Explaining International Productivity Differences

Jens Krüger, Uwe Cantner and Horst Hanusch

University of Augsburg
July 1998

Wiso-Fakultät, Universitätsstr. 16, D-86135 Augsburg, Tel.: +49 821 598 4179, Fax: +49 821 598 4229,
E-Mail: jens-joerg.krueger@wiso.uni-augsburg.de

Abstract:

In this paper we add new results to the emerging field of investigating productivity levels rather than productivity change, as initiated by Hall and Jones (1996, 1997). To obtain measures of relative productivity levels we depart from traditional growth accounting and calculate the Malmquist index of total factor productivity change using the nonparametric Data Envelopment Analysis (DEA) for a broad cross country sample. This index can be decomposed in measures of technological progress and efficiency change that are cumulated to level measures. The so obtained heterogeneity in productivity levels is next related to several determinants of technology driven growth in an econometric exercise. Doing this (1) we are able to provide confimation of the validity of the decomposition of the Malmquist index and (2) we find innovation-related explanations for international technological frontier shifts and imitative catching up and falling behind.

JEL classification: O33, O47

1. Introduction

Starting with the contributions of Barro (1991) and Mankiw, Romer and Weil (1992) there has been built up a vast literature on cross country regression analyses that relates the growth rate of output per capita (or per worker) as a productivity measure to various growth stimulating or depressing factors. Most researchers in this field attempt to explain the average growth rates in a cross section of countries during a period of twenty to thirty years by the initial GDP per capita. By this they test for convergence and add various other factors that control for differences in the steady state levels of GDP per capita to which the countries converge conditionally. Among the variables that contribute to the explanation of growth rates are commonly the investment ratio in GDP, life expectancy, indicators of educational attainment and openess to trade. Other sometimes quite exotic variables are designed in order to capture influences from government regulation, democracy, political stability and the quality of institutions (see e.g. Barro/Lee (1994), Barro/Sala-i-Martin (1995)).

Only recently Hall and Jones (1996,1997) make a strong case for the relevance of differences in the levels of productivity (output per worker and total factor productivity) instead of growth rates.[1] They argue that the focus on growth rates "removes the effect of permanent or long-run influences and highlights the role of transitory movements" (Hall/Jones 1996, p.4). A further reason for the emphasis on levels is the widespread instability of growth rates between different decades as investigated in Easterly et al. (1993).

With this background our work departs from usual type of cross country growth regressions in at least three ways. First, instead of using per worker growth rates or growth accounting residuals as explained variable we employ the Malmquist index of total factor productivity change towards a production frontier function, determined by the nonparametric Data Envelopment Analysis (DEA). This index can be decomposed in measures for technological progress and efficiency change. Second, we construct indexes for technology levels, starting from relative positions in 1970 and then accumulating subsequent growth rates until 1990. Third, whereas only very few cross country studies have used technology indicators like R&D expenditures, number of scientists and engineers engaged in R&D or patent counts to explain growth rates[2],

---

1 Mankiw/Romer/Weil (1992) also report regressions on levels but their main contribution lies in explaining growth rates.

2 Notable exceptions are Gittleman und Wolff (1995), Lichtenberg (1993) and Verspagen (1991). Possible reason therefore are the limited data availability and that the empirical growth literature tries to a large extent

we put the emphasis on the role of education, patents and trade related technological spillovers as the main determining factors of relative technology levels.

Our investigation proceeds as follows: Section 2 introduces the Malmquist index and derives the measures of relative productivity levels. In section 3 we perform regressions to explain these productivity measures by a bundle of productivity driving factors. The concluding section summarizes the results.

2. Productivity Levels

Growth accounting in the tradition of Abramovitz (1956) and Solow (1957) is to date the most widely used method of calculating total factor productivity growth on the macroeconomic level. Hall and Jones (1996) do also apply this approach, but make some clever modifications to measure relative productivity levels across countries instead of productivity change over time. In this paper we employ a method quite different from growth accounting to calculate productivity levels: the Malmquist index of total factor productivity. This productivity index originates from microeconomic research to investigate the evolution of deterministic frontier functions over time and has been first employed in a macroeconomic context to 17 OECD countries by Färe et al. (1994). It measures productivity changes by using distances relative to a deterministic constant returns to scale production frontier function which can be calculated by the non-parametric Data Envelopment Analysis (DEA) based on solving a sequence of linear programming problems.[1]

Malmquist Index Calculations:

The combination of the Malmquist index and DEA has several main advantages over the growth accounting approach to measure total factor productivity. From a conceptual point of view DEA simultaneously evaluates the performance of all countries towards a best-practice frontier function which results from solving a series of linear programming problems. This performance measure is a productivity or efficiency measure. Doing this there is no need to make

to defend the old neoclassical growth theory of Solow (1956) against the new endogenous growth models with their emphasis on research and knowledge accumulation (see Grossman/Helpman (1994) for a survey).

[1] The following description of the methods used to measure productivity is very brief. We refer to Färe et al. (1994) and Färe/Grosskopf/Lovell (1994) for a detailed formal treatment and graphical illustration of the functioning of the Malmquist index. Ali/Seiford (1993) or Charnes et al. (1994) are useful surveys of the various DEA models.

strong assumptions about factor shares (i.e. factors are payed with their marginal product on competitive factor markets) to aggregate the production factors because the DEA procedure determines the aggregation weights in a optimization procedure using only quantity data on output and input factors. The rate of change of performance will be measured by the Malmquist index. Most important, the Malmquist index can be decomposed multiplicatively in two terms which can be related to changes in efficiency and technological progress between two subsequent points in time. The efficiency term captures changes in the distance of a particular country towards the frontier function, whereas the technology term quantifies movements of the frontier function itself. These two important aspects of productivity improvements cannot be identified separately in the traditional growth accounting framework. Growth accounting rather measures technological progress only if we make the assumption that there are no changes in efficiency which is rather unlikely to hold in reality.

