The approach used here relates to the growth accounting literature, but goes beyond it. Growth accounting decomposes increases in output into two parts. One is explained by input changes and the other, calculated as a residual, as "technical change". Interpretation of the unexplained residual as technical change is reasonable only if all countries are producing on their frontier. The strength of the stochastic frontier model in this article is that the residual can be decomposed into technical change, inefficiency and statistical noise. Efficiency measures describe the deviation from the best practice technology.[11] Estimation of the stochastic frontier allows an analysis of the factors which affect technical efficiency.

4. RESULTS

Empirical results derive from a panel for 57 developing countries for the period 1960-90.[12] The dependent variable is the log of real GDP, and the independent variables the log of the labour force and physical capital. Explanatory variables for the efficiency term are import of machinery and transport equipment, the inflow of FDI, and human capital.[13] Data are from the World Bank CD-ROM (1999), except for real physical capital (physical capital at market prices, Nehru and Dhareshwar, 1993) and labour (calculated from GDP per worker series in the Penn World Table, 5.6).

The empirical model is a translog production function with regional dummy

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[10] See also Koop *et al*. (1997).

[11] For a detailed treatment of this argument see Maddala (1994).

[12] The countries are: Algeria, Argentina, Bangladesh, Bolivia, Cameroon, Chile, Colombia, Costa Rica, Cote d'Ivoire, Cyprus, Dominican Republic, Ecuador, Egypt, El Salvador, Ethiopia, Ghana, Guatemala, Haiti, Honduras, India, Indonesia, Iran, Jamaica, Jordan, Kenya, Korea, Rep., Madagascar, Malawi, Malaysia, Mali, Malta, Mauritius, Mexico, Morocco, Mozambique, Myanmar, Pakistan, Panama, Paraguay, Peru, Philippines, Rwanda, Senegal, Sierra Leone, Singapore, Sri Lanka, Sudan, Tanzania, Thailand, Trinidad and Tobago, Tunisia, Turkey, Uganda, Uruguay, Venezuela, Zambia, Zimbabwe.

[13] Human capital takes the role of a control variable. It accounts for the part of the learning-by-doing effect which is not due to trade related influences. The measure is from Collins and Bosworth (1996), and is a weighted average of the percentage of a country's population attained 7 levels of schooling (1: no schooling to 7: beyond secondary completed). The weights are estimated returns to each level of schooling.

variables for African countries (D_1), Asian countries (D_2),[14] and five time dummies ($D_{3,\ldots,7}$)[15]:

$$y_{it} = b_0 + b_1 k_{it} + b_2 l_{it} + \frac{1}{2} b_3 k_{it}^2 + \frac{1}{2} b_4 l_{it}^2 + b_5 k_{it} l_{it} + \sum_{j=1}^{7} \mathrm{d}_j D_j + \mathrm{v}_{it} - u_{it}, \qquad (4.1)$$

where y_{it} is the log of output (Y), k_{it} is the log of capital (K), and l_{it} is the log of labour (L). The translog production specification is more flexible than a function of the Cobb-Douglas type, because it does not impose constant substitution elasticity. This seems more appropriate when analysing low-income countries, where structural rigidities may be more in evidence (Blomstrom, Lipsey and Zejan, 1994). Note that because the variable on the lhs of (4.1) is the log of real GDP, the parameters associated with the time dummies can be reformulated as growth rates to compare the average technology levels for the 8 subperiods:

$$\begin{aligned} \frac{Y_{66-70}}{Y_{60-65}} - 1 &= \frac{Y_{66-70} - Y_{60-65}}{Y_{60-65}} = \exp(d_3) - 1; \\ \frac{Y_{71-75}}{Y_{66-70}} - 1 &= \frac{Y_{71-75} - Y_{66-70}}{Y_{66-70}} = \frac{\exp(d_4)}{\exp(d_3)} - 1; \\ &\text{etc.} \end{aligned} \qquad (4.2)$$

The same holds for the country dummies: $\exp(d_1)$-1 measures the percentage technical change in moving from the reference group to Africa, and $\exp(d_2)$-1 measures the percentage difference between Asia and the reference group. The inefficiency term u_{it} is determined by

$$u_{it} = d_1 FDI_{it} + d_2 IMP_{it} + d_3 HC_{it}, \qquad (4.3)$$

where FDI_{it} denotes the log of foreign direct investment, IMP_{it} is the log of

[14] The reference group contains the Latin American countries, Cyprus, Malta, and Turkey.
[15] The time periods covered by the dummies are 1966-1970, 1971-1975, 1976-1980, 1981-1985, and 1986-1990.

imported capital goods, and HC_{it} the log of human capital. While FDI_{it} and IMP_{it} allow us to test the model in Section 2, HC_{it} controls for other determinants of efficiency.

