat{\varepsilon}_t - \hat{\varepsilon}_{t-1}\,. \tag{17}$$

Tests for constant returns to scale nearly always favour variable returns to scale. However, it is well known that, as the sample size increases, statistical tests have a tendency to over-reject the null hypothesis of constant returns to scale. Generally, the sum of the estimated parameters, α and β, is close to unity. In any case, with variable returns to scale, a measure of the scale component can be obtained.

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[35] Technical change in the case of the translog (and unconstrained returns to scale) is calculated as follows: $TC = \Delta A = \frac{\partial\,ln\,Y}{\partial T} = \beta_{KT}\,ln\,K + \beta_{LT}\,ln\,L + \beta_T + 2\beta_{TT}T$.

Based on these equations, the next topic is the estimation procedures. With only 41 observations per country, it does not seem fruitful to estimate country-specific production functions.[36] In their stead, pooling of the country data produces much better statistical properties (for example, 41 years*112 countries=4,592 observations). The main disadvantage, however, is the masking of potentially important country-specific differences.

To remedy partially such masking, "regional" regression analyses are undertaken. Subsets of countries, primarily based on geography and stage of development, are formed. There are three development groups: industrialized, developing and least developed countries (LDCs). For the geographical subsets, the industrialized country grouping is retained, while the remaining countries are divided into Asia, Middle East and North Africa, Latin America and sub-Saharan Africa. In cases where a country group contains too few countries for meaningful estimation, the group is simply dropped.[37] The country table, Table 1, lists these groups and their constituent countries.

Equation (18) illustrates the case of pooled regional regression analysis, where, as opposed to pooling of the entire sample, regional parameters add more country-characteristic information to the TFP calculation

$$ln Y_{irt} = ln A_{irt} + \hat{\alpha} ln K_{irt} + \hat{\beta} ln L_{irt} + \hat{\varepsilon}_{irt} , \quad (18)$$

where *i* and *r* denote countries and regions, respectively.

If cross-sectional heterogeneity is omitted, the estimated parameter might be rendered biased, and hence TFP growth will be biased. WPD, therefore, supplies TFP growth measures based on the fixed-effects estimator. Panel-data estimators allow the analyst to account directly for country-specific effects, while maintaining the degrees-of-freedom advantage. Country-specific effects imply that each country will have its own intercept, while maintaining the assumption that the slope parameters are the same for all countries.

There are two ways to account for country-specific effects. One is to include country dummy variables, while the other is to transform the data (so-called within transformation). Although the former consumes many degrees of freedom and, thus, may reduce efficiency and produce larger standard errors, thanks to the large dataset this is the solution chosen. The

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[36] This has actually been tried, but the estimated parameters and their significant levels were too affected by the incidence of small sample size.

[37] This occurs when a labour measure other than labour force is used. For example, LDCs are dropped for all cases in which analysis is based on employment.

main reason for choosing country dummies is that they can be used to obtain country-specific technical change by way of interaction terms between such dummies and a trend variable. Equation (19) shows the fixed-effects production function

$$\ln Y_{it} = \hat{\mu}_i + \hat{\alpha} \ln K_{it} + \hat{\beta} \ln L_{it} + \hat{\varepsilon}_{it} , \qquad (19)$$

where $\hat{\mu}_i$ are the unobserved country-specific effects and TFP growth is calculated as before.

3.2.3 Measurement based on frontier methods

So far it has been assumed that countries are technically efficient and that TFP growth primarily is driven by technical change. Perhaps a more realistic picture is that of allowing for technical inefficiency, defined as falling short of best practice. This benchmark of best practice can be seen as a technology frontier and even as a world technology frontier if all industrialized countries are part of the sample.

The implication of frontier analysis is that TFP growth may source from technical change as well as change in technical efficiency. In case returns to scale is unrestricted, change in technical efficiency further decomposes into change in scale efficiency and pure technical efficiency, respectively. However, change in scale efficiency does not impact on the measurement of TFP growth. Yet, it is important to know whether there is scope in trying to become more (technically) efficient or whether inefficiency simply stems from missed scale opportunities.

Frontier analysis does not directly deliver measures of TFP growth but primarily exists to measure technical efficiency. However, with panel data, frontier analysis produces the necessary components for computing TFP growth. If change in technical efficiency and technical change can be derived, these entities can be combined to an index that measures TFP growth. The Malmquist TFP index, due to Malmquist (1953), is such an index and used in WPD.

The Malmquist TFP index can be defined using distance functions. Let the technology for each production unit (country) be represented by a technology set, *S*, defined as

$$S = \{ y : y \;\; can \; be \;\; produced \; by \;\; x \}, \qquad (20)$$

where y is a vector of outputs and x a vector of inputs. It is assumed that S is bounded, closed and convex, and has strong disposability of outputs and inputs. At the moment, assume constant returns to scale.[38]

The output distance function on the output set S is

$$d_o(x,y) = min\{\delta : (y/\delta) \in S\}. \tag{21}$$

The distance function is smaller or equal than one if y is an element of S, including if it is on S, but will be greater than one if y is outside S.

The Malmquist TFP index measures TFP growth between two data points. It does so by calculating the ratio of the distances of each data point relative to a technology frontier. Note that there is an index number problem involved, since output and input vectors can be evaluated in period s against the technology in period t or in period t relative to period s. The inherent dilemma of this arbitrary base period problem is that the results are dependent on the choice of the two. The solution proposed is to compute the geometric average of the two. Hence, the (output-oriented) Malmquist TFP growth between period s and period t can be written as

$$m_o(y_s, x_s, y_t, x_t) = \left[\frac{d_o^s(y_t, x_t)}{d_o^s(y_s, x_s)} \times \frac{d_o^t(y_t, x_t)}{d_o^t(y_s, x_s)} \right]^{1/2}, \tag{22}$$

where $d_0^s(y_t, x_t)$ denotes the distance of the observation of period t from the technology frontier of period s. Re-writing (22) yields

$$m_o(y_s, x_s, y_t, x_t) = \frac{d_o^t(y_t, x_t)}{d_o^s(y_s, x_s)} \left[\frac{d_o^s(y_t, x_t)}{d_o^t(y_t, x_t)} \times \frac{d_o^s(y_s, x_s)}{d_o^t(y_s, x_s)} \right]^{1/2}, \tag{23}$$

where the ratio outside the brackets is the change in the output-oriented measure of (Farrell) technical efficiency between periods s and t. The expression within the brackets is a measure

[38] This assumption is not arbitrarily chosen, as it is needed for proper measurement of TFP growth when using the Malmquist index (Grifell-Tatjé and C.A. Knox Lovell, 1995).

of technical change. More precisely, it is the geometric mean of the shifts of the technology frontier between s and t, evaluated at x_t and at x_s, respectively. If m_o is greater (smaller) than one, TFP change from period s to period t has been positive (negative). Under the assumption of constant returns to scale, there are four distance measures that need to be calculated for each country and pair of adjacent time periods.