Formally, we suppose a general production process that transforms m input factors (given by vector **x**), in s output goods (**y**) at every point in time t. The Malmquist index M then states the productivity change of country h between two points in time t and t+1:

$$M_h^{t+1}(\mathbf{x}^t, \mathbf{y}^t, \mathbf{x}^{t+1}, \mathbf{y}^{t+1}) = \left[\frac{D_h^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{D_h^t(\mathbf{x}^t, \mathbf{y}^t)} \frac{D_h^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{D_h^{t+1}(\mathbf{x}^t, \mathbf{y}^t)} \right]^{1/2} . \tag{1}$$

Taking the geometric mean avoids possible biases due to an exclusive fixing of the production frontier function in t or t+1 as a benchmark for the evaluation of the productivity change. $D_h^p(\mathbf{x}^q, \mathbf{y}^q)$ gives the distance to the frontier function as the reciprocal of the maximum proportional expansion of outputs[1] that is required to reach the frontier function in period p with constant inputs for an observed input-output combination in period q (p,q=t,t+1). The within-period distance functions (p=q) are bounded in the intervall (0,1], with efficient production points characterized by a value of 1 for the distance function. In the case of the between-period distance functions (p≠q), which measure distances of the production points in the period p (q) towards the frontier function in period q (p), values larger than 1 are also possible.

[1] Output orientation is the more plausible assumption on the macroeconomic level because it is closer to the target notions of growth policy to achieve a social product as high as possible with a given ressource endowment, instead of the aim of realizing a given social product objective with a minimized amount of ressource inputs.

The Malmquist index (1) can now be easily decomposed in the above mentioned measures for efficiency change (EF) and technological progress (TP):

$$M_h^{t+1}(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}) = \underbrace{\frac{D_h^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1})}{D_h^t(\mathbf{x}^t,\mathbf{y}^t)}}_{EF_h^{t+1}} \underbrace{\left[\frac{D_h^t(\mathbf{x}^{t+1},\mathbf{y}^{t+1})}{D_h^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1})}\frac{D_h^t(\mathbf{x}^t,\mathbf{y}^t)}{D_h^{t+1}(\mathbf{x}^t,\mathbf{y}^t)}\right]^{1/2}}_{TP_h^{t+1}} . \tag{2}$$

Changes in efficiency are captured by alterations of the distance towards the frontier functions in periods t and t+1 respectively. They reflect changes in the degree of exploitation of production possibilities between t and t+1. A measure of technological progress can be specified via a geometric mean in form of intertemporal shifts of the frontier function. It is calculated using the distance functions of the observations in periods t and t+1 towards the production frontier in the periods t+1 and t respectively. For identical input and outputs for all observations in t and t+1 the calculation of the Malmquist index and its two components leads exactly to 1. Improvements (deteriorations) of the components or the whole index are expressed by values larger (smaller) than 1.

The distance functions used above match exactly with the reciprocal efficiency scores ϕ_h of the output oriented formulation of the DEA. Therefore, we calculate the distance functions empirically by using the output oriented DEA model under constant returns to scale. For the Malmquist index and thus the productivity change between t and t+1 for every country, we have to solve four linear programming problems of the type

$$\begin{array}{llrcll} \max\limits_{\phi,\lambda} & \phi_h & & & & \\ \text{s.t.} & \phi_h y_{rh}^q - & \sum\limits_{i=1}^n \lambda_i y_{ri}^p & \leq & 0 & \forall\ r=1,\ldots,s \\ & & \sum\limits_{i=1}^n \lambda_i x_{ji}^p & \leq & x_{jh}^q & \forall\ j=1,\ldots,m \\ & & \lambda_1,\ldots,\lambda_n & \geq & 0 & \end{array} \quad \Rightarrow D_h^p(\mathbf{x}^q,\mathbf{y}^q) = \phi_h^{-1} , \tag{3}$$

where $(p,q) \in \{(t,t),(t+1,t+1),(t,t+1),(t+1,t)\}$.

The so obtained factors ϕ_h indicate the maximum proportional amount of augmentation of all output values of period q in presence of constant inputs required to achieve a point of the frontier function in period p, which is described in the s+m constraints. This DEA efficiency measure is exactly reciprocal to the distance function required in (2).

Data and Measures of Relative Technology Levels:

Using data from the Penn World Table 5.6 (Summers/Heston 1991) for real GDP (chain index) as output (s=1), the number of workers and cumulated real investment for the capital stock estimates by the perpetual inventory method[1] as inputs (m=2), we apply the procedure above to h=1,...,87 countries[2] for the years t=1970,...,1990. In total we have to solve 5307 linear programming problems.[3] Using these results we then construct the Malmquist index.

After that we cumulate productivity changes of each country h=1,...,87 starting from the distance towards the frontier function in 1970 to get our measures of relative multifactor productivity levels in 1990:

$$\mathrm{MALM}_h = \mathrm{D}_h^{1970}(\mathbf{x}^{1970}, \mathbf{y}^{1970}) \times \prod_{t=1971}^{1990} \mathrm{M}_h^t .$$

Likewise we define another two indexes by cumulating only the efficiency change and technology progress measures from the Malmquist decomposition:

$$\mathrm{EFF}_h = \mathrm{D}_h^{1970}(\mathbf{x}^{1970}, \mathbf{y}^{1970}) \times \prod_{t=1971}^{1990} \mathrm{EF}_h^t ,$$

$$\mathrm{TECH}_h = \mathrm{D}_h^{1970}(\mathbf{x}^{1970}, \mathbf{y}^{1970}) \times \prod_{t=1971}^{1990} \mathrm{TP}_h^t .$$

They account for the productivity levels achieved if we only allow for the realized efficiency changes and technology progress rates, whereas MALM represents the technology level if both components of productivity are taken into account.

