1. INTRODUCTION

Less developed countries tend to adopt existing technologies rather than invent new ones. In a closed economy, new technology already in use in the developed countries has to be internally produced. In an open economy, technology can also be transferred through importing of capital goods from developed countries or foreign direct investment (FDI). The issue debated in the literature is whether technical progress is more likely to occur in a closed economy (infant-industry argument) or in open economies.[1]

The issue addressed in this article is whether openness raises production efficiency, and the link that "learning" creates between trade policy and output growth patterns in developing countries (Arrow 1962, Romer 1986, Lucas 1988, and Quah and Rauch 1990). If knowledge transferred by trade is general,[2] openness should raise total factor productivity through increasing efficiency.

Up to now, there is no evidence in the literature on the relative importance of channels through which trade diffuses technology (Tybout 1998). The main contribution of this article is providing for the first time evidence on the macro level. Estimation of a stochastic production frontier for a panel of 57 countries[3] shows that FDI and imported capital goods are important channels for improving

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[1] There are two views in the literature on the benefits of openness in relation with productivity in LDCs. On the one hand, there is the infant-industry argument: protection policy can help the high-skill industries (import-substitution industries), which use the production technology of industrial countries to develop. In the long-run, there will be a dynamic productivity gain (Nishimizu and Robinson 1984, 1986, Nishimizu and Page 1991, Pack 1992, Stockey, 1991, Rodrik 1992a,b, Rodriguez and Rodrik 1999, Matsuyama 1992). On the other hand, some studies find that trade liberalisation increases the production of high-skill intensive industries (import-competition industries), which use the production technology and the capital goods imported from developed countries (Pack 1988, 1999, Tybout 1992, Coe and Helpman 1995, Coe, Helpman, and Hoffmaister 1997, Robbins 1996, Levin and Raut 1997, Pissarides 1997).

[2] General human capital represents general knowledge associated to some technology, whereas specific human capital refers to technology specific to some industry. Technological change specific to some production process requires investment, whereas general (neutral) technological change does not.

[3] Observation period: 1960-1990.

efficiency. Analysis reveals, however, an important difference between the two channels. Knowledge diffused through FDI is more general (disembodied) than that from imported capital goods (embodied). Over the observation period, whereas all countries become more efficient, gains are especially evident for the group of Asian countries in the panel. This result can be linked to the early outward orientation and the favourable climate for FDI in the 80s.

The remainder of the paper is organised as follows. In the model developed in Section two, the high value-added sectors (i.e. import-substitution sectors) benefit from technological diffusion through trade liberalisation. Section three explains the stochastic frontier methodology used. The fourth section uses this stochastic frontier approach to test the model in Section two and analyses the results. A fifth section concludes.

2. THE MODEL

The model in this section builds on the argument that openness allows an economy's dynamic sector to develop. Drawing on the ideas of Lucas (1988), Matsuyama (1992) and Weinhold and Rauch (1999), the model links imports of intermediate goods and faster less developed country (LDC) growth. Trade openness leads to increased specialisation and this, in turn, accelerates productivity growth through dynamic economies of scale. The dynamic sectors (import-substitution) sectors benefit from technological diffusion by trade liberalisation.

Consumption side

The number of individuals is assumed equal to L. Each individual is endowed with one unit of labour per unit of time, and supplies this inelastically without disutility.[4] Therefore, total labour supply per unit of time is equal to L.

[4] Barro and Sala-i-Martin (1995) p. 62.

The utility function of the representative individual is

$$U(C) = \int_0^\infty C e^{-\delta t} dt \qquad , \qquad (2.1)$$

where δ is the rate of time preference. Consumption, C, is given by

$$C = \left[A^\rho + M^\rho \right]^{1/\rho} \qquad , \qquad (2.2)$$

where A is the consumption of agricultural goods and M is the consumption of manufacturing goods. The parameter ρ represents the preference for each good. The elasticity of substitution between agricultural and manufacturing goods is constant and equal to $\sigma = 1/(1-\rho)$ $(\sigma > 1)$. Aggregate consumption C is a sub-utility function of two varieties of goods defined by a constant elasticity of substitution.