This is where frontier methods enter the picture because these are used to measure those distances. Popular methods for frontier analysis include both parametric and non-parametric tools. On the parametric side, WPD offers the random-effects Stochastic Frontier Analysis (SFA) estimator due to Battese and Coelli (1992), while in the case of non-parametric estimation, Data Envelopment Analysis (DEA) and Long-Memory DEA (LMDEA) are provided. The former entails parametric estimation of a production function where the error term has certain properties that allow for measurement of technical efficiency. DEA and LMDEA, on the other hand, are non-parametric methods based on linear programming (LP) to measure a best practice frontier. The difference between DEA and LMDEA is that the latter is constrained not to accept technical regress.

Although it is useful to be able to account for technical inefficiency, frontier analysis has its own problems. In the case of SFA, previous issues discussed under regression analysis apply. In addition, distributional assumptions of the error term are crucial, as they can have profound effects on the outcome. Non-parametric methods are freed from these problems, but, because they are deterministic in nature, they are sensitive to outliers and measurement problems of output and inputs. Because SFA is stochastic, it does not share these problems. Coupled with the fact that standard errors can be obtained and hypotheses tested, these are SFA's main advantages over non-parametric frontiers. The advantage of DEA and LMDEA is that no distributional assumptions or functional form have to be assumed regarding the "production function" and, generally, compared to parametric methods, they are very flexible.

3.2.3.1 Stochastic Frontier Analysis[39]

The *random-effects* Stochastic Frontier Analysis (SFA) model is a classical linear regression model but with non-normal asymmetric error term. The frontier, which has to be estimated, determines the maximum amount of output that can be produced at different levels of capital

[39] Currently, only random-effects SFA is available. A fixed-effects version was tried but proved unsuccessful. Work will continue to provide alternatives.

intensity (K/L). Units inside the frontier are deemed technically inefficient, while those on the frontier are fully efficient. A time trend is included in the production function to allow for composition of the Malmquist TFP index. If variable returns to scale are assumed, scale becomes yet another component in the index.

That some units can be inside the frontier implies that the error has a negative expected value. The best that can be achieved in this respect is zero—the unit is on the frontier—while the worst is unity. The error term of the production function, therefore, has two components, namely, the usual normal distributed error term (with positive and negative error terms) and the above-mentioned technical efficiency component. The former reflects measurement errors and factors out of control of the production unit and, thus, brings the stochastic element, while the latter reflects the extent to which a unit is inside the (stochastic) frontier.

In the Battese-Coelli specification, the technical efficiency effects are defined as

$$\begin{aligned} &\mu_{it} = \{\exp[-\eta(t-T)]\}\mu_i, \\ &i = 1, 2, ..., N; t = 1, 2, ..., T \end{aligned} . \qquad (24)$$

The u_is are assumed to be *i.i.d.*, have a generalized truncated-normal distribution and are time-variant, while η is an unknown scalar to be estimated. If the *i-th* unit is observed in the last period in the panel T, then $u_iT = u_i$. This is simply a mathematical consequence of the exponential function, which takes the value of unity when $t = T$. Hence, the random variable u_i can be seen to be the *i-th* unit's technical inefficiency effect in the last period. For earlier periods in the panel, technical efficiency is the product of technical inefficiency effects for the *i-th* unit in the last period and the value of the exponential function, where the latter depends on η and the number of periods in the panel minus the last period. If η is positive, $u_{it} > -u_i$, while if η is negative, $u_{it} <-u_i$.

A useful feature of this method is that if technical change is appropriately specified in x_{it}, it can be distinguished from change in technical inefficiency. However, a crucial drawback of the model is the inability to account for a situation where some units are, initially, relatively inefficient but become relatively more efficient in subsequent periods. In other words, units can improve relative to other units but not surpass other units that initially were more efficient.

In WPD, a simple testing procedure to make sure the preferred specification provides an adequate representation of the data is followed. For this procedure, the following three parameters are of particular interest:

μ, which governs whether the distribution is half-normal (μ = 0) or not (i.e., non-negative truncations)

η, which concerns whether the technical efficiencies are time-invariant (η = 0) or not

γ, which indicates whether an SFA approach is needed or not (γ = 0).

The test procedure is sequential as follows:

1. H_0: $\gamma = \mu = \eta = 0$ ==> countries are technically efficient, i.e., there are no u_{it}:s in the model. This implies that a standard production function suffices, with no need for SFA. Rejection of H_0 leads to test 2.

2. H_0: $\mu = \eta = 0$ ==> SFA is appropriate, but the u_{it}:s are time-invariant and distribution half-normal. Rejection of H_0 leads to tests 3 and 4.

3. H_0: $\eta = 0$ ==> SFA is appropriate and u_{it}:s are time-invariant, but the distribution is non-negatively truncated.

4. H_0: $\mu = 0$ ==> u_{it}:s are distributed half-normal.

Unfortunately, serious convergence problems in the estimations were encountered in the case of translog. Furthermore, for those cases where convergence did occur, TFP growth turned out almost flat, suggesting the production function might be over-parameterized. Therefore, WPD is currently unable to provide measures of TFP growth based on the translog functional form. Table 6 lists a few additional cases for Cobb-Douglas where no TFP growth could be derived.

3.2.3.2 Non-parametric frontier analysis[40]

Two versions of data envelopment analysis (DEA) are employed in WPD. First, the standard version that many practitioners use and, secondly, a modified version, dubbed long-memory DEA (LMDEA) by Forstner and Isaksson (2002), which restricts technical change to be non-negative. The justification for the use of LMDEA is the difficulty of accepting the notion of technical regress, in particular, at country level and if the frontier is given the interpretation of a world technology frontier.[41] All other methods previously discussed allow for technical regress.

Measurement of TFP growth using DEA and LMDEA starts from cross-sectional measurement of technical efficiency (Farrell, 1957), based on an output-distance function ("maximal proportional expansion of output given inputs"). Efficiency of a production unit, in this case a country, is measured relative to the efficiency of all other production units, subject to the restriction that all units are on or below the best-practice frontier. Under constant returns to scale, two events can occur between this and an arbitrary subsequent period. First, a given production unit changes its relative position to the frontier, i.e., change in technical efficiency or "catching up"). Secondly, the frontier itself moves, i.e., technical change or "innovation". Together, these two events generate TFP growth.[42] Under variable returns to scale, change in technical efficiency can be further decomposed into change in scale efficiency and change in pure technical efficiency.

As shown in Coelli, Rao and Battese (1998), and essentially using their notation, on the assumption of constant returns to scale, the following four LP problems are to be solved

$$\begin{aligned} &[d_0^t(y_t, x_t]^{-1} = max_{\nu,\lambda}\, \nu \\ &st \qquad -\nu\, y_{it} + Y_t \lambda \geq 0 \\ &\qquad\quad x_{it} - X_t \lambda \geq 0 \\ &\qquad\quad \lambda \geq 0 \end{aligned}, \qquad (25)$$

[40] It is important to note that these measurement methods present TFP growth in index form. In this case it means that 1.00 implies no TFP growth, 1.01 approximately one per cent TFP growth and 0.99 a negative growth of approximately one per cent. Hence, a comparison of DEA/LMDEA results with those obtained from, say, growth accounting is enhanced by first transforming the former into percentage form.

[41] The first to question technical regress in a DEA framework were Tulkens and Vanden Eeckaut (1995). Other empirical applications using macro data include Timmer and Los (2005).