For the purpose of comparison we calculate related measures of relative labour productivity in 1990 using a sligthly modified procedure. Therefore, we start with the levels of GDP per capita (GDPP) and GDP per worker (GDPW) in 1970 relative to the USA in 1970 and then again cumulate subsequent growth factors until 1990:[4]

---

[1] Starting from the early period of available investment data in the data set we calculate initial capital stock estimates from an infinite geometric progression (assuming average logarithmic growth rate of investment in the first 5 years for which data are availabe). Then we accumulate subsequent investments by the usual perpetual inventory method with a geometric depreciation rate of 10 per cent per year. Because the investment data start at least in 1960 and in 1950 for many countries and our analysis begins in 1970 the effects of the initial capital stock are substantially mitigated. See Krüger/Cantner/Hanusch (1998) for more details about the capital stocks and a discussion of alternative methods.

[2] See the appendix for a list of all countries in the sample.

[3] Because the solutions of th same period programs can be used twice we have to solve 21×87=1827 within-period problems plus 2×20×87=3480 between-period problems.

$$\mathrm{CGDPP_h} = \frac{\mathrm{GDPP_h^{1970}}}{\mathrm{GDPP_{USA}^{1970}}} \times \prod_{t=1971}^{1990} \frac{\mathrm{GDPP_h^t}}{\mathrm{GDPP_h^{t-1}}},$$

$$\mathrm{CGDPW_h} = \frac{\mathrm{GDPW_h^{1970}}}{\mathrm{GDPW_{USA}^{1970}}} \times \prod_{t=1971}^{1990} \frac{\mathrm{GDPW_h^t}}{\mathrm{GDPW_h^{t-1}}}.$$

Productivity Results:

Table 1 summarizes the five measures of relative technology levels in 1990 calculated from the above described procedure for various country groups and subgroups. The measures for country groups are the arithmetic means of the country specific measures.

Table 1
Relative Technology Levels in 1990

Country Group/ Subgroup	Productivity (MALM)	Efficiency (EFF)	Technology (TECH)	Output/Capita (CGDPP)	Output/Worker (CGDPW)
OECD	0.874042	0.832468	0.754361	0.993356	0.896636
European Union	0.881912	0.849456	0.728141	0.951524	0.898164
G7	0.913341	0.866813	0.809739	1.140697	0.990233
Latin America	0.516569	0.653281	0.477421	0.233021	0.286937
Sub-Saharan Africa	0.477173	0.546604	0.436743	0.114429	0.110835
North Afr/Middle East	0.713287	0.866886	0.616949	0.291809	0.404195
Asia	0.608459	0.664884	0.482336	0.416212	0.360882
4Tiger	0.629310	0.820747	0.402614	0.796401	0.669776
7NICs	0.582266	0.724249	0.407155	0.572762	0.496690
Mean	0.633934	0.693473	0.554598	0.435597	0.424671
Standard deviation	0.232243	0.205658	0.231323	0.412045	0.353524

Note: cumulated growth factors from 1970 to 1990, starting from relative positions in 1970 (see text).

Herein we obeserve an expected ranking of the different country groups with respect to productivity. The G7 countries have the highest, Sub-Saharan Africa the lowest productivity levels and Asia outperforms Latin America. Quite surprising is the productivity measure for the North African and Middle East countries as compared to Asia. This result is mainly due to the exeptional performance of Israel and the fact that this group consists of only seven countries in our sample. This pattern continues to show up in the efficiency column, but there with substantionally higher efficiency levels in the four Asian "Tiger" states (Hong Kong, Korea, Singapore

[1] Data are again from the Penn World Table 5.6.

and Taiwan) and the seven Asian newly industrialized countries (NICs) - consisting of the four "Tiger" states and Indonesia, Malaysia and Thailand. However, these two subgroups are ranked last if we solely take account of the cumulated growth rates of technological progress.

With respect to the relative levels of the GDP per capita or per worker we observe a much wider dispersion between the country groups. There is one large gap between the OECD and the Asian countries and two other gaps between Asia and Latin America and between Latin America and Sub-Saharan Africa which is ranked lowest. The result that the dispersion regarding the labour productivity measures is much wider than the dispersion regarding the multifactor productivity measures may be to some extent due to possible inaccuracies in the procedure to estimate the capital stocks. But it is not unplausible since Sub-Saharan African and Latin American countries use less capital to produce their GDP. Thus their multifactor productivity measures will be above their respective labour productivity levels.

In the following section we will undertake an econometric analysis to investigate whether variables that are deemed responsible for low or high productivity in growth theory can be successfully related to our measures of relative productivity levels.

3. Econometric Analysis

Theoretical Background:

The theoretical basis for our econometric estimates can be found in a heuristic interpretation of the Romer (1986) model that triggered the current revival of interest in long-run growth and initiated a tremendous research program, both theoretically and empirically. At the heart of Romer's general equilibrium model is a production function of the following type:

$$Y = AL^{1-\alpha}K^{\alpha+\gamma} \text{ where } 0 < \alpha < 1, \gamma > 0.$$

It describes how the ouput (Y) is produced with labour input (L), capital input (K), spillover effects from the aggregated capital stock and the level of technology (A) in an economy. The spillover effects stem from a learning-by-doing mechanism (Arrow 1962) in which investment of a single firm contributes to the economy-wide stock of knowledge. If the strength of the spillover effect (parameterized by γ) is large enough so that $\alpha+\gamma=1$, the economy sustains continuous growth even in the absence of an exogenous growth rate of the level of technology.