The parameters of the model defined by (4.2) and (4.3) are estimated simultaneously using the computer program, FRONTIER Version 4.1 (Coelli, 1996). It provides maximum-likelihood estimates of the parameters and predicts technical efficiencies. The results of the estimation are displayed in Table 1. The variance parameter

$$g = \frac{s_u^2}{s^2} \text{ and } s^2 = s_u^2 + s_e^2 \qquad (4.4)$$

can be used to perform a diagnostic likelihood-ratio test to show of whether inefficiency is present in the model (H_0: $\gamma = \delta_0=\delta_1=\delta_2=\delta_3=0$). The test statistic *LR* is approximately distributed following a mixed chi-square distribution, critical values can be found in Kodde and Palm (1986). The null hypothesis is decisively rejected at the 5 per cent level of significance.[16] A likelihood ratio test with the Cobb-Douglas production function as null model (H0: $b_3=b_4=b_5=0$) can be used to test whether the translog production function is adequate. The test statistic follows a χ^2_3 distribution. Again, the hypothesis can be rejected at the 5 per cent level.[17] In addition, the results allow discrimination between a stochastic and a deterministic frontier: if the frontier was deterministic, we would be unable to reject the hypothesis that $\gamma=1$. A *t*-ratio of t=-5.408 allows rejection of this hypothesis at the 1% significance level.

Before turning to the efficiency results, we look at the dummy variables: the time dummies show a trend with positive slope, and there is a significant difference between the reference group and the Asian and African countries in the data set. Converting these differences into growth rates, the technology level in the reference group is about 50 per cent higher than in the group of African countries, but only 16

[16] Test statistic *LR*=144.8, critical value: 10.371 (Kodde and Palm, 1986).
[17] Test statistic *LR*=41.2, critical value of the χ^2_3 distribution (%5 significance level): 12.84.

per higher than for the Asian countries.

The results for the determinants of technical inefficiency strongly support the implications of the model in Section 2. All the variables reduce inefficiency significantly. Besides the more general effect of human capital accumulation, knowledge diffuses through both FDI and imported machinery and equipment. It should be stressed, however, that the coefficient of FDI (δ_1) is greater (1 per cent significance level) than those of either imported capital goods (δ_2) or human capital (δ_2): at the same efficiency level, FDI has the biggest impact on efficiency.[18] With respect to imported capital, this result is consistent with the importance of externalities in FDI: its knowledge transfer is more general than imported machinery and equipment. Knowledge embodied in imported capital is specific to the technology of the firms that use them, and therefore less neutral than knowledge associated with FDI. Accordingly, FDI has the stronger effect on efficiency.

Efficiency medians for all subperiods and regions are displayed in Table 2 (see also Figure 2 for the distribution). Although there is an increase over time (25 per cent for all countries from 1960 to 1990), substantial regional differences are evident. The increase from 1960 to 1990 is about 50 per cent for the Asian countries, but only 7 per cent for Africa. Furthermore, the efficiency median for the African countries actually decreases in the period 1966-1975. The result for the reference group is in between (20 per cent). For all regional groups, the spread of efficiency increases over time, i.e. the distance between efficient and inefficient countries increases. African countries in the panel exhibit the lowest efficiency spread. They are more homogeneously concentrated at a lower efficiency level than the other country groups. The relative size of the medians and the spread is comparable to the averages reported in Koop, Osiewalsky and Steel (2000, Table 4).

[18] $\frac{\partial \tau}{\partial FDI} = -\delta_1 \tau; \frac{\partial \tau}{\partial IMP} = -\delta_2 \tau; \frac{\partial \tau}{\partial HC} = -\delta_3 \tau.$

Table 1:Estimation Results

Parameter	Estimate	Standard Error	*t*-Ratio
b_0	0.6808	1.9256	0.3535
b_1	0.3923	0.0806	4.8671
b_2	1.5740	0.1749	8.9986
b_3	0.0128	0.0026	4.9285
b_4	0.0065	0.0132	0.4954
b_5	-0.0377	0.0071	-5.3010
d_1	-0.7121	0.0389	-18.3011
d_2	-0.1712	0.0441	-3.8780
d_3	0.0989	0.0526	1.8810
d_4	0.1887	0.0527	3.5809
d_5	0.2329	0.0532	4.3813
d_6	0.2185	0.0547	3.9975
d_7	0.2031	0.0549	3.7000
δ_0	2.6546	0.2380	11.1524
δ_1	-0.0284	0.0130	-2.1811
δ_2	-0.0121	0.0018	-6.6526
δ_3	-0.0117	0.0024	-4.8686
$\bar{\sigma}^2$	0.2562	0.0121	21.2044
γ	0.2597	0.1369	1.8978

Number of observations: 1416, log-likelihood: -1030.494
The estimates $b_{1,\ldots,5}$ are the parameters of the translog production function (equation 4.1), d_1 and d_2 are the parameters of the regional dummies for the Asian and African countries, and $d_{3,\ldots,7}$ are the parameters of the time dummies. The estimates $\delta_{0,\ldots,3}$ are the parameters of the inefficiency model (equation 4.3), $\bar{\sigma}^2$ is the estimate of the composite variance, and γ is the estimate if the variance ratio. The constant b_0 can be interpreted as the technology parameter of the reference group in the period 1960-66.