[42] See also Caves *et al.* (1982), Nishimizu and Page (1982), and Färe *et al.* (1994). Coelli *et al.* (1998) provide an excellent introduction to the Malmquist TFP index.

$$[\, d_0^s(\, y_s \,, x_s \,]^{-1} = max_{\nu,\lambda}\, \nu$$

$$\begin{aligned} st \quad & -\nu\, y_{is} + Y_s \lambda \geq 0 \\ & x_{is} - X_s \lambda \geq 0 \\ & \lambda \geq 0 \end{aligned} \quad , \tag{26}$$

$$[\, d_0^t(\, y_s \,, x_s \,]^{-1} = max_{\nu,\lambda}\, \nu$$

$$\begin{aligned} st \quad & -\nu\, y_{is} + Y_t \lambda \geq 0 \\ & x_{is} - X_t \lambda \geq 0 \\ & \lambda \geq 0 \end{aligned} \quad , \tag{27}$$

$$[\, d_0^s(\, y_t \,, x_t \,]^{-1} = max_{\nu,\lambda}\, \nu$$

$$\begin{aligned} st \quad & -\nu\, y_{it} + Y_s \lambda \geq 0 \\ & x_{it} - X_s \lambda \geq 0 \\ & \lambda \geq 0 \end{aligned} \quad , \tag{28}$$

where *Y* and *X* represent the output and input data, respectively, for the entire sample of countries, y_i and x_i the i-th country’s output and input, and υ and λ are unknown parameters to be estimated.

By adding another two LPs to the above, scale can also be accommodated, allowing change in technical efficiency to be decomposed into change in scale efficiency and in pure technical efficiency. These two additional distances are calculated relative to a variable returns technology by adding a convexity restriction to (25) and (26). The scale efficiency component falls out as a residual by computing the difference between the technical efficiency values coming from constant and variable returns to scale technologies

$$[\, d_0^t(\, y_t \,, x_t \,]^{-1} = max_{\nu,\lambda}\, \nu$$

$$\begin{aligned} st \quad & -\nu\, y_{it} + Y_t \lambda \geq 0 \\ & x_{it} - X_t \lambda \geq 0 \\ & N1' \lambda = 1 \\ & \lambda \geq 0 \end{aligned} \quad , \tag{29}$$

$$
\begin{aligned}
&[\, d_0^s(\, y_s \,, x_s \,]^{-1} = max_{\nu,\lambda}\, \nu \\
&st \qquad -\nu\, y_{is} + Y_s \lambda \geq 0 \\
&\qquad\quad x_{is} - X_s \lambda \geq 0 \quad , \\
&\qquad\quad N1'\lambda = 1 \\
&\qquad\quad \lambda \geq 0
\end{aligned}
\tag{30}
$$

where N is the number of countries in the sample.

The final measurement method discussed considered is LMDEA. It is calculated the same way as DEA, but with the crucial exception of an additional restriction, namely, that technical change must be non-negative. Practically, this entails comparison of year s with cumulated past data instead of with data for year t only. The principle is illustrated in Figure 4.

Quadrant I shows the technology frontier when there is only one country (B) on the frontier. For expository purposes, only one country (A) out of the many positioned inside the frontier is shown. Country B on the frontier is technically efficient, while country A is technically inefficient. The degree of inefficiency of country A can be measured by drawing a vertical line through point A up to the frontier. The ratio between ED and EA is a measure of the technical inefficiency of country A.

Now consider two arbitrary time periods. With the bold line showing the frontier of year 1 and the broken one representing the frontier in year 2, quadrant II shows how the frontier country B has moved to the right due to attaining a higher K/L ratio. The movement of country B is such that a certain segment of the new world-technology frontier is positioned inside the previous year’s frontier. For the likes of country A, this would entail technical regress, despite the assumption that it is supposed *not* to have moved at all between the two time periods. A further consequence turns out to be overestimation of change in technical efficiency.

Quadrant III shows how the problems of technical regress and consequent overestimation of change in technical efficiency can be rectified. That part of Figure 4 reflects the assumptions that the frontier country moves linearly from point B to B’ and that, in order to prevent loss of knowledge, B is retained as a potential frontier point in all subsequent periods of the analysis. Hence, an “artificial” frontier country (B) has been created in period 2. Country A is now at the same distance from the frontier in the second time period as it was in the first. Furthermore, the knowledge of production techniques that A had in the first period is retained in the second period. Quadrant IV shows the new world-technology frontier after points B and B' have been connected.

This leads to certain observations. First, according to some of the applications, it seems that measures of TFP growth using DEA or LMDEA are nearly identical, with numerical differences being negligible. Hence, if only TFP growth is of interest and not its decomposition, DEA can be used without serious problems. Secondly, since point B in the second period is an artificial frontier country, it cannot play the role of a so-called peer country, i.e., a reference country from which to learn on policy issues. However, country B can still be used for policy discussions relating to the first period.

Thirdly, in terms of production techniques, the area outlined by B, C and B' represents unknown territory. For countries located between B and B', it can be argued that there is a risk of underestimating technical-efficiency change or, conversely, of overestimating technical progress. The line can, however, not be drawn from B to C and further to B', as that would violate the concavity assumption needed for applying the DEA method. As only those data points that are actually observed are of interest, the frontier country's move from B to B' through C is irrelevant in this context. Since tracking the movement from B to B' has more to do with the dynamic path measured in smaller time intervals than that of a year, approximating the (possibly non-linear) move from B to B' with a straight line seems as good as any other approximation.

In short, change in technical efficiency is upwards biased because in one segment the frontier has been allowed to recede. Similarly, it can be argued that technical change has been measured with a downward bias. These biases, however, do not significantly affect TFP growth, because the downward bias of technical change is more or less compensated for by the upward bias of change in technical efficiency. For that reason, if interest centres on TFP growth alone, the analysis can still produce useful results. However, if the sources of productivity change are to be identified and quantified, problems arise, as country A would erroneously be seen as improving its technical efficiency, while, in fact, nothing has changed for A.

3.3 Forecasting TFP

WPD has endeavoured to tackle the complicated challenge of forecasting TFP levels and growth, which can be approached in two broad ways. Either the individual components of TFP—outputs and inputs—are forecast separately and TFP is calculated based on those, or forecasts are derived directly from the TFP series. Because the TFP growth series are stationary, i.e., there is a tendency for the series to return to their mean values (innovations are only temporary) and it is simpler to forecast one series than three or more (for example, output, capital and labour), WPD forecasts are based directly on the TFP growth series.