Further arguments for the postulate of non-diminishing marginal returns to capital are contained in the wide interpretation of capital. In endogenous growth theory capital includes not only private investment in structures and equipment, but also components which have external effects to the whole economy. Such components of a wide notion of capital are investment in public infrastructure, education, research and development and governmental measures to secure a stable instituitional and legal environment that protects the property rights of the individuals. So we can split the production function in two terms:

$$Y = [AK^{\gamma}]\, L^{1-\alpha}K^{\alpha} = \underbrace{AK^{\gamma}}_{\begin{array}{l}\text{productivity driving factors:}\\ \bullet\ \text{research and develpment}\\ \bullet\ \text{education and human capital}\\ \bullet\ \text{openess to foreign trade}\\ \bullet\ \text{public and private investment}\\ \bullet\ \text{institutional environment}\end{array}} L^{1-\alpha}K^{\alpha}.$$

Here, the first term (in brackets) contains all productivity driving factors, whereas the second part is the conventional formulation of a production function with constant returns to scale in capital and labour. Although we determine productivity as relative towards a production frontier function, the term in brackets is approximated by our productivity level measures. The results regarding the levels of labour productivity are given for sake of comparison, but it should be remarked that they are related only weakly to the concept of productivity required for our interpretation of the Romer (1986) model.

A theoretical justification for each single productivity driving factor can be found in the accumulation oriented endogenous growth models of Lucas (1988) for education and human capital, Romer (1986) for private and Barro (1990) for public investment via spillover effects. Research and development is the main driving force of productivity and growth in the innovation oriented branch of endogenous growth theory, initiated by Romer (1990), Grossman/Helpman (1991) and Aghion/Howitt (1992). Openess to foreign trade is emphasized as the main channel for the transmission of international technological spillover effects by Grossman/Helpman (1991). The national innovation system introduced by appreciative evolutionary theorizing can be viewed as the general frame comprising all the single productivity driving factors which describes their interconnections and interplay via various institutional arrangements (see Nelson 1992). The quality and stability of the institutional environment as a slowly changing characteristic of countries is responsible for the long-run efficiency of a country's effort to spend ressources on the other main productivity driving factors in order to achieve higher productivity levels relative to other countries.

Data and Methodology:

In the following regression analysis we test, whether indicators of the above mentioned productivity driving factors can be statistically related to the five measures of relative productivity levels discussed in section 2. For this exercise we have assembled cross section data from various sources. Because of missing data 15 countries[1] drop out of the sample. Additionally we excluded Bangladesh and Lesotho which seem to be outliers in the Malmquist index calculations, so that the regressions are based on 70 obervations for the following variables:

- Research activities: sum of the per capita number of patent grants for inhabitants from the country in the USA over the period 1963-90 from the US Patent and Trademark Office and also used in Verspagen (1991).

- Human capital: average schooling years in the total population over age 25 averaged over all six five-year values from 1960 to 1985 reported in Barro and Lee (1993).

- Investment ratio: average percentage share of public and private investment in real GDP during 1960-90 obtained from the Penn World Table 5.6.

- Openess to trade: fraction of years open to international trade between 1960 and 1990 according to the classification of Sachs and Warner (1995).[2]

- Quality of institutions: government anti-diversion policy indicator (GADP) averaged over the period 1986-95 and normalized between zero and one from Hall and Jones (1996), based on country expert's evaluations of commercial policy risk services.[3]

---

[1] See the appendix.

[2] A country is classified as open if it satisfies the following five criteria: (a) average quota and licensing coverage of imports of less than 40 percent, (b) average tariff rates below 40 percent, (c) black market exchange rate premium that averaged less than 20 percent during the decade of the 1970s and 1980s, (d) no extreme controls (taxes, quotas, state monopolies) on exports and (e) no socialist economic system (Sachs/Warner 1995, p.22).

[3] The index is an equal-weighted average of evaluations in the five categories: (a) quality of bureaucracy, (b) political corruption, (c) maintenance of the rule of law, (d) risk of government expropriation and (e) goverment repudiation of contracts. These data perform highly significant in conventional growth regressions (see Knack/Keefer 1995). Only one of our 70 countries (Mauritius) is affected by the imputation procedure to fill data gaps used by Hall/Jones (1996, pp.25f.).

The fact that our productivity levels are cumulated over the period 1970-90 and most of the explaining variables are averaged over the period of about 1960-90 allows for some time lags until the effects from the productivity driving factors show up.

We estimate classical linear regressions models by OLS for each of the five measures of relative productivity levels. Heteroskedasticity of the residuals is a potential problem in cross section regression of a heterogenous sample that comprises both developed and developing countries. If a statistical test gives us indication of heteroskedasticity, we have two possibilities to proceed: (a) making assumptions about the precise form of the heteroskedasticity and estimating the model again with generalized least squares or (b) using a covariance matrix estimator that is robust against heteroskedasticity of unknown form. Because we have no idea of the correct form of the heteroskedasticity and because heteroskedasticity generally does not affect the unbiasedness or consistency of the parameter estimates the second approach is more appealing.