Based on the empirical support of the main predictions of the model in Section 2, one might ask the question why Africa fails to attract foreign capital goods, and why Asia obviously did better. The results in Tables 1 and 2 are indicative for "Africa's Growth Tragedy" (Easterly and Levine, 1997). The decrease in efficiency

in 1966-1975 is in line with the implications of the model. As Devarajan, Dollar, and Holmgren (2001, p. 7) point out, typical African countries at the beginning of the 80s were characterised by a very high level of government intervention, especially trade intervention. These policies did not lead to an improvement in the standard of living, and, in addition, "seemed to exacerbate the effects of the external shocks of the 1970s" (Devarajan, Dollar, and Holmgren, 2001, p. 7). Political pressure generated by economic disasters forced some countries into reforms, which is reflected in the increase in efficiency after 1976.

However, the increase in efficiency with respect to the other countries is low. Besides the choice of policy, there are other factors determining the lack of growth performance in Sub-Saharan Africa. The high inefficiency is perfectly in line with Devarajan, Easterly and Pack (1999), who find public and private capital to be not productive. The lack of "social capability" (Temple and Johnson, 1998) and the geographic determinants of the "Tragedy" identified in e.g. Gallup, Sachs and Mellinger (1999) have certainly also a deteriorating effect on the diffusion of technology via trade, because they induce transfer cost. The group of countries is characterised by a very high proportion of land concentrated in the tropics, 81 per cent of population concentrated in the interior regions, i.e. far away from the coast, and more than a quarter of population actually living in landlocked regions. In addition, the distance to core markets in Europe is very high.[19] All in all, if FDI and imports of machinery and equipment increase efficiency, all these factors will push Africa away from the frontier. Although reform-oriented governments and policies were able to attract foreign investors in some African countries (Morriset 2000), the above mentioned characteristics have had an inevitably negative effect on overall business climate.

Similarly,

For Asia, on the other hand, the historical and geographical circumstances were less

[19] One could also speculate on how the devastating effect of HIV/AIDS on physical and human will show up in the framework of the model. The epidemic started in sub-Saharan Africa in the late 70s/early 80s. As pointed out by Bonnel (forthcoming), AIDS-related diseases are the main cause of mortality in this region. It affects the most productive age group, and reduces saving and investment incentives. With respect to human capital, Bonnel (forthcoming, Table 1) shows that

problematic.[20] The literature stresses three elements in explaining the "Asian Miracle": outward orientation, sound macroeconomic management, and investment in human capital. Although there were early attempts to protect import substitution industries, these policies were soon abandoned,[21] reducing import control and tariffs, together with strong incentives to export. Government intervention was systematic, selective and performance based. Leipziger (1997, p.11) stresses the especially favourable domestic climate for FDI in the eighties, which, in the framework of the model in Section 2, would have had an efficiency increasing effect.

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the HIV epidemic had a negative effect on formal education (measured by the change in secondary enrolment rate) - by destroying human capital, this would reduce efficiency.

[20] For the following, see Leipziger (1997), World Bank (1993).

[21] For Latin-America, the distortions caused by import-substituting industrialisation were persistent in the seventies and eighties, although this policy has shown to have deteriorating effects on economic growth (Taylor 1998). In the framework of the model in Section 2, this explains the lower efficiency in the reference group with respect to Asia after 1975 (Table 2).

Table 2: Efficiency (Median)

	1960-65	1966-70	1971-75	1976-80	1981-85	1986-90
All Countries	0.452	0.469	0.476	0.503	0.540	0.566
	(0.128)	(0.147)	(0.186)	(0.209)	(0.227)	(0.229)
Africa	0.408	0.397	0.396	0.409	0.418	0.436
	(0.074)	(0.095)	(0.090)	(0.107)	(0.177)	(0.156)
Asia	0.427	0.455	0.498	0.577	0.633	0.644
	(0.117)	(0.121)	(0.176)	(0.184)	(0.180)	(0.168)
Reference Group	0.492	0.544	0.541	0.556	0.560	0.589
	(0.151)	(0.145)	(0.221)	(0.222)	(0.229)	(0.228)

Notes: interquartile ranges (distance between 75^{th} and 25^{th} percentile) in parentheses.

Figure 2: Efficiency Distribution