WPD offers ten-year forecasts (2001-2010) for TFP growth based on K06 and labour force, LMDEA and constant returns to scale for the five specifications discussed above (i.e., labour and capital, labour, capital and schooling, labour, capital, schooling and health, capital and labour adjusted for schooling, and capital and labour adjusted for schooling and health). These are, in turn, extended to measures of TFP growth, based on the other capital stock calculations (Keff, K13 and Ks). Forecasts of TFP growth are, then, used to forecast TFP levels, based on labour force and the four capital stocks.[43]

The starting point for forecasting is an autoregressive, integrated, moving-average (ARIMA) model. Through a testing procedure this model was quickly reduced to the general case of AR(2), i.e., an autoregressive model with two lags sufficient to ensure white noise errors. Country by country, the AR(2) specification was then applied to LMDEA TFP growth time series. In the few cases where initial values were not feasible, a higher order AR specification was employed.[44] Another issue dealt with was the effect of sample endpoints that had too large an impact on the forecasts, showing up as excessive peaks and troughs. For these cases, endpoints were smoothed beyond the initial smoothing exercise to avoid excessive effects.[45]

4. Conclusions and next steps

This paper has reported on a new productivity database, the World Productivity Database (WPD). Its main focus is total factor productivity (TFP), level and growth. It also features information on partial measures, such as labour productivity, as well as on primary inputs to production. The database contains annual TFP measures for as many as 112 countries from 1960 to 2000, based on four capital stocks, five labour input measures, such secondary inputs as schooling and health, two functional forms, global and regional income shares, measures of technical progress and change in technical efficiency and more than ten measurement methods. In addition, ten-years forecasts of TFP levels and growth up to 2010 are provided.

[43] As explained above, LMDEA presents TFP growth in index form. To facilitate use of these forecasts, they have been transformed into percentage form. Also note that there are no forecasts of technical change or change in technical efficiency.

[44] These four cases uses AR(4) or AR(5): Angola, Equatorial Guinea, Nicaragua and Thailand.

[45] This pertains to Burkina Faso, Burundi, Fiji, Hong Kong (SAR of China), Indonesia, Malaysia, Mauritius and Sierra Leone.

WPD is useful to many different user groups. One important target group is policymakers round the globe. While productivity concerns often take centre stage in policy discussions, figures more complicated than labour productivity are difficult to obtain. This is no longer the case. With the primacy of industry for overall development and the significant role played by productivity, WPD could prove crucial for multilateral organizations, such as UNIDO and the World Bank. Academia constitutes a third group of potential users. Researchers not specialized in productivity sometimes encounter problems when measuring TFP with the purpose of, for example, analyzing the relation between environmental regulation and productivity performance. With WPD, this is no longer the case.

Although WPD is the first of its kind, much work remains. First, to date only total economy productivity measures have been calculated. The next step is to proceed to manufacturing TFP for a large number of countries. To this end, a database for aggregate manufacturing has been developed and will shortly be uploaded to the WPD website for general access. Secondly, the next version of WPD will contain TFP measures to at least 2005, with forecasts to at least 2015. Thirdly, to date, only countries with data spanning long time periods have been included. The plan is to include more countries, in particular, Germany and all of Eastern Europe, as well as other transition economies.

Fourthly, whereas land as input has largely become relatively unimportant for most industrialized countries, with Japan being an obvious exception, the contrary is true for developing countries. The next edition of WPD will expand specifications to include land. Fifthly, in the current version, labour has been accompanied with two quality measures, schooling and health. For a subset of countries, it has also been corrected for utilization, in terms of unemployment of both people and hours worked. However, no such correction has been made to capital. Ideally, in future, WPD will rectify some of these shortcomings. Sixthly, besides Cobb-Douglas and translog, the CES function is popular and will be added to the database. Finally, since only one SFA version is currently provided, more alternatives will be implemented in the next version of WPD.

Data from WPD are a public good. As such they can be freely downloaded from www.unido.org. When data are used, please include the following reference:

Isaksson, Anders (2007), "World Productivity Database: A Technical Description," *RST Staff Working Paper 10*/2007 Vienna: UNIDO.

Views and comments on WPD are gratefully solicited.

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Figure 1. Physical efficiency and the effects of depreciation