To give a short description of the covariance matrix estimation procedure without digging to much into the details[1] we start with the familiar OLS covariance matrix of the form

$$\hat{\mathbf{V}}(\hat{\beta})_{\text{OLS}} = \hat{\sigma}^2(\mathbf{X}'\mathbf{X})^{-1},$$

with $\mathbf{X}$ the $(n \times k)$ data matrix of k regressors and the standard deviation of the residuals $\hat{\sigma}^2 = \frac{\hat{\mathbf{u}}'\hat{\mathbf{u}}}{n-k}$ from an OLS regression with n observations. Statistical tests based on this covariance matrix lead to incorrect inference in the presence of heteroskedasticity. Because often there is no indication about the form of the heteroskedasticity, it has become popular in recent years to use covariance matrix estimators that are robust with respect of heteroskedasticity of unknown form as proposed by White (1980). MacKinnon and White (1985) examine the finite sample properties of various corrections to the original covariance matrix of White (1980) in a Monte Carlo study and find the socalled jackknife correction to be closest to the exact finite sample distribution. This finding has been subsequently confirmed by Chesher and Austin (1991) with asymptotic approximations. A close approximation to the jackknife corrected heteroskedasticity robust covariance matrix estimator is given by

$$\hat{\mathbf{V}}(\hat{\beta})_{\text{robust}} = (\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'\hat{\mathbf{\Omega}}\mathbf{X}(\mathbf{X}'\mathbf{X})^{-1},$$

where the diagonal matrix in the middle of the sandwich structure is

[1] For details and discussion we refer to MacKinnon/White (1985) and Chesher/Austin (1991).

$$\hat{\Omega} = \begin{bmatrix} \hat{u}_1^2/(1-h_1)^2 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \hat{u}_n^2/(1-h_n)^2 \end{bmatrix},$$

with h_i the i-th diagonal element of the socalled "hat" matrix $\mathbf{X}(\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'$.

In the following presentation of the regression results all t-statistics, the Ramsey RESET (regression specification error test) and the ANN (artificial neural network) linearity test are based on this robust covariance matrix estimator.[1] The RESET F-statistic tests the joint significance of three fitted values of the dependent variable raised to the second, third and forth power added to the original regression specification. The ANN test[2] is based on the Lagrange Multiplier principle and approximates the logistic activation function of a single hidden neuron of an artificial neural network by a third order Taylor series approximation. In this Taylor series a large number of redundant terms appear and have to be cancelled. The remaining terms are further reduced by a principal components analysis, where the number of principal components is determined by the restriction that they have to contain at least 95% of the information of the Taylor series. After that the principal components are included in the regression equation under consideration as additional linear terms in the same way as it is done in the calculation of the RESET and then their joint significance is determined with an F test.

These tests are primarily designed to have power against the hypothesis of incorrect functional form but should have also considerable ability for the detection of omitted variables (Godfrey 1988; Davidson/MacKinnon 1993). We also report the White's general test for heteroskedasticity and the Jarque-Bera statistic as a test for normality of the OLS residuals.[3] White (1980, p.823) claims that his test has also some power against nonlinear alternatives.

Regression Results:[4]

We report now two sets of regression results: a frist one, termed basic regressions, without the

---

[1] MacKinnon and White (1985) give support to the claim that there is not much lost if the jackknife corrected robust covariance matrix is applied in a situation of homoskedasticity. In almost every situation with a degree of heteroskedasticity that is not strong enough to be detected by statistical tests, using the jackknife corrected robust covariance matrix instead of the OLS covariance matrix will lead to improved inference.

[2] This test and Monte Carlo results for finite samples are descriped in Teräsvirta/Lin/Granger (1993).

[3] In the case of the White test we report the value of the F-statistic rather then the usual chi-square distributed nR^2 statistic because of its better properties in finite samples (see Davidson/MacKinnon 1993, p.190).

[4] The regressions are reported for the productivity levels that were constructed from capital stock estimates based on an assumed depreciation rate of 10 per cent. These productivity levels are highly correlated with those calculated using capital stocks with the "adjacent" depreciation rates of 5 and 15 per cent. Since all pairwise correlation coefficients are above 0.98 we do not expect any dependence of our conclusions on the choice of

institutional quality indicator (GADP) and a second one, termed extended regressions, with GADP included. Table 2 contains the results of the basic regressions and shows positive coefficients of the productivity driving factors research, human capital and openess on the relative productivity levels.

Table 2
Basic Regressions

Dependent Variable→ Regressors ↓	Productivity (MALM)	Efficiency (EFF)	Technology (TECH)	Output/Capita (CGDPP)	Output/Worker (CGDPW)
Constant	0.509129*** (9.595471)	0.676482*** (11.373635)	0.474222*** (7.639801)	-0.208929*** (-3.654459)	-0.113429** (-2.518926)
Patents granted USA	0.054786** (2.606412)	0.008989 (0.799454)	0.089944*** (2.989888)	0.086190*** (3.350034)	0.057459*** (3.592097)
Human (school years)	0.040986*** (4.434032)	0.033189*** (3.340511)	0.047814*** (4.310036)	0.068081*** (6.490076)	0.056098*** (5.495535)
Share of years open	0.175523*** (3.125990)	0.204578*** (3.517082)	0.025740 (0.465632)	0.255887*** (3.056240)	0.211747*** (3.307433)
Investment ratio	-0.008172** (-2.070882)	-0.011335*** (-2.818161)	-0.009942** (-2.377352)	0.012345** (2.449693)	0.011130*** (2.699920)
Sample size	70	70	70	70	70
$\bar{R}^2$	0.558356	0.346310	0.492401	0.847478	0.806081
RESET(3): F (robust)	0.124207	0.433501	0.249390	3.892408**	1.503241
ANN test: F (robust)	1.395989	0.363051	2.186761*	3.006070**	1.419232
White: F (no cross)	1.458396	4.127507***	0.193336	1.393874	1.763742
White: F (cross terms)	1.072150	2.620210***	0.233032	2.016292**	1.180362
Jarque-Bera residuals	2.782021	0.545244	6.669497**	0.627284	0.918889

Note: t-statistics (in parentheses), the RESET and the ANN test are based on jackknife corrected heteroskedasticity consistent covariance matrix; significance is indicated by * on 10%, ** on 5% and *** on 1% level.