The budget constraint of the agents is

$$\dot{a} = w + ra - c \quad , \qquad (2.3)$$

where a represents the assets in the form of ownership claims on capital (both domestic and foreign capital, the dot over the variable represents a time derivative), r is the interest rate on these assets and w is the wage rate paid per unit of labour services. Equation (2.3) states that assets per person rise with per capita income and fall with consumption.[5]

A two-stage budgeting procedure applies. The first step in the consumer's problem is the choice of each good in order to minimise the cost of attaining a given level of consumption C:

$$\min\left(A+pM\right) \qquad \text{s.t. } C=\left[A^{\rho}+M^{\rho}\right]^{1/\rho} \quad , \tag{2.4}$$

where p is the price of manufacturing goods relative to agricultural goods.
The first order condition implies

$$\frac{M^{\rho-1}}{A^{\rho-1}}=p \quad , \tag{2.5}$$

and therefore

$$M=\left(p\right)^{1/\rho-1}A \quad . \tag{2.6}$$

The second step of the consumer's problem is to choose consumption such as to maximise the utility function (2.1). The growth rate of consumption

$$\frac{\dot{c}}{c}=\sigma\left(r-\delta\right) \tag{2.7}$$

gives the optimal condition for consumption growth. Equation (2.7) says that individuals choose a pattern of consumption according to the relation between the interest rate on assets (capital) and the rate of time preference. A lower willingness to substitute intertemporally (a small value of σ) implies a lower rate of growth of consumption for a given gap between r and δ. Accordingly, individuals save more today and postpone consumption.

Production side

The economy has two sectors: a low-value added sector (*a*) and a high value-added sector (*m*). The latter is subject to learning-by-doing. For convenience, the low-value added sector can be associated with "agriculture", and the high-value added sector with "manufacturing". Labour is mobile between the two sectors, and both it

[5] Population is assumed to be constant. Relaxing this assumption would require to subtract the

and the relative world price of goods from sector *m* are normalised to unity. The production functions of the two sectors are:

$$X_t^m = M_t L_t^\alpha K_t^\beta \tag{2.8}$$

$$X_t^a = A(1-L_t)^\alpha \tag{2.9}$$

where L_t represents labour in manufacturing sector and α is the share of labour in value added; *t* is a time subscript; K_t is the capital stock used only in the manufacturing sector, and β is the share of capital in value added. The parameter *A* captures the specific characteristics of the agricultural sector, M_t represents the productivity coefficient in manufacturing and evolves according to

$$\dot{M}_t = \delta F_t^m \quad . \tag{2.10}$$

The parameter δ is the learning coefficient, and F_t^m is the level of foreign capital employed in the manufacturing sector.

The first order condition of the profit maximisation problem states that the real interest rate is equal to the marginal productivity of the capital in the manufacturing sector:

$$r = \beta M_t L_t^\alpha K_t^{\beta-1} \quad . \tag{2.11}$$

Inserting equation (2.11) into (2.7) gives

$$\frac{\dot{c}}{c} = \sigma\left(\beta M_t L_t^\alpha K_t^{\beta-1} - \delta\right). \tag{2.12}$$

Equation (2.12) states that consumption growth depends positively on M_t. From

term *na*, where *n* is population growth (Barro and Sala-i-Martin , 1995, p.62).

equation (2.10) manufacturing grows at a rate proportional to the foreign capital. To simplify the model without altering the main assumptions, assume that capital in the manufacturing sector is equal to one. The equilibrium condition of the labour market requires an equal marginal product of labour in the two sectors:

$$A(1-L_t)^{\alpha-1} = M_t L_t^{\alpha-1} \qquad . \tag{2.13}$$

From equation (2.13) it is possible to calculate labour growth in sector *m*:

$$L_t = \frac{A^{\frac{1}{\alpha-1}}(1-L_t)}{M^{\frac{1}{\alpha-1}}} \qquad . \tag{2.14}$$

Taking logs yields

$$\ln L_t = \frac{1}{\alpha-1}\ln A + \ln(1-L_t) - \frac{1}{\alpha-1}\ln M_t . \tag{2.15}$$

Deriving equation (2.15) with respect to time, and taking into account that *A* is constant, gives

$$\frac{\dot{L}_t}{L_t} = -\frac{1}{1-L_t}\dot{L}_t - \frac{1}{\alpha-1}\delta\frac{F_t^m}{M} . \tag{2.16}$$