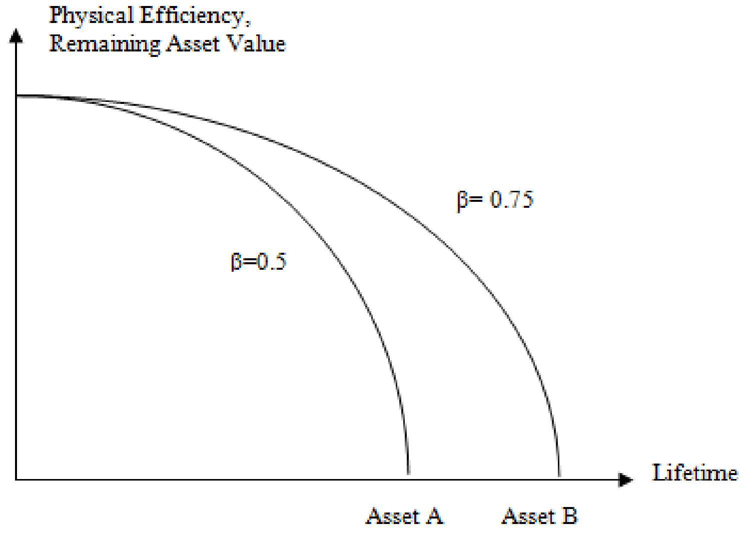

Figure 2. Hicks-neutral technical change

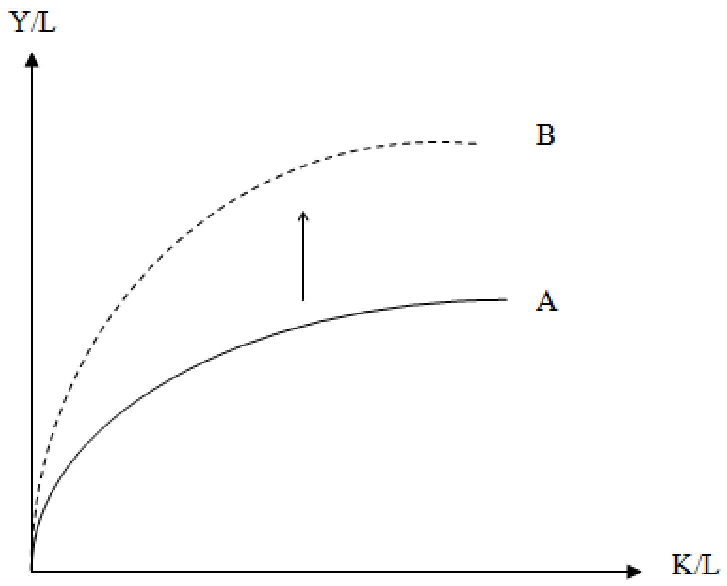

Figure 3. Harrod-neutral technical change

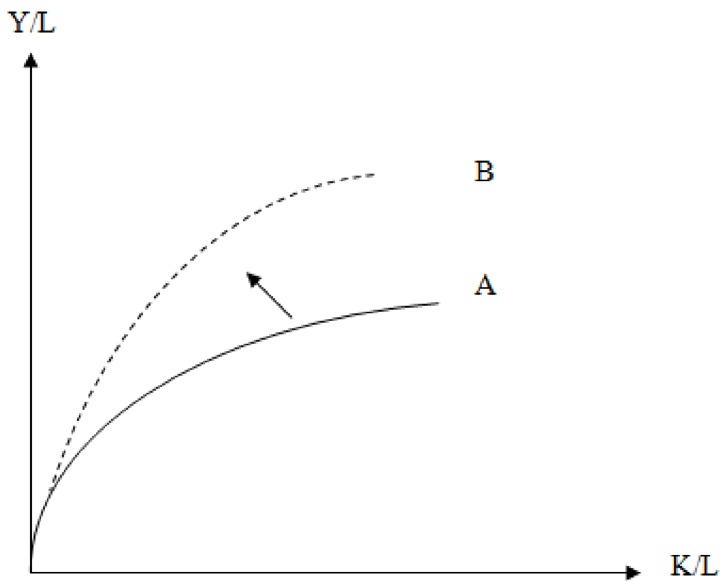

Figure 4. Illustration of LMDEA

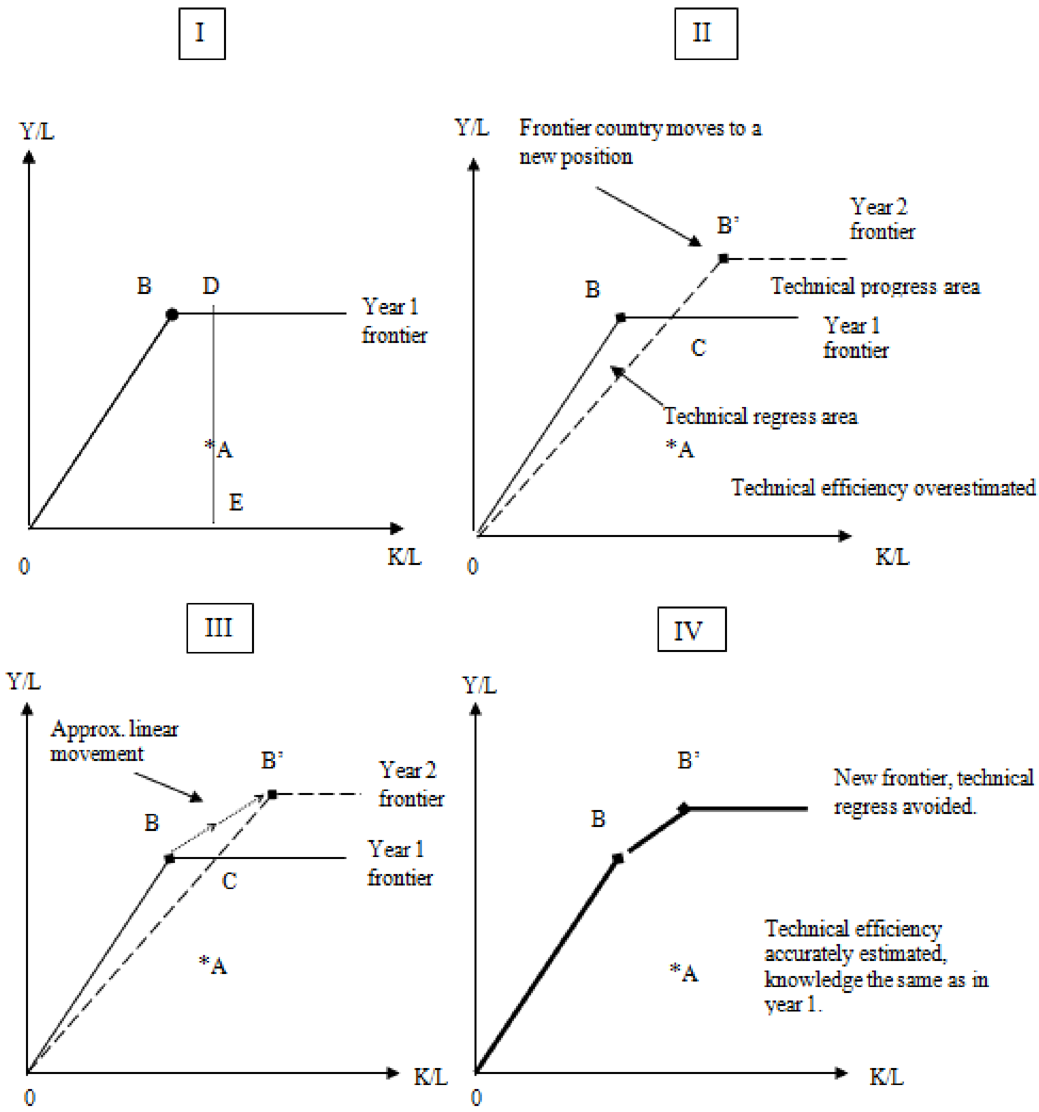

Table 1. List of countries and country groups

Industrialized (23 countries)	***Developing (45 countries)***	***LDCs (43 countries)***
Australia	Algeria	Angola
Austria	Argentina	Bangladesh
Belgium	Barbados	Benin
Canada	Botswana	Bolivia
Cyprus	Brazil	Burkina Faso
Denmark	Cape Verde	Burundi
Finland	Chile	Cameroon
France	China	Central African Republic
Greece	Colombia	Chad
Iceland	Costa Rica	Comoros
Israel	Dominican Republic	Congo
Italy	Ecuador	Cote d'Ivoire
Japan	Egypt	DR Congo
Luxembourg	El Salvador	Ethiopia
Netherlands	Equatorial Guinea	Fiji
New Zealand	Gabon	Gambia
Norway	Guatemala	Ghana
Portugal	Honduras	Guinea
Spain	Hong Kong, SAR of China	Guinea-Bissau
Sweden	India	Guyana
Switzerland	Indonesia	Haiti
United Kingdom	Iran	Kenya
USA	Jamaica	Lesotho
	Jordan	Madagascar
	Korea, Republic of	Malawi
	Malaysia	Mali
	Mauritius	Mauritania
	Mexico	Mozambique
	Morocco	Nepal
	Namibia	Nicaragua
	Nigeria	Niger
	Pakistan	Papua New Guinea
	Panama	Peru
	Paraguay	Rwanda
	Philippines	Senegal
	Singapore	Seychelles
	South Africa	Sierra Leone
	Syria	Sri Lanka
	Taiwan, Province of China	Tanzania, United Republic of
	Thailand	Togo
	Trinidad and Tobago	Uganda
	Tunisia	Zambia
	Turkey	Zimbabwe
	Uruguay	
	Venezuela	

Asia (17 countries)	*Latin America (23 countries)*	*Sub-Saharan Africa (40 countries)*
Bangladesh	Argentina	Angola
China	Barbados	Benin
Fiji	Bolivia	Botswana
Hong Kong, SAR of China	Brazil	Burkina Faso
India	Chile	Burundi
Indonesia	Colombia	Cameroon
Iran	Costa Rica	Cape Verde
Korea, Republic of	Dominican Republic	Central African Republic
Malaysia	Ecuador	Chad
Nepal	El Salvador	Comoros
Pakistan	Guatemala	Congo
Papua New Guinea	Guyana	Cote d'Ivoire
Philippines	Haiti	DR Congo
South Africa	Honduras	Ethiopia
Singapore	Jamaica	Equatorial Guinea
Taiwan, Province of China	Mexico	Gabon
Thailand	Nicaragua	Gambia
	Panama	Ghana
Mid. East and N. Africa (7 countries)	Paraguay	Guinea
Algeria	Peru	Guinea-Bissau
Egypt	Trinidad and Tobago	Kenya
Jordan	Uruguay	Lesotho
Morocco	Venezuela	Madagascar
Syria		Malawi
Tunisia		Mali
Turkey		Mauritania
		Mauritius
		Mozambique
		Namibia
		Nigeria
		Rwanda
		Senegal
		Seychelles
		Sierra Leone
		Sri Lanka
		Tanzania, United Republic of
		Togo
		Uganda
		Zambia
		Zimbabwe