In contrast public and private investment in physical capital is significantly negative correlated with the total factor productivity levels (MALM, EFF, TECH), whereas it is significantly positive correlated with the labour productivity levels (CGDPP, CGDPW). According to this we can not confirm any positive externalities from capital accumulation in the sense of Romer (1986). It may be the case that not only the national investment has learning by doing effects, but also the world wide amount of capital accumulation. Especially this result should be interpreted with caution because the investment ratio data are the same as the ones used in the

the depreciation rate.

construction of the capital stocks for the Malmquist index calculations and rapid accumulation of capital input naturally depresses the Malmquist index.

Regarding the fine structure of the results for the levels of total factor productivity, we can observe interesting differences between the efficiency (EFF) and technology (TECH) levels with the results for the productivity levels (MALM) in between. First, patents granted are insignificant in the EFF regression but significant on the 1% level in the TECH regression with a much higher coefficient estimate. This implies that patents represent the amount of research activities leading to technological progress. In catching up through efficiency improvements there seems not to be a strong case for activities that lead to inventions which are valuable enough to be granted in the USA. Second, for the share of years open to international trade we have exactly the reverse pattern. There is a substantially stronger relation between openess and the efficiency levels than between openess and the technology levels. That last result gives support for the growth models of Grossman and Helpman (1991) which predict that countries that are more open to trade are more successful in the adoption of new technologies from abroad. Additionally, human capital is a significant contributor to both higher efficiency levels and technology levels. From a theoretical point of view human capital improves the ability of an economy to invent new blueprints in the sense of Romer (1990) and helps also in forming a kind of absorptive capacity or social capability (Abramovitz 1986) with the aim of a better exploitation of innovations made somewere else.

The adjusted coefficients of determination in the second section of the table are within a resonable range for the Malmquist index based productivity measures, especially if we look at the usually low numbers from regressions that try to explain DEA results in other studies. About one third to above a half of the variation in the total factor productivity levels and more than 80 per cent of the variation in the labour productivity levels can be explained by these four regressors.

These main results of the basic regressions are not affected by detrimental outcomes of the diagnostic test statistics. In the case of the efficiency levels we have a indication for heteroskedasticity, but our use of the jackknife corrected heteroskedasticity consistent covariance matrix ensures correct inference regarding the t-statistics and the specification tests which show no strong significance here. The RESET leads only in the regression equation for CGDPP to a rejection of the specification due to either a wrong functional form or omitted variables. This outcome is supported by the ANN test and, surprisingly, this carries not over to the estimates for output per worker. Only in the regression for the technology levels is the Jarque-Bera statistic high enough to reject the normality of the residuals. The histogramm of these residuals is heavily right skewed because of the fact that only the industrialized countries in our sample are related to forward shifting frontier facets for most of the time which lead to high technology levels. But this outcome does not affect the validity of the other test statistics asymptotically. Even in small samples there is evidence in favour of robustness of F-tests in the presence of nonnormal or nonsymmetric error terms (Zaman 1996, p.200).

Table 3
Extended Regressions

Dependent Variable→ Regressors ↓	Productivity (MALM)	Efficiency (EFF)	Technology (TECH)	Output/Capita (CGDPP)	Output/Worker (CGDPW)
Constant	0.295206*** (5.133013)	0.497612*** (8.165304)	0.321185*** (4.488652)	-0.540064*** (-8.563710)	-0.371764*** (-7.120618)
Patents granted USA	0.040340*** (2.789439)	-0.003091 (-0.274531)	0.079609*** (3.144756)	0.063828*** (3.693011)	0.040013** (2.599534)
Human (school years)	0.019542* (1.944864)	0.015258 (1.380542)	0.032473** (2.631396)	0.034886*** (3.709375)	0.030201*** (3.218707)
Share of years open	0.079968* (1.776601)	0.124680** (2.453036)	-0.042619 (-0.726394)	0.107975 (1.645135)	0.096353* (1.887977)
Investment ratio	-0.013399*** (-4.497384)	-0.015706*** (-4.399877)	-0.013682*** (-3.500640)	0.004253 (1.478391)	0.004817 (1.487166)
Quality of institutions	0.688934*** (5.525341)	0.576049*** (3.993765)	0.492853*** (3.100436)	1.066415*** (8.316016)	0.831965*** (7.326217)
Sample size	70	70	70	70	70
$\bar{R}^2$	0.662161	0.440796	0.536442	0.915238	0.864510
RESET(3): F (robust)	1.155667	2.408966*	0.424162	4.913220***	1.838014
ANN test: F (robust)	0.914651	0.757399	1.899661	1.416874	0.929145
White: F (no cross)	0.759213	2.955927***	0.342506	1.007477	0.646388
White: F (cross terms)	0.875995	1.590405*	0.387006	0.694992	0.545236
Jarque-Bera residuals	3.116713	0.529521	7.610499**	13.086560***	2.497041

Note: t-statistics (in parentheses), the RESET and the ANN test are based on jackknife corrected heteroskedasticity consistent covariance matrix; significance is indicated by * on 10%, ** on 5% and *** on 1% level.

The extended regressions in table 3 include the institutional quality measure GADP as an additional regressor. Like the estimates of Hall and Jones (1996) the instutional indicator shows a marked power in explaining our productivity level measures. All coefficients of determination are substantially higher than before. The institutional variable exerts not only a highly significant effect on all productivity level measures but also withdraws explanatory power from all other regressors. In particular it lowers the coefficiens of the other regressors. Besides the coefficient magnitude, above all, human capital and openess are affected by its inclusion. Their t-statistics drop recognizably when compared with the results of the basic regressions. In the case of the equation for the labour productivity levels the openess variable and the investment ratio are most heavily affected.