Rearranging the terms in (2.16), one obtains the final expression for labour growth:

$$\frac{\dot{L}_t}{L_t} = (1-L_t)\frac{1}{1-\alpha}\delta\frac{F_t^m}{M} \tag{2.17}$$

The growth rate of labour depends positively on the learning coefficient δ and the amount of foreign capital in manufacturing sector. It depends negatively on the productivity coefficient *M*: labour and foreign capital are substitutes more than complements.[6] Aggregate output in the economy is given by

$$Y_t = M_t L_t^{\alpha} + A(1-L_t)^{\alpha} \quad . \tag{2.18}$$

Taking the time derivative of equation (2.18) results in

$$\dot{Y} = \dot{M} L_t^{\alpha} + \alpha L_t^{\alpha-1} M \dot{L}_t + \dot{A}(1-L_t)^{\alpha} - \alpha A(1-L_t)^{\alpha-1}\dot{L}_t \quad . \tag{2.19}$$

After substituting $\dot{A} = 0$, $\dot{M} = \delta F_t^m$, and dividing by Y_t, one obtains the growth rate of output

$$\frac{\dot{Y}_t}{Y_t} = \delta \frac{F_t^m}{Y_t} L_t^{\alpha} + \alpha L_t^{\alpha-1} \frac{M_t}{Y_t}\dot{L}_t - \alpha \frac{A}{Y_t}(1-L_t)^{\alpha-1}\dot{L}_t . \tag{2.20}$$

Rearranging terms, substituting $\dot{L}_t$ with expression (2.17) and using the ratio of foreign capital in total output at time t, $\lambda_t = \frac{F_t^m}{Y_t}$, yields

$$\frac{\dot{Y}}{Y} = \delta\lambda_t L_t^{\alpha} + \alpha L_t^{\alpha-1}\frac{M_t}{Y_t}\left(1-L_t\right)\frac{1}{1-\alpha}\delta\lambda_t - \alpha\frac{A}{Y_t}(1-L_t)^{\alpha}\frac{1}{1-\alpha}\delta\lambda_t . \tag{2.21}$$

Substituting $X_t^m = M_t L_t^{\alpha}$ and $X_t^a = A(1-L_t)^{\alpha}$, $x_t^m = \frac{X_t^m}{Y_t}$ (share of manufacturing output in total output) and $x_t^a = \frac{X_t^a}{Y_t}$ (share of agricultural output in total output) in (2.21) gives

$$\frac{\dot{Y}}{Y} = \delta\lambda_t L_t^{\alpha} + \frac{\left(1-L_t\right)}{L_t}\frac{\alpha}{1-\alpha}\delta\lambda_t x_t^m - \frac{\alpha}{1-\alpha}\delta\lambda_t x_t^{\alpha} . \tag{2.22}$$

[6] The import substituting, or manufacturing, sector is capital-intensive. The export, or agricultural, sector is labour intensive.

It follows from equation (2.13) that $x_t^m = L_t$. Using this equality, the growth equation can be rewritten as

$$\frac{\dot{Y}}{Y_t} = \delta\lambda_t \left[L_t^{\alpha} + \left(\frac{\alpha}{1-\alpha} \right) \left(1 - L_t - x_t^{\alpha} \right) \right] \qquad (2.23)$$

The growth rate of output depends positively on the learning coefficient in manufacturing, δ, and on the foreign capital's share in total output, λ, but negatively on output in the agricultural sector. The larger the proportion of foreign capital, the higher the growth rate.

Learning is assumed not to be subject to decreasing returns, and this implies unbounded productivity growth. LDCs face a technological frontier exogenously expanding as determined by research in the technologically developed countries.[7] Technology is embodied in imported capital, and since the LDCs never reach the frontier they escape decreasing returns.

The main theoretical implications of the model are that growth in LDCs depends on the human capital accumulation. The latter stems from specific training and on-the-job experience, captured by the learning coefficient in the manufacturing sector δ. An increase of foreign capital will raise human capital and, consequently, the productivity of labour. Therefore, policies which favour free trade and promote the import of foreign capital goods will help developing countries to close the technology gap and increase productivity growth. In the empirical analysis which follows, these gains will show up through an effect on the efficiency term in the stochastic frontier model.

3. Econometric Methodology

To test empirically the implications of the model requires a measure of technological progress, one widely used approach is a residual of the Abramovitz/Solow type, where output growth is decomposed into a weighted sum of input growth rates. The residuum, which represents the change in output that cannot be explained by input growth, is identified as technological progress. This measure is subject to criticism: the Solow residual ignores monopolistic markets, non-constant returns to scale (Hall, 1990) and variable factor utilisation over the cycle (Burnside *et al.*, 1995, Basu 1996).

A second approach is directly to estimate a production function, and to distinguish between technological change, or a shift in technological frontier, and efficiency, or a movement towards the technological frontier. To fix ideas, consider the example in Figure 1. It compares the output of two countries, *A* and *B*, as a function of labour, *L*. Given the same production technology, the higher output in country *A* than *B* can occur for four possible reasons. First, this difference can be due to differences in input levels, as is the case in panel (A). Second, technology acquisition may differ between countries or regions, with the consequence that for the same level of inputs different outputs result (panel (B)). Third, it might be that country *B* produces less efficiently than country *A*. In other words, both countries have the same frontier and the same input level, but output in *B* is lower (panel (C)). And fourth, differences could be due to some combination of the three causes. The Solow residual fails to discriminate between the second and the third possibility: efficiency is part of the residual. Stochastic frontier methodology, pioneered by Aigner, Lovell and Schmidt (1977) and by Meeusen and van den Broeck (1977), allows this important distinction.

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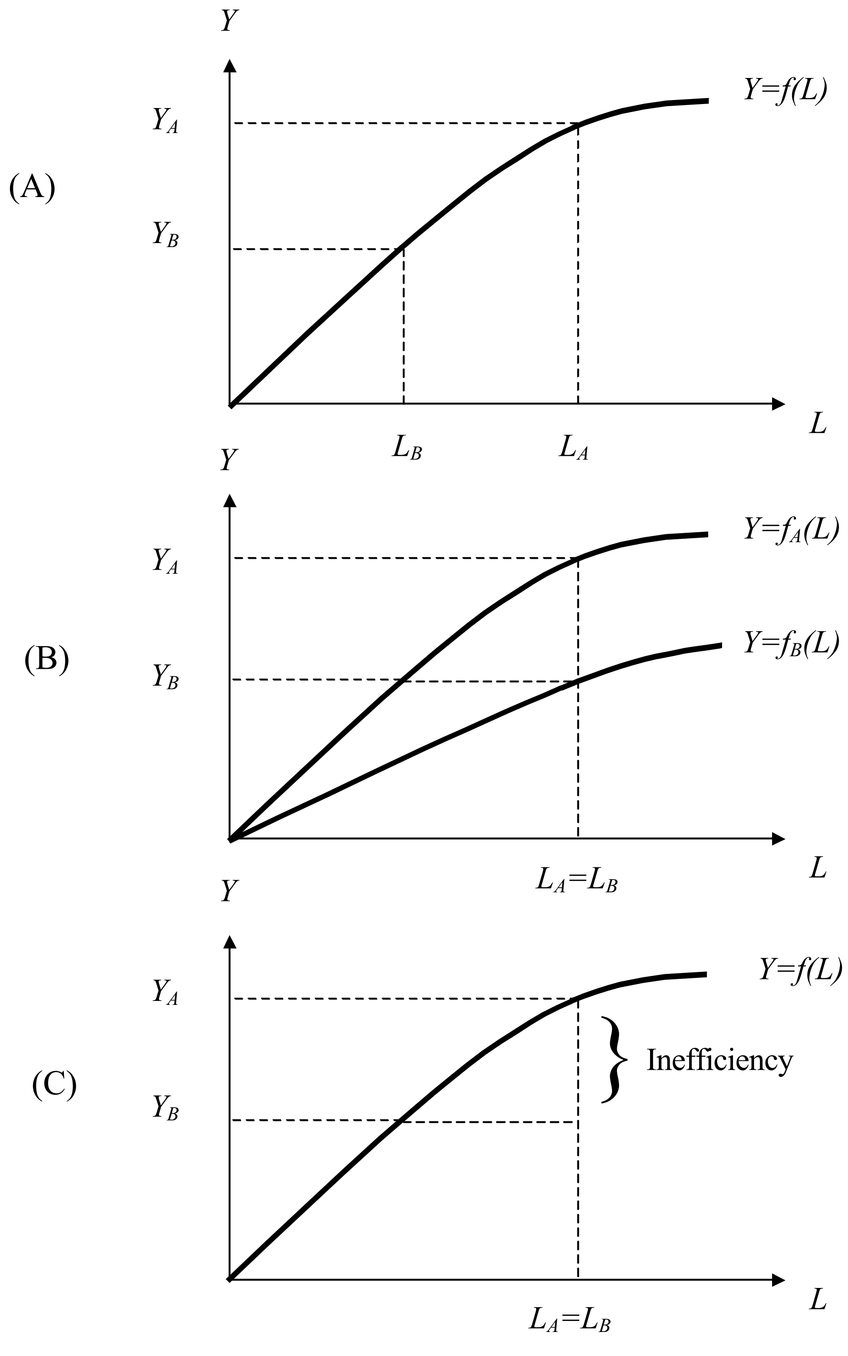
[7] See Rauch and Weinhold (1997)

Figure 1: Production Functions



Assume the following common production frontier for the countries under analysis:

$$Y_{it} = f(X_{it})\tau_{it}\omega_{it} \;\; i = 1,......N; \; t = 1,....T . \tag{3.1}$$

where τ_{it} is the efficiency measure, with $0<\tau_{it} \leq 1$,[8] and ω_{it} captures the stochastic nature of the frontier. Assuming a production function of the Cobb-Douglas type, and writing it in log-linear form, we obtain

$$y_{it} = x_{it}^{'}\beta + v_{it} - u_{it} , \tag{3.2}$$

where u_{it} = -lnτ_{it} is a non-negative variable. In matrix form, we obtain the basic panel data stochastic frontier model:

$$y_t = \mathbf{I}_{\mathrm{N}}\alpha + \mathbf{x}_t\beta + \mathbf{v}_{\mathrm{t}} - \mathbf{u} \text{ ; t =1,…,T.} \tag{3.3}$$

$$\mathbf{y}_{\mathrm{t}} = \begin{pmatrix} y_{1,t} \\ y_{2,t} \\ . \\ . \\ . \\ y_{N,t} \end{pmatrix}; \; \mathbf{x}_t = \begin{pmatrix} x_{1,1,t} & . & . & . & x_{1,k,t} \\ x_{2,1,t} & . & . & . & x_{2,k,t} \\ . & & & & \\ . & & & & \\ . & & & & \\ x_{N,1,t} & . & . & . & x_{N,k,t} \end{pmatrix}; \tag{3.4}$$

$$\mathbf{v}_t = \begin{pmatrix} v_{1,t} \\ . \\ . \\ . \\ v_{N,t} \end{pmatrix}; \; \mathbf{u} = \begin{pmatrix} u_1 \\ . \\ . \\ . \\ u_N \end{pmatrix}.$$

In logarithmic specification, technical efficiency of country i is defined as

$$\tau_{it} = e^{-u_{it}} \quad . \tag{3.5}$$

Efficiency is ranked as $u_N \leq \ldots \leq u_2 \leq u_1$: Country *N* produces with maximum efficiency in the sample.

Jondrow *et al*. (1982) suggest a measure of efficiency. They show that the distribution of $u_i|\varepsilon_i$ is normal with mean $\mu^*_i = \sigma_u^2\varepsilon_i(\sigma_u^2 + \sigma_v^2)^{-1}$ and variance $\sigma_*^2 = \sigma_u^2\sigma_v^2(\sigma_u^2 + \sigma_v^2)^{-1}$.[9]

This measure of efficiency is based on the distribution of the inefficiency term conditional to the composite error term, $u_i|\varepsilon_i$. The distribution contains all the information that ε_i yields about u_i,. The expected value of the distribution can therefore be used as a point estimate of u_i. When the distribution of the inefficiency component is a truncated distribution, a point estimate for technical efficiency TE_i is given by

$$TE_i = E\left[\exp(-u_i)|\varepsilon_i\right] = \frac{\left[1 - \Phi(\sigma_* - \mu^*_i/\sigma_*)\right]}{\left[1 - \Phi(-\mu^*_i/\sigma_*)\right]}\exp\left[-\mu^*_i + \frac{1}{2}\sigma_*^2\right], \tag{3.6}$$

where $\Phi(\bullet)$ is the standard normal cumulative density function. To implement this procedure requires estimates of μ^*_i and σ_*^2. In other words, we need estimates of the variances of the inefficiency and random components and of the residuals $\hat{\varepsilon}_i = y_i - \hat{\alpha} - x_i\hat{\beta}$.