Table 2. Country coverage, by types of labour, schooling and health

Country	Labour force (LF)				Employment (EMP)				Derived employment (DEMP)				Hours worked, Employment (HEMP)				Hours worked, Derived employment (HDEMP)			
	LF	S	SH1	SH2	EMP	S	SH1	SH2	DEMP	S	SH1	SH2	HEMP	S	SH1	SH2	HDEMP	S	SH1	SH2
Algeria	•	•	•	•	•	•	•	•	•	•	•	•								
Angola	•																			
Argentina	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Australia	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Austria	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Bangladesh	•	•	•	•	•	•	•	•	•	•	•	•								
Barbados	•	•	•	•	••	••	••	••	••	••	••	••								
Belgium	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Benin	•	••	••	••																
Bolivia	•	•	•	•	••	••	••	••	••	••	••	••								
Botswana	•	•	•	•	•	•	•	•												
Brazil	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Burkina Faso	•								•											
Burundi	•																			
Cameroon	•	•	•	•																
Canada	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Cape Verde	•																			
Central African Republic	•	•	•	•																

	LF	S	SH1	SH2	EMP	S	SH1	SH2	DEMP	S	SH1	SH2	HEMP	S	SH1	SH2	HDEMP	S	SH1	SH2
Chad	•																			
Chile	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
China	•	••	••	••	•	••	••	••	•	••	••	••								
Colombia	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Comoros	•																			
Congo	•	••	••	••																
Costa Rica	•	•	•	•	••	••	••	••	•	•	•	•								
Cote d’Ivoire	•																			
Cyprus	•	•	•	•	••	••	••	••	•	•	•	•								
Denmark	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Dominican Republic	•	•	•	•																
DR Congo	•	•	•																	
Ecuador	•	•	•	•	•	•	•	•	•	•	•	•								
Egypt	•	••	••	••	•	••	••	••	•	••	••	••								
El Salvador	•	•	•	•																
Equatorial Guinea	•																			
Ethiopia	•																			
Fiji	•	•	•	•	•	•	•	•	•	•	•	•								
Finland	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
France	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

Country	Labour force (LF)				Employment (EMP)				Derived employment (DEMP)				Hours worked, Employment (HEMP)				Hours worked, Derived employment (HDEMP)			
	LF	S	SH1	SH2	EMP	S	SH1	SH2	DEMP	S	SH1	SH2	HEMP	S	SH1	SH2	HDEMP	S	SH1	SH2
Gabon	•																			
Gambia	•	••	••	••																
Ghana	•	•	•	•					•	•	•	•								
Greece	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Guatemala	•	•	•	•	•	•	•	•												
Guinea	•																			
Guinea-Bissau	•	••	••	••																
Guyana	•	•	•	•																
Haiti	•	•	•	•																
Honduras	•	•	•	•					••	••	••	••								
Hong Kong, SAR of Ch.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Iceland	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
India	•	•	•	•	•	•	•	•	•	•	•	•								
Indonesia	•	•	•	•	•	•	•	•	•	•	•	•								
Iran	•	•	•	•																
Ireland	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Israel	•	•	•	•	•	•	•	•	•	•	•	•								
Italy	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Jamaica	•	•	•	•	•	•	•	•	•	•	•	•								
Japan	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

Country	Labour force (LF)				Employment (EMP)				Derived employment (DEMP)				Hours worked, Employment (HEMP)				Hours worked, Derived employment (HDEMP)			
	LF	S	SH1	SH2	EMP	S	SH1	SH2	DEMP	S	SH1	SH2	HEMP	S	SH1	SH2	HDEMP	S	SH1	SH2
Jordan	•	•	••																	
Kenya	•	•	•	•	•	•	•	•												
Korea, Republic of	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Lesotho	•	•	•	•																
Luxembourg	•				•				•				•				•			
Madagascar	•																			
Malawi	•	•	•	•	•	•	•	•												
Malaysia	•	•	•	•	•	•	•	•	•	•	•	•								
Mali	•	•	•	•																
Mauritania	•																			
Mauritius	•	•	•	•	•	•	•	•	•	•	•	•								
Mexico	•	•	•	•	•	•	•	•												
Morocco	•																			
Mozambique	•	•	•	•																
Namibia	•																			
Nepal	•	•	•	•																
Netherlands	•	•	•		•	•	•		•	•	•		•	•	•		•	•	•	
New Zealand	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Nicaragua	•	•	•	•																
Niger	•	•	•	••																

Country	Labour force (LF)				Employment (EMP)				Derived employment (DEMP)				Hours worked, Employment (HEMP)				Hours worked, Derived employment (HDEMP)			
	LF	S	SH1	SH2	EMP	S	SH1	SH2	DEMP	S	SH1	SH2	HEMP	S	SH1	SH2	HDEMP	S	SH1	SH2
Nigeria	•																			
Norway	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Pakistan	•	•	•	•	•	•	•	•	•	•	•	•								
Panama	•	•	•	•	•	•	•	•	•	•	•	•								
Papua New Guinea	•	•	•	•																
Paraguay	•	•	•	•																
Peru	•	•	•	•	•	•	•	•												
Philippines	•	•	•	•	•	•	•	•	•	•	•	•								
Portugal	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Rwanda	•	••	••	••																
Senegal	•	•	•	•																
Seychelles	•	••	••																	
Sierra Leone	•	•	•	•																
Singapore	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
South Africa	•	•	•	•																
Spain	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Sri Lanka	•	•	•	••	•	•	•	•	•	•	•	•								
Sweden	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Switzerland	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Syria	•	•	•																	

Country	Labour force (LF)				Employment (EMP)				Derived employment (DEMP)				Hours worked, Employment (HEMP)				Hours worked, Derived employment (HDEMP)			
	LF	S	SH1	SH2	EMP	S	SH1	SH2	DEMP	S	SH1	SH2	HEMP	S	SH1	SH2	HDEMP	S	SH1	SH2
Taiwan, Province of Ch.	•	•			•	•			•	•			•	•			•	•		
Tanzania, United Rep. of	•	•	•	•																
Thailand	•	•	•	•	•	•	•	•	•	•	•	•								
Togo	•	•	•	•																
Trinidad and Tobago	•	•	•	•	•	•	•	•	•	•	•	•								
Tunisia	•	•	•	•					•	•	•	•								
Turkey	•	•	•	•	•	•	•		•	•	•		•	•	•		•	•	•	
Uganda	•	•	•	•																
United Kingdom	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Uruguay	•	•	•	•					•	•	•	•								
USA	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Venezuela	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Zambia	•	•	•	•																
Zimbabwe	•	•	•	•	•	•	•	•												
N balanced	**112**	**87**	**85**	**79**	**57**	**54**	**53**	**51**	**56**	**52**	**51**	**49**	**32**	**31**	**30**	**28**	**32**	**31**	**30**	**28**
N unbalanced	**112**	**95**	**94**	**88**	**61**	**60**	**59**	**57**	**59**	**57**	**56**	**54**	**32**	**31**	**30**	**28**	**32**	**31**	**30**	**28**

Note: N=number of observations; LF=labour force; S=schooling; SH1=schooling and life expectancy; SH2=schooling and adult mortality rate. One 'dot' indicates full data coverage and inclusion in both balanced and unbalanced datasets, while two 'dots' represents inclusion in unbalanced datasets only. Hence, unbalanced datasets contain more countries. Schooling as a separate regressor and labour adjusted for schooling have the same data coverage—hence only one of them is displayed.