The most probable reason for this outcome is that we are now faced with a multicollinearity problem which leads to unstable estimates. To get a clearer impression of this we look at the condition number as a multicollinearity indicator[1]. We have a condition number of 10.19 in the basic regressions and this rises to 18.11 after the inclusion of the institutional variable which is near to the widely used benchmark value of 20. Condition numbers in excess of 20 suggest a potential multicollinearity problem. Further confirmation for this can be obtained from pairwise correlation coefficients between the institutional variable and human capital (0.793768), openess (0.721741) and the investment ratio (0.751732).

Virtually unaffected from the changes is the significance pattern of the patent variable in the equation for the technology levels as the dependent variable. The remarks on the diagnostic test statistics are the same as for the basic regressions. Interestingly, the ANN test is never significant in the extended regressions, so that we can state in conjunction with the RESET that the linear specification for our Malmquist based multifactor productivity levels is a valid approximation to the functional form of the relationship as it appears in reality.

4. Conclusion

In this paper we follow the argument of Hall and Jones (1996,1997) in favour of focussing on productivity levels instead of output per capita change or total factor productivity growth rates in cross country regression analysis. To enlarge the results in this new research field, we

[1] See Greene (1997, p.422).

construct three measures of relative productivity levels from results of Malmquist total factor productivity index calculations, a method based on linear programming that is largely unnoticed in macroeconomic growth research. These productivity levels are constructed by the accumulation of productivity, efficiency and technological change terms, starting from the initial distance towards a picewise linear production frontier function. In a comparable manner we also calculate two level measures of relative labour productivity.

After that we perform a regression analysis to judge the validity of the productivity level measures. Among the growth factors deemed most relevant by endogenous and evolutionary growth theories we have made use of research activities, human capital, openess to foreign trade, public and private investment in physical capital and an institutional quality index. In order to mitigate effects from heteroskedasticity we employ a robust covariance matrix estimate with the jackknife correction of MacKinnon and White (1985). Misspecification is also tested with the RESET. All but the investment ratio could be positively related to the total factor productivity levels. However, investment has a positive sign in the equations for the labour productivity levels.

The most exiting result of the above discussed econometric evidence is that it provides a strong confirmation for the decomposition of the Malmquist total factor productivity index in measures for the relative levels of technology and efficiency. The former is significantly related to research activities which lead to patent grants, but insignificantly related to the openess variable. The latter, in contrast to that, is not significantly related to research activities, but highly significant related to the openess variable. These differences show up also in the respective coefficient magnitudes. Human capital is a main contributor to both efficiency and technology levels. The same holds true for the institutional quality index whose inclusion leads unfortunately to a multicollinearity problem with detrimental effects on all other coefficient estimates.

Appendix:

List of the 87 countries which are included in the Malmquist index calculations (together with their World Bank country codes in parentheses); the countries typed in italics are excluded from the regression analysis because of data availability or outlier identification.

Cameroon (CMR)	El Salvador (SLV)	Malaysia (MYS)
Central Afr.R. (CAF)	Guatemala (GTM)	Pakistan (PAK)
Chad (TCD)	Honduras (HND)	Philippines (PHL)
Egypt (EGY)	Jamaica (JAM)	Singapore (SGP)
Gabon (GAB)	Mexico (MEX)	Sri Lanka (LKA)
Gambia (GMB)	Nicaragua (NIC)	Syria (SYR)
Ghana (GHA)	Panama (PAN)	Taiwan (OAN)
Guinea (GIN)	U.S.A. (USA)	Thailand (THA)
Kenya (KEN)	Argentina (ARG)	Austria (AUT)
Lesotho (LSO)	Bolivia (BOL)	Belgium (BEL)
Madagascar (MDG)	Brazil (BRA)	Denmark (DNK)
Malawi (MWI)	Chile (CHL)	Finland (FIN)
Mali (MLI)	Colombia (COL)	France (FRA)
Mauritius (MUS)	Ecuador (ECU)	Germany (DEU)
Morocco (MAR)	Guyana (GUY)	Greece (GRC)
Mozambique (MOZ)	Paraguay (PRY)	Iceland (ISL)
Namibia (NAM)	Peru (PER)	Ireland (IRL)
Nigeria (NGA)	Uruguay (URY)	Italy (ITA)
Senegal (SEN)	Venezuela (VEN)	*Luxembourg (LUX)*
Seychelles (SYC)	*Bangladesh (BGD)*	Netherlands (NLD)
South Africa (ZAF)	*China (CHN)*	Norway (NOR)
Togo (TGO)	Hong Kong (HKG)	Portugal (PRT)
Tunisia (TUN)	India (IND)	Spain (ESP)
Uganda (UGA)	Indonesia (IDN)	Sweden (SWE)
Zambia (ZMB)	Iran (IRN)	Switzerland (CHE)
Zimbabwe (ZWE)	Israel (ISR)	Turkey (TUR)
Canada (CAN)	Japan (JPN)	U.K. (GBR)
Costa Rica (CRI)	Jordan (JOR)	Australia (AUS)
Dominican Rep. (DOM)	Korea Rep. (KOR)	New Zealand (NZL)

References:

Abramovitz, M. (1956), Resource and Output Trends in the United States since 1870, American Economic Review, Papers and Proceedings, vol. 46, pp. 5-23.

Abramovitz, M. (1986), Catching Up, Forging Ahead, and Falling Behind, Journal of Economic History, vol. 46, pp. 385-406.

Aghion, P., Howitt, P. (1992), A Model of Growth through Creative Destruction, Econometrica, vol. 60, pp. 323-351.

Ali, A.I., Seiford, L.M. (1993), The Mathematical Programming Approach to Efficiency Analysis, in: H.O. Fried, C.A.K. Lovell, S.S. Schmidt (ed.), The Measurement of Productive Efficiency, Oxford: Oxford University Press, pp. 120-159.