If the distribution of the inefficiency component follows a half-normal distribution (with $\mu^*_i = 0$), the point estimate of technical efficiency will take the more simple form

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[8] When τ_i=1 there is full efficiency, in this case the country i produces on the efficiency frontier.

[9] The following assumptions must hold : (i) the v_i are iid $N(0, \sigma_v^2)$, (ii) x_i and v_j are independent, (iii) u_i is independent of x and v, and (iv) u_i follows a one-sided normal distribution (e.g. truncated or half-normal).

$$TE_i = E\left[\exp(-u_i)\middle|\varepsilon_i\right] = 2\left[1-\Phi(\sigma_*)\right]\exp\left[\frac{1}{2}\sigma_*^2\right], \qquad (3.7)$$

where $\Phi(\bullet)$ is the cumulative distribution function.

Often studies estimate the stochastic frontier and calculate the efficiency term according to equation (3.6), and, as a second step, they regress predicted efficiency on specific variables to study the factors which determine efficiency. But such a two-stage procedure is logically flawed. It requires a first-stage assumption that the inefficiencies are independent and identically distributed. Kumbhakar, Ghosh and McGukin (1991) and Reifschneider and Stevenson (1991) address this issue by proposing a single-stage Maximum Likelihood procedure. I use this approach, but in the modified form suggested by Battese and Coelli (1995). They propose an extended version of the model of Kumbhakar, Ghosh and McGuckin (1991) to allow the use of panel data[10]. Battese and Coelli (1995) specify inefficiency as

$$u_{it} = z_{it}\,\delta \quad , \qquad (3.8)$$

where u_{it} are technical inefficiency effects in the stochastic frontier model that are assumed to be independently but not identically distributed, z_{it} is vector of variables which influence efficiencies, and δ is the vector of coefficients to be estimated.

Since this article aims to analyse the effect of foreign direct investment and imports of machinery and equipment, equation (3.8) specifies these as exogenous variables. Maximum likelihood estimation is used to take into consideration the asymmetric distribution of the inefficiency term. Greene (1980) argues that the only distribution which provides a maximum likelihood estimator with all desirable properties is the Gamma distribution. However, following van den Broeck et al (1994), the truncated distribution function is preferred, which better distinguishes between statistical noise and inefficiency terms.

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

[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]:

$$y_{it} = b_0 + b_1 k_{it} + b_2 l_{it} + \frac{1}{2} b_3 k_{it}^2 + \frac{1}{2} b_4 l_{it}^2 + b_5 k_{it} l_{it} + \sum_{j=1}^{7} d_j D_j + v_{it} - u_{it}, \tag{4.1}$$

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:

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

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

$$u_{it} = \delta_1 FDI_{it} + \delta_2 IMP_{it} + \delta_3 HC_{it}, \tag{4.3}$$

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

$$\gamma = \frac{\sigma_u^{\ 2}}{\bar{\sigma}^2} \text{ and } \bar{\sigma}^2 = \sigma_u^{\ 2} + \sigma_\varepsilon^2 \qquad (4.4)$$

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 γ=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).

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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.

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).

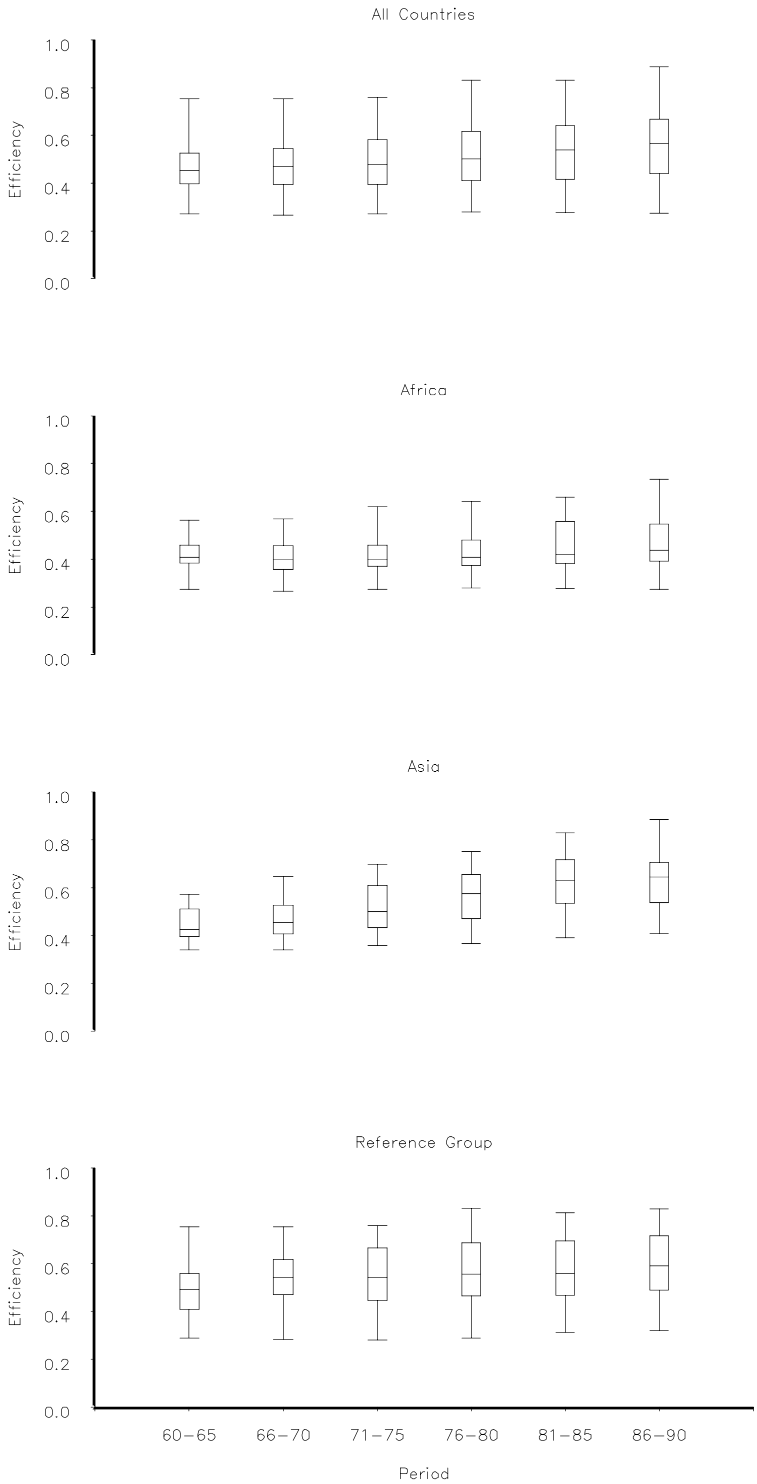
[21] For Latin-America, the distortions caused by import-substituting industrialisation were persistent in the seventies and eighties, although this policy has shown to have deteriorating effects on economic growth (Taylor 1998). In the framework of the model in Section 2, this explains the lower efficiency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



5. CONCLUSION

As noted by Tybout (1998), imported capital and intermediate goods may be the most important channel through which trade diffuses technology. Using the stochastic frontier methodology and applying the method by Battese and Coelli (1995), this article provides the first empirical evidence of the importance of these channels. As the theoretical model in Section 2 implies, FDI and imported capital goods are important channels for improving efficiency. Because of the externalities in foreign direct investment, knowledge diffused through this channel is more general (disembodied) than that from imported capital goods (embodied). Such foreign technology transfer has important policy implications. In fact, since imported capital goods create externalities, government intervention is justified. Governments need to facilitate the process of technology transfer by encouraging the establishment of the necessary infrastructure and providing incentives to support the development of domestic innovative capabilities. For countries at the early stage of industrialisation, it will be more effective and economically more convenient to import foreign technologies rather than developing them locally. Another important policy implication of the results in this article is that the infant-industry argument seems invalid: with respect to efficiency, protectionism is harmful. Policies promoting free trade and importing foreign capital goods will help developing countries to increase productivity growth and to close the gap with the technology frontier.

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