Table 3. Countries with missing *nominal* output and investment data, used for Dynamic Growth Accounting

	Output	**Investment**	
Country	**Missing years**		**Missing data were replaced by:**
Angola		1997-2000	Growth of real GDP in US$ from WDI.
Botswana		2000	Growth of real GDP in US$ from WDI.
Central African Rep.		1999-2000	Growth of real GDP in US$ from WDI.
Chad		1973	WDI
Congo, Dem. Rep.		1998-2000	Growth of real GDP in US$ from WDI.
Cyprus		1997-2000	Growth of real GDP in US$ from WDI.
Fiji		2000	Growth of real GDP in US$ from WDI.
Guyana		2000	Growth of real GDP in US$ from WDI.
Haiti		1999-2000	Growth of real GDP in US$ from WDI.
Mauritania		2000	Growth of real GDP in US$ from WDI.
Namibia		2000	Growth of real GDP in US$ from WDI.
Papua New Guinea		2000	Growth of real GDP in US$ from WDI.
Seychelles			Growth of real GDP in US$ from WDI.
Sierra Leone		1997, 1999-2000	Growth of real GDP in US$ from WDI.
Singapore		1997-2000	Growth of real GDP in US$ from WDI.
Taiwan, Province of China		1999-2000	National publication
Tunisia		1960	Growth of real GDP in US$ from WDI.

Note: WDI stands for World Development Indicators 2004 (World Bank).

Table 4. For capital, countries with back cast, extra and interpolated data

	Output	Investment	
Country	**Missing years**		**Missing data were replaced by:**
Algeria	Pre-1960	Pre-1960	
Angola	Pre-1960, 1997-2000	Pre-1960, 1997-2000	Growth of real GDP in US$ from WDI.
Bangladesh	Pre-1959	Pre-1959	
Barbados	Pre-1960	Pre-1960	
Benin	Pre-1959	Pre-1959	
Botswana	Pre-1960, 2000	Pre-1960, 2000	Growth of real GDP in US$ from WDI.
Burkina Faso	Pre-1959	Pre-1959	
Burundi	Pre-1960	Pre-1960	
Cameroon	Pre-1960	Pre-1960	
Cape Verde	Pre-1960	Pre-1960	
Central African Rep.	Pre-1960, 1999-2000	Pre-1960, 1999-2000	Growth of real GDP in US$ from WDI.
Chad	Pre-1960	Pre-1960, 1973	1973 interpolated
Chile	1950	1950	
China	1950-1951	1950-1951	
Comoros	Pre-1960	Pre-1960	
Congo	Pre-1960, 1960-1961	Pre-1960	1960-1961 adjusted to fit with 1962 and onwards.
Congo, Dem. Rep.	1998-2000	1998-2000	Growth of real GDP in US$ from WDI.
Cote d'Ivoire	Pre-1960	Pre-1960	

Cyprus	1997-2000	1997-2000	Growth of real GDP in US$ from WDI.
Dominican Republic	1950	1950	
Ecuador	1950	1950	
Equatorial Guinea	Pre-1960	Pre-1960	
Fiji	Pre-1960, 2000	Pre-1960, 2000	Growth of real GDP in US$ from WDI.
Gabon	Pre-1960	Pre-1960	
Gambia	Pre-1960	Pre-1960	
Ghana	Pre-1955	Pre-1955	
Greece	1950	1950	
Guinea	Pre-1959	Pre-1959	
Guinea-Bissau	Pre-1960	Pre-1960	
Guyana	2000	2000	Growth of real GDP in US$ from WDI.
Haiti	Pre-1960, 1966, 1999-2000	Pre-1960, 1966, 1999-2000	1966 interpolated. 1999-2000 based on growth of real GDP in US$ from WDI.
Hong Kong, SAR of C.	Pre-1960	Pre-1960	
Indonesia	Pre-1960	Pre-1960	
Iran	Pre-1955	Pre-1955	
Jamaica	Pre-1953	Pre-1953	
Jordan	Pre-1954	Pre-1954	
Korea	Pre-1953	Pre-1953	
Lesotho	Pre-1960	Pre-1960	
Madagascar	Pre-1960	Pre-1960	
Malawi	Pre-1954	Pre-1954	

Malaysia	Pre-1955	Pre-1955	
Mali	Pre-1960	Pre-1960	
Mauritania	Pre-1960, 2000	Pre-1960, 2000	Growth of real GDP in US$ from WDI.
Mozambique	Pre-1960	Pre-1960	
Namibia	Pre-1960, 2000	Pre-1960, 2000	Growth of real GDP in US$ from WDI.
Nepal	Pre-1960	Pre-1960	
Nicaragua		I < 0 in 1979	Interpolated between 1978 and 1980.
Niger	Pre-1960	Pre-1960	
Papua New Guinea	Pre-1960, 2000	Pre-1960, 2000	Growth of real GDP in US$ from WDI.
Paraguay	1950		
Rwanda	Pre-1960	Pre-1960	
Senegal	Pre-1960	Pre-1960	
Seychelles	Pre-1960	Pre-1960	Growth of real GDP in US$ from WDI.
Sierra Leone	Pre-1961, 1997, 1999-2000	Pre-1960, 1997, 1999-2000	1960 estimated based on trend. 1997 and 1999-2000 based on growth of real GDP in US$ from WDI.
Singapore	Pre-1960, 1997-2000	Pre-1960, 1997-2000	Growth of real GDP in US$ from WDI.
Sweden	1950	1950	
Syria	Pre-1960	Pre-1960	
Taiwan, Province of China	1950, 1999-2000	1950, 1999-2000	1999-2000 estimated based on trend.
Tanzania, Unit. Rep. of	Pre-1960	Pre-1960	
Togo	Pre-1960	Pre-1960	

Tunisia	Pre-1961	Pre-1961	1960 based on trend.
Zambia	Pre-1955	Pre-1955	
Zimbabwe	Pre-1954	Pre-1954	

Note: For the calculation of capital stocks with 15 years initialisation, *all* countries data are back cast to 1946, while for 5 and 10 years initialisation, only countries in the Table had to be back cast. When data were missing between two data points, a simple averaging procedure was applied. The growth rate of relevant series, obtained from the World Development Indicators (WDI), is applied to extend series with missing endpoint data. In cases where data for 1960 was missing in both PWT 6.1 and the WDI, the data series was extended based on the underlying trend of the series.