Arrow, K.J. (1962), The Economic Implications of Learning by Doing, Review of Economic Studies, vol. 29, pp. 155-173.

Barro, R.J. (1990), Government Spending in a Simple Model of Endogenous Growth, Journal of Political Economy, vol. 98, pp. S103-S125.

Barro, R.J. (1991), Economic Growth in a Cross Section of Countries, Quarterly Journal of Economics, vol. 106, pp. 407-443.

Barro, R.J., Lee, J.-W. (1993), International Comparisons of Educational Attainment, Journal of Monetary Economics, vol. 32, pp. 363-394.

Barro, R.J., Lee, J.-W. (1994), Sources of Economic Growth, Carnegie-Rochester Conference Series on Public Policy, vol. 40, pp. 1-46.

Barro, R.J., Sala-i-Martin, X. (1995), Economic Growth, New York: McGraw-Hill.

Charnes, A., Cooper, W.W., Lewin, A.Y., Seiford, L.M. (ed.) (1994), Data Envelopment Analysis: Theory, Methodology, and Application, Boston: Kluwer Academic Publishers.

Chesher, A., Austin, G. (1991), The Finite-Sample Distributions of Heterskedasticity Robust Wald Statistics, Journal of Econometrics, vol. 47, pp. 153-173.

Davidson, R., MacKinnon, J.G. (1993), Estimation and Inference in Econometrics, Oxford: Oxford University Press.

Easterly, W., Kremer, M., Pritchett, L., Summers, L.H. (1993), Good Policy or Good Luck? Country Growth Performance and Temporary Shocks, Journal of Monetary Economics, vol. 32, p. 459-483.

Färe, R., Grosskopf, S., Lovell, C.A.K. (1994), Production Frontiers, Cambridge (Mass.): Cambridge University Press.

Färe, R., Grosskopf, S., Norris, M., Zhang, Z. (1994), Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries, American Economic Review, vol. 84, pp. 66-83.

Gittleman, M., Wolff, E.N. (1995), R&D Activity and Cross-Country Growth Comparisons, Cambridge Journal of Economics, vol. 19, pp. 189-207.

Godfrey, L.G. (1988), Misspecification Tests in Econometrics, Cambridge (Mass.): Cambridge University Press.

Greene, W.H. (1997), Econometric Analysis, 3rd ed., New Jersey: Prentice Hall.

Grossman, G.M., Helpman, E. (1991), Innovation and Growth in the Global Economy, Cambridge (Mass.): MIT Press.

Grossman, G.M., Helpman, E. (1994), Endogenous Innovation in the Theory of Growth, Journal of Economic Perspectives, vol. 8, pp. 23-44.

Hall, R.E., Jones, C.I. (1996), The Productivity of Nations, NBER Working Paper No. 5812.

Hall, R.E., Jones, C.I. (1997), Levels of Economic Activity Across Countries, American Economic Review, Papers and Proceedings, vol. 87, pp. 173-177.

Knack, S., Keefer, P. (1995), Institutions and Economic Performance: Cross-Country Tests Using Alternative Institutional Measures, Economics and Politics, vol. 7, pp. 207-227.

Krüger, J., Cantner, U., Hanusch, H. (1998), An International Comparison of Growth and Technological Progress: New Evidence on the Krugman-Controversy, University of Augsburg, mimeo.

Lichtenberg, F.R. (1993), R&D Investment and International Productivity Differences, in: H. Siebert (ed.), Economic Growth in the World Economy, Tübingen: Mohr, pp. 89-110.

Lucas, R.E. (1988), On the Mechanics of Economic Development, Journal of Monetary Economics, vol. 22, pp. 3-42.

MacKinnon, J.G., White, H. (1985), Some Heteroskedasticity-Consistent Covariance Matrix Estimators with Improved Finite Sample Properties, Journal of Econometrics, vol. 29, pp. 305-325.

Mankiw, N.G., Romer, D., Weil, D.N. (1992), A Contribution to the Empirics of Economic Growth, Quarterly Journal of Economics, vol. 107, pp. 407-437.

Nelson, R.R. (1992), National Innovation Systems: A Retrospective on a Study, Industrial and Corporate Change, vol. 1, pp. 347-374.

Romer, P.M. (1986), Increasing Returns and Long-Run Growth, Journal of Political Economy, vol. 94, pp. 1002-1037.

Romer, P.M. (1990), Endogenous Technological Change, Journal of Political Economy, vol. 98, pp. S71-S102.

Sachs, J.D., Warner, A. (1995), Economic Reform and the Process of Global Integration, Brookings Papers on Economic Activity, no. 1, pp. 1-118.

Solow, R.M. (1956), A Contribution to the Theory of Economic Growth, Quarterly Journal of Economics, vol. 70, pp. 65-94.

Solow, R.M. (1957), Technical Change and the Aggregate Production Function, Review of Economics and Statistics, vol. 39, pp. 312-320.

Summers, R., Heston, A. (1991), The Penn World Table (Mark 5): An Expanded Set of International Comparisons 1950-1988, Quarterly Journal of Economics, vol. 106, pp. 327-368.

Teräsvirta, T., Lin, C.-F., Granger, C.W.J. (1993), Power of the Neural Network Linearity Test, Journal of Time Series Analysis, vol. 14, pp. 209-220.

Verspagen, B. (1991), A New Empirical Approach to Catching Up or Falling Behind, Structural Change and Economic Dynamics, vol. 2, pp. 359-380.

White, H. (1980), A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity, Econometrica, vol. 48, pp. 817-838.

Zaman, A. (1996), Statistical Foundations for Econometric Techniques, San Diego: Academic Press.