research paper series

Globalisation, Productivity and Technology

Research Paper 2003/50

Trade, Technology Transfer and National Efficiency in Developing Countries

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The Centre acknowledges financial support from The Leverhulme Trust
under Programme Grant F114/BF

Leverhulme Centre
for Research on Globalisation and Economic Policy

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Acknowledgements

The authors are grateful to The Leverhulme Trust for financial support under Programme Grant F114/BF. The authors wish to thank Jöerg Mayer from UNCTAD for making the trade data, extracted from COMTRADE, available to us. They also wish to thank Carlos Arias for helpful discussant's comments and other participants of the 8th European Workshop on Efficiency and Productivity Analysis (Oviedo, September 2003) for their comments and suggestions. Helpful comments were also received on an earlier version of the paper from Oliver Morrissey and Francis Teal, and from participants at seminars at the Centre for the Study of African Economies (University of Oxford) and the Universities of Lancaster and Nottingham.

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MICHAEL HENRY, RICHARD KNELLER AND CHRIS MILNER

Abstract

This paper simultaneously explores the determinants of the developing countries' production frontier and their 'efficiency' in using the available resources and technology. In doing so it allows for the transfer of (industrial country) technology in determining the frontier and for international trade to influence absorptive capacity and national efficiency levels. Stochastic frontier analysis is used to model the production frontier for 57 developing countries for the period 1970-1998, to measure cross-country and temporal differences in efficiency levels and to explain the differences in efficiency levels. The results indicate significant convergence of efficiency levels and an important influence of trade and trade policy in raising efficiency levels.

JEL classification: O47, O57

Keywords: Trade, Technology Transfer, Aggregate Efficiency

Outline

Non-Technical Summary

There is a long history in economics of representing countries as individual production units, each nation using its available factor inputs and aggregate stock of know-how to produce the country's output. It has been usual in this literature to assume that countries were on their production frontier, producing as much output as possible for the available inputs and technology. This contrasts with what is often assumed at the more micro level. Firms as individual units of production (firms, farms, public service providers etc.) are often represented as operating within their production frontier. There is a large theoretical and empirical literature concerned with the modelling and measurement of technical inefficiency as production slack in such individual production units. In recent years, however, researchers have begun to extend similar ideas of technical inefficiency to the aggregate or national level. This requires that we identify the international (aggregate) production frontier for countries, and identifying whether specific countries are or are not on the production frontier. If they are not, we can also use the measured 'distance' of a country from the frontier to represent the country's degree of technical inefficiency.

In this paper we use data on 57 developing countries' outputs and inputs over the period 1970-1998 to identify an international production frontier. The inputs include physical and human capital inputs and labour inputs. We also incorporate technology inputs, but given the dependence of developing countries on industrial countries for technical know-how we use a measure of the stock of foreign (industrial country) knowledge. In order to allow for differences in technologies between countries we use a very flexible form of production technology, and allow for region-specific fixed effects and for country-specific time effects for stochastic or random influences. It is unrealistic to assume that there is extreme uniformity of technologies across countries, but on the other hand imposing extreme heterogeneity would have risked accounting for actual national efficiency differences in terms of assumed technology differences.

In some analyses of technical efficiency the production frontier and efficiency measures are identified in stage one, and then at a second stage of analysis there is an attempt to explain differences in efficiency levels across time and production units (countries). But clearly the frontier and each country's level of technical efficiency are determined simultaneously. We therefore use a one-stage estimation method that avoids such biases, and incorporate the determinants of efficiency levels alongside the model of the international production frontier. We allow for the country's ability to absorb foreign technical know-how through capital imports, and for the impact of trade policy openness on the competitiveness and therefore efficiency of domestic producers. We also seek to explain the greater constraints (health, weather etc.) on the absorption and utilisation of resources in tropical and agricultural-intensive economies.

The empirical findings of the paper are strongly in line with our model and expectations. The production frontier is well specified and is consistent with the findings of related studies. We also identify marked differences in efficiency levels between countries and regions, and systematic changes over time. We specifically identify substantial convergence toward higher levels of efficiency. Indeed the evidence is strongly in line with the view that international trade matters. The general rise in efficiency levels coincides with a period of substantial trade policy reform and liberalisation, and we find that the absorptive capacity of countries increases as capital imports increase and that increases in trade policy openness increase the opportunity and incentives for reducing slack in the use of resources.

1. Introduction

Recent studies by Coe and Helpman (1995, henceforth CH), Coe, Helpman and Hoffmaister (1997, henceforth CHH), Keller (2001a) and Eaton and Kortum (1999) have demonstrated the importance of foreign research and development (R&D) and international trade to domestic productivity growth. The theoretical motivation for this work can be found in Grossman and Helpman (1991) and Rivera-Batiz and Romer (1991). Technical progress embodied in new materials; intermediate manufactured products; capital equipment *etc.,* are traded on international markets thus allowing countries to import the R&D investments made by others.

Technology transfer and therefore international trade takes on even greater importance for productivity growth in developing countries, which as a group undertake little domestic R&D and therefore have few domestic sources of new technology. According to CHH (1997), a 1 per cent increase in the R&D capital stock in the industrialised countries raises output in developing countries by 0.06 per cent. In 1990, this amounted to 22 billion US dollars. Clearly, the spillovers to developing countries through international trade are substantial.

Yet, by focussing primarily on technology transfer, it is likely that this literature provides only a partial explanation of cross-country productivity differences. Countries are also likely to differ in the efficiency with which they use technologies (Fagerberg, 1994). As Blomström et al. (1992) indicated, "one might suppose that the rate of economic growth of a backward country would depend on the extent of technology transfers from the leading countries and **the efficiency with which they are absorbed and diffused** [authors' emphasis] (p.10)". With regard to the efficiency of technology absorption, Fagerberg (1994); Griffith et al. (2000); and Kneller and Stevens (2003) have found variables such as human capital, social institutions and international trade to be important.

The implication of the above is clear. Having access to leading edge technologies through technology transfers may not of itself lead to productivity improvements if these technologies are not absorbed and utilised efficiently. Therefore the absorptive capacity and technical efficiency of a country is a critical factor in its ability to "catch up" with countries at the technological frontier. For developing countries this is even more of an imperative.

In this paper we use the methodology of Stochastic Frontier Analysis (SFA) to consider the effects of both technology transfer and absorptive capacity on the output levels of developing countries. The production frontier refers to the maximum technically feasible output attainable from a given set of inputs. Countries (the producers of output for given inputs) then either operate on or within this frontier. The first outcome represents a technically efficient outcome while the latter admits to some level of technical inefficiency.

Technical efficiency therefore refers to the ability to avoid waste or slack by producing as much output as input usage allows. In micro or firm level applications of efficiency measurement it is appropriate to view X-inefficiency as the product of market and policy conditions that allow slack in input usage. At the aggregate or national level it is rather more appropriate to view any measured technical inefficiency as a composite of unconstrained slack in the usage of national factors (facilitated by policy conditions that do not foster competitive pressures), and constrained under-utilisation of capacity or output loss imposed by 'natural' factors (floods, drought, disease etc.) and by poverty, market and/or institutional failures which constrain the utilisation of resources or know-how. The term 'slack' is used in the present context therefore in a technical rather than judgemental sense.

In addition to efficiency improvements as a means of achieving productivity increases, another source of productivity growth is through technical progress which leads to an outward shift of the frontier. In this paper however, our focus is not on decomposing output growth into its constituent sources (see Färe et al., 1994; Koop et al., 1999; 2000; Kumar and Russell, 2002) but on examining factors that help determine the production frontier as well as explain deviations from it.[1] In so doing, we consider the role of international trade in both respects. This is a novel aspect of this paper. Previous studies that have investigated the role of trade in explaining cross-country efficiency differences, either using SFA (e.g. Mastromarco, 2002; Kneller and Stevens, 2003) or the related non-

[1] In addition to the two sources of productivity growth – technical change and efficiency improvements- factor accumulation (movement along the frontier by changing inputs) represents another source of output growth.

stochastic methodology of data envelopment analysis (DEA) [Milner and Weyman-Jones, 2003], have only focused on its role as a determinant of relative technical efficiency or distance from the frontier. Consequently, the role of trade as a conduit for technology transfer or specifically in our case, for international R&D spillovers, have not been investigated within the SFA framework. This paper seeks to fill this void. We do so by including, along with the traditional inputs of production (capital and labour), foreign machinery R&D stock as a determinant of the level of frontier technology.[2] To capture the technology transfer effect, we weight this variable by machinery imports from developed countries. In keeping with previous studies in this literature we also consider the absorptive capacity role of trade, namely whether trade narrows the gap between frontier countries and those that are behind it.