Table 5. Countries with missing or enhanced labour force, employment and unemployment data

	Labour force (LF)	Employment (EMP)	Unemployment (UNEMP)	Comments
Country	**Adjustments**	**Missing years**		
Algeria	1960-1995			LF obtained from PWT 6.0
	1960-1969			LF aligned with the 1970 value
			1972-1988	UNEMP extended based on EMP growth rate
Angola	1960-1989			LF aligned with the 1990 value
Argentina	1960-1994		1960-1969	LF aligned with the 1995 value
Bangladesh	1960-2000			PWT LF replaced with World Bank
			1972-1974	UNEMP extended based on EMP growth rate
Barbados		1972-1974		EMP extended based on LF growth rate
			1972-1975	UNEMP extended based on EMP growth rate
Bolivia	1960-1991			LF aligned with the 1992 value
Brazil	1960-1998			LF obtained from PWT 6.0 and
				LF aligned with the 1999 value
			1974-1975	UNEMP interpolated
Burkina Faso	1960-1998		1960-1970	LF obtained from PWT 6.0
				LF aligned with the 1999 value
Cameroon	1960-2000			PWT LF replaced with World Bank
Chad	1960-2000			PWT LF replaced with World Bank
Chile			1972-1974	UNEMP extended based on EMP growth rate
China			1972-1977	UNEMP extended based on EMP growth rate

Colombia	1960-1994			LF aligned with the 1994 value
			1972-1974	UNEMP interpolated
Congo	1999-2000			LF extended with World Bank LF growth
Congo, D.R.	1998-2000			LF extended with World Bank LF growth
Costa Rica		1972,		EMP extended based on UNEMP growth rate
		1974-1975		EMP interpolated
			1972-1975	UNEMP interpolated
Ecuador	1960-2000			PWT LF replaced with World Bank
			1972-73	UNEMP extended based on EMP growth rate
			1976, 1978-84	UNEMP interpolated
Egypt	1960-2000			PWT LF replaced with World Bank
		1977, 1997		EMP interpolated
		1986-1989		EMP interpolated
El Salvador	1960-2000			PWT LF replaced with World Bank
Equatorial Guinea	1960-2000			LF obtained from PWT 6.0
Fiji			1972-1981	UNEMP extended based on EMP growth rate
Gabon	1960-1989			LF aligned with the 1990 value
Gambia, The	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
Ghana	1960-1989			LF aligned with the 1990 value
			1996-2000	UNEMP extended based on LF growth rate
Greece	1960-2000			PWT LF replaced with World Bank
Guatemala	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value

Guinea-Bissau	1960-2000			PWT LF replaced with World Bank
Guyana	1999-2000			LF extended with World Bank LF growth
Honduras	1960-2000			PWT LF replaced with World Bank
Hong Kong, SAR of China	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
			1972-1974	UNEMP extended based on EMP growth rate
India	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
Indonesia	1960-1998			LF obtained from PWT 6.0
			1972-1975	LF aligned with the 1999 value
				UNEMP extended based on EMP growth rate
Israel	1991-2000			LF aligned with the 1990 value
			1972-1975	UNEMP extended based on EMP growth rate
Jordan	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
Kenya	1960-1989			LF aligned with the 1990 value
			1998-2000	UNEMP extended based on EMP growth rate
Korea, Republic of	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
Luxembourg			1972-1973	UNEMP extended based on EMP growth rate
Madagascar	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
Malawi	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value

Malaysia	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
			1972-1974	UNEMP extended based on EMP growth rate
Mali	1960-1989			LF aligned with the 1990 value
Mauritania	1999-2000			LF extended with World Bank LF growth
Mauritius	1960-1998			LF aligned with the 1999 value
Mexico	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
Morocco	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
Mozambique	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
Nepal	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
Netherlands	1960-1993			LF aligned with the 1994 value
Nicaragua	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
Nigeria	1960-1989			LF aligned with the 1990 value
Pakistan	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
			1972-1974	UNEMP extended based on EMP growth rate
Panama (excl. Canal Zone)	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
			1980-1981, 1990	UNEMP interpolated

Papua New Guinea	1999-2000			LF extended with World Bank
Paraguay	1960-1993			LF aligned with the 1994 value
Peru	1960-1993			LF aligned with the 1994 value
Portugal	1960-1975			LF aligned with the 1976 value
Senegal	1960-1989			LF aligned with the 1990 value
Seychelles	1999-2000			LF extended with 5-year average growth
South Africa	1960-2000			PWT LF replaced with World Bank
Spain	1960-1993			LF aligned with the 1994 value
Sri Lanka			1972-1977,	UNEMP extended based on EMP growth rate
			1980, 1982-1984,	UNEMP interpolated
			1987-1989	UNEMP interpolated
Syria	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
Taiwan, Province of China			1972-1974	UNEMP extended based on EMP growth rate
Tanzania, United Republic of	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
Thailand	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
Togo	1960-1969			LF aligned with the 1970 value
Trinidad and Tobago	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
Tunisia	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
Turkey	1960-2000			PWT LF replaced with World Bank

Uganda	1960-2000			PWT LF replaced with World Bank
Uruguay	1960-1992			LF aligned with the 1993 value
			1972-1975	UNEMP interpolated
Venezuela	1960-1998			LF obtained from PWT 6.0
				LF aligned with the 1999 value
			1972-1974	UNEMP interpolated
Zambia	1960-2000			PWT LF replaced with World Bank
Zimbabwe	1960-1989			LF aligned with the 1990 value

Note: WDI stands for World Development Indicators 2004 (World Bank), while PWT 6.0 is short for Penn World Tables version 6.0. The comment "LF obtained from PWT 6.0 in most, if not all, cases means that World Bank data are being used, since PWT 6.0 obtained its LF data from the World Bank.

Missing years for the categories Employment and Unemployment refer to cases where data have been extended to allow for countries to be included in regressions. Thus, no information could either imply that the country was not included (for lack of data) or that no adjustments were necessary due to complete data.

Table 6. Availability of TFP growth estimates based on Stochastic Frontier Analysis

Capital stock	Labour force (LF)					Employment (EMP)					Derived employment (DEMP)					Hours worked, Employment (HEMP)					Hours worked, Derived employment (HDEMP)				
Specification: Cobb-Douglas, constant returns to scale and trend																									
	LF	S	SH2	exp^{s}	exp^{sH2}	EMP	S	SH2	exp^{s}	exp^{sH2}	DEMP	S	SH2	exp^{s}	exp^{sH2}	HEMP	S	SH2	exp^{s}	exp^{sH2}	HDEMP	S	SH2	exp^{s}	exp^{sH2}
K06	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
K13	•	•	•	•	•	•	•		•			•			•	•	•	•	•	•	•	•	•	•	•
Keff	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Ks	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Specification: Cobb-Douglas, variable returns to scale and trend																									
Capital stock	Labour force (LF)					Employment (EMP)					Derived employment (DEMP)					Hours worked, Employment (HEMP)					Hours worked, Derived employment (HDEMP)				
	LF	S	SH2	exp^{s}	exp^{sH2}	EMP	S	SH2	exp^{s}	exp^{sH2}	DEMP	S	SH2	exp^{s}	exp^{sH2}	HEMP	S	SH2	exp^{s}	exp^{sH2}	HDEMP	S	SH2	exp^{s}	exp^{sH2}
K06	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
K13	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Keff	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Ks	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

Note: LF=labour force; S=schooling; SH2=schooling and health; exp^{S}=labour adjusted for schooling; exp^{SH1}=labour adjusted for schooling and health.
A 'dot' indicates the existence of information for that specification. No information available when the functional form is translog.

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