Because our entire sample comprises only developing countries, then it should be noted that the technical frontier we measure is not the global frontier. The latter is likely to be defined by the industrialised countries in general, which in 1990 accounted for 96% of total world R&D expenditures, and by the G-7 OECD countries (U.S.A., Japan, U.K., France, Germany, Italy and Canada) in particular. The latter group accounting for 92% of total OECD R&D expenditure in 1991 (See CHH, 1997).

Using a translog production function we investigate cross-country differences in output levels for 57 developing countries over the period 1970-1998. To preview our results, we find evidence that physical capital, labour and foreign R&D all contribute positively to output in developing countries, but that the effect of human capital is more complex. While it is positive in many countries, its contribution is negative in many Sub-Saharan African countries. This result appears to support the argument of Pritchett (1996) that human capital has a positive direct effect on production when the social institutional structure is such that additional education does not lead to rent seeking.

We find significant and positive contributions to absorptive capacity and efficiency from both the policy and outcome measures of international trade. A country's location (i.e. whether it is tropical or not) as well as it's share of agriculture in GDP are also shown to significantly affect efficiency.

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[2] As indicated by Griffith et al. (2000) the substantive assumption is separability between R&D and the other factors of production.

Finally, even when we control for the possibility that not all technologies will have yet diffused to all developing countries, large differences in efficiency are still apparent. The time variation in these efficiency scores suggests convergence i.e. differences in average efficiency levels have narrowed across time. This coincides with a period of increases in the trade openness and general macroeconomic policy environments. Thus by the end of the period, differences in efficiency appear less important than differences in factor inputs and technology transfer, although low efficiency is still evident in some countries.

The rest of the paper is organised as follows, Section 2 outlines the methodology upon which this study is based; reviews the empirical literature that highlights international trade as one of the main channels of technology diffusion/transfer and; discusses the data used in the empirical analysis. The results of this empirical exercise are presented in Section 3. Section 4 concludes the paper.

2. Methodology, Existing Literature and Data

Prescott (1998), Hall and Jones (1999) and Easterly and Levine (2001) have suggested that the large differences in per capita income levels across countries are largely due to differences in productivity, rather than to differences in capital accumulation (both physical and human). Statistical investigations have centred on absorptive capacity and technology transfer as the principal explanations of these productivity differences (Keller, 2000; 2001a; 2001b; Eaton and Kortum, 1999; Griffith *et al*, 2000a).[3] We review these literatures in the context of a discussion of the empirical methodology used in this paper.

Technical Frontier

This section outlines the stochastic frontier methodology on which this study is based. Since its development independently by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977), a large empirical literature utilising SFA has developed. This literature straddles a diverse range of economic inquiry and incorporates both cross-section

[3] Kneller and Stevens (2002) identify two additional explanations in the literature, which they label: resistance to new technologies because of institutional design and appropriate technology.

and panel data. Forsund, Lovell and Schmidt (1980), Bauer (1990), Green (1993) and Coelli (1995b) provide comprehensive reviews of this literature.

In this study we assume that output, *Y*, is a function of the production technology set out in (1):

$$Y_{it} = f\left(K_{it}, L_{it}, H_{it}, RD_{it}^{m}\right)e^{\eta_{it}+\varepsilon_{it}}, \quad i=1,2, \ldots N; \; t=1,2,\ldots T \qquad \textbf{(1)}$$

where *Y* is output (GDP); $f(.)$ is a suitable functional form; *K* is the stock of physical capital; *H* is a measure of the stock of human capital; *L* is the labour supply; RD^m is the stock of foreign technical knowledge; η $(0 < \eta \leq 1)$ measures technical efficiency and is unique to the SFA approach; ε captures random influences on the frontier, due to measurement error or other effects not captured by the model. Finally, *i* indexes country and *t* indexes time.

In light of the questions raised over the suitability of the Cobb-Douglas functional form (Duffy and Papageorgiou, 2000; Kneller and Stevens, 2002), we adopt a translog production function to characterise the production frontier facing developing countries.[4] Equation (1) can be expressed in log-linear form to give:

$$\ln Y_{it} = \beta_0 + \sum_{r=1}^{4}\beta_r \ln X_{rit} + \tfrac{1}{2}\sum_{r=1}^{4}\sum_{s=1}^{4}\beta_{rs} \ln X_{rit} \ln X_{sit} + \sum_{j=1}^{3} d_j D_{ji} + \sum_{j=1}^{56}\gamma_j D_j t + v_{it} - \upsilon_{it}$$

$$D_{ji} = 1 \text{ if } i \in j,\; D_{ji} = 0 \text{ if } i \notin j;\; D_j = 1 \text{ if } j = i \qquad \textbf{(2)}$$

where Y remains as defined in Equation (1), X is a vector of the factor inputs also defined in (1) i.e. X_r (X_s) equals physical capital, labour, human capital and the stock of machinery R&D respectively. $v_{it} = \ln \varepsilon_{it}$, and $\upsilon_{it} = -\ln \eta_{it}$. Equation (2) also contains region

[4] As is well known, the translog production function is a flexible functional form and provides a local approximation to any production frontier.

specific dummy variables (D_{ji}) for Latin America and the Caribbean (LAC), Sub-Saharan Africa (SSA) and Asia (ASIA). These capture differences in the initial level of technology for these regions and are preferred to country specific fixed effects (Temple, 1999). Country specific time trends ($D_j\, t$) are included to measure elements of domestic technical progress not captured by imported foreign R&D.

This representation of the frontier can be viewed as the intermediate case between on the one hand a commonly available or universal frontier or technology approach (with no regional or country specific effects) and on the other a view of extreme heterogeneity in technologies (with individual country and time specific fixed effects). The latter may allow for greater scope for efficiency in estimating econometrically the relationship between actual inputs and actual output. If it was the actual production function of each country we were seeking to represent it would be unambiguous that this was preferable. However our current purpose is to represent the technological frontier (potential output to actual inputs relationship) available to each country. The comprehensive capturing of specific effects runs the risk of 'mopping-up' the very differences in efficiency between countries that we are seeking to explain. By contrast an assumption of total homogeneity, with a common technology available to all countries, does not appear to accord with reality. Our intermediate case seeks to avoid the potential over or underestimation biases of these two more extreme representations.[5]

Given our focus on the production side, and in the absence of information on relative factor prices, we are unable to comment on allocative efficiency issues. The computation of technical efficiency is therefore conditional upon the actual inputs chosen, which may or may not be the allocatively efficient factor mix. It is possible therefore that some countries may be identified as technically efficient (i.e. define the frontier) but may not have defined the frontier with the allocatively efficient mix. Recall also that we are measuring efficiency in relative terms. The adequacy of the measure is therefore fashioned by the appropriateness of the coverage of countries, at any range of factor mixes. This may be particularly relevant for 'outlier' or extreme factor mixes or for countries for whom a more

[5] More extreme alternatives of allowing for no fixed effects or for both individual country and time specific effects simultaneously were in fact explored. The intermediate case remained our preferred representation of the frontier.

appropriate technological comparator may have been the developed rather than developing countries.

In terms of the inputs into the production function, there is some debate in the literature over the role of human capital in economic growth. Mankiw, Romer and Weil (1992, henceforth MRW) advocate the inclusion of human capital as a separate term in the production function. Benhabib and Spiegel (1994), Islam (1995) and Pritchett (1996) argue instead that human capital influences growth indirectly through its effect on TFP. We do not explicitly address this issue in this paper. We choose to follow Griliches (1969) and MRW (1992) and allow for possible complementarity between human and physical capital by including the former as a separate input in the production function.[6] Consequently, the technical efficiency scores produced from our estimation are net of the influences of human capital (see Coelli et al., 1999).

Apart from the usual set of factor inputs in Equation 1, output is also assumed to be a function of the total stock of knowledge in country *i* at time *t*. Following Griliches and Lichtenberg (1984) we assume this depends on the stock of R&D.[7] Given that most developing countries undertake little domestic R&D, the stock of knowledge is assumed to depend on the stock of foreign R&D. The measure of technology transfer used in this paper builds on that found from earlier studies; albeit where that literature uses a two-stage approach. Productivity estimates are generated as the residuals from a production function (where the parameters are either estimated or imposed) in a first stage. Then in the second stage these are regressed on domestic and/or foreign R&D stocks and measures of international trade. The implicit assumption is that countries are efficient in the use of all technologies imported.

Within the technology transfer literature, we focus on those studies that propose international trade (specifically imports) as the principal channel for the diffusion of

[6] Of course there may be *a priori* grounds for believing that human capital might simultaneously influence both production and efficiency levels. There are, however, estimation problems of doing so in a one stage approach.

[7] Nadiri and Kim (1996) model the stock of knowledge as a geometric mean of own and foreign R&D capital, with the latter constructed like CH (1995) as an import-share weighted sum of the R&D capital stock in other countries. Similarly, Kneller and Stevens (2002) assume that knowledge depends on domestic and foreign R&D, but is global in nature. In contrast, Koop *et al*. (1999, 2000) use an alternative assumption that technology growth depends on a (quadratic) time trend.

technological knowledge.[8] The level of imported R&D in that literature is calculated as the R&D stock of foreign countries weighted by some appropriate variable. Differences across studies are concentrated largely on differences in the choice of weights. For example, CH (1995) estimate an equation of the following form,

$$\log TFP_{it} = \alpha_i + \alpha_t + \beta_r \log R_{it} + \beta_s \log S_{it} + \varepsilon_{it} \qquad \textbf{(3)}$$

where *TFP* is total factor productivity; *R* measures domestic R&D stock; *S* foreign R&D stock; α_i and α_t are country and time varying intercepts; ε is an error term; *i* indexes countries and *t* indexes time. CH (1995) measure foreign R&D spillovers (S) on the domestic economy as the bilateral-imports-share weighted sum of R&D capital stocks of trade partners, that is:

$$S_i = \sum_{h \neq i} \frac{M_{ih}}{M_i} S_h \qquad \textbf{(4)}$$

where M_{ih} is the flow of imports of goods and services of country *i* from country *h;* and $M_i = \sum_{h \neq i} M_{ih}$. Thus CH's (1995) bilateral weight captures the relative importance of R&D in country *h* for productivity in country *i*.

Doubts over the conclusions reached by CH (1995) were raised however by Keller (1998) and Lichtenberg and van Pottelsberghe de la Potterie (1998, henceforth LP). Keller (1998) repeated CH's (1995) regressions using counterfactual (or constructed) 'import' shares and obtained similarly high coefficients and levels of explained variation. This led him to conclude that the import composition of a country does not have a strong influence on the regression results. Subsequent work by Keller (2000) based on industry level data for industrialised countries have however given partial support to the import composition effect by CH (1995). The composition of a country's imports is important only when it receives a disproportionately high share of its imports from one country.

[8] Other channels identified in the literature are: foreign direct investment, foreign technology payments and disembodied R&D spillovers (e.g. scientific literature, international patenting, international conferences etc.).

Extensions of this approach can be found in Xu and Wang (1999), CHH (1997) and in Mayer (2001). The first study finds (for OECD countries) that the foreign R&D variable, when weighted by capital goods imports, explains more of the variation in productivity across countries compared to total manufacturing imports. Similarly, CHH (1997) find stronger and more robust evidence for spillovers from the North (industrialised countries) to the South (77 LDCs) when using machinery and equipment import data (SITC class 7) instead of either all-manufacturing or total import data as their weighting variable. They also argue that the use of capital goods imports is "more consistent with the theory and does a better job empirically"(p.140). Finally, Mayer (2001) finds that the coefficient on the machinery imports variable is twice as large as the coefficient on the machinery and equipment imports variable for a corresponding regression.[9] Mayer argues that the entire class of SITC 7 imports includes many consumption and equipment goods that are unlikely to lead to much technology diffusion.

Previous research has also concentrated on the choice of denominator in equation (4). In questioning CH's weighting methodology, LP (1998) demonstrated that the import-share weighting scheme of CH (1995) is highly sensitive to a potential merger between countries. They contended that what really matters is the real R&D intensity embodied in the import flows of the home country from the foreign country. As such, they propose that the denominator of the weighting variable be foreign country GDP rather than the total imports of the home country. This was shown to significantly reduce the 'aggregation bias' associated with CH's measure and also to empirically outperform it.

Following this literature, we measure the stock of frontier technology as the stock of machinery R&D in 15 OECD countries.[10] We next weight this variable by the ratio of developing countries' machinery imports in the OECD countries' GDP. The stock of foreign machinery R&D spillovers to the domestic economy of developing country i from the foreign OECD country j is therefore given by :

[9] The theoretical basis of Mayer's (2001) study is an augmented model of Nelson and Phelps (1966) which really addresses the issue of absorptive capacity. Specifically, the role of human capital in helping countries that are technological laggards to successfully close the gap with countries at the technological frontier. However, as Mayer also considers the direct impact of capital goods on productivity we consider his study alongside the technology diffusion studies.

[10] The 15 OECD countries used to generate this measure are: Australia, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Norway, Spain, Sweden, United Kingdom and the United States.

$$RD_i^m = \sum_{j \neq i} \frac{MM_{ij}}{Y_j} RD_j^m \qquad \textbf{(5)}$$

where MM_{ij} is machinery imports of developing country *i* from developed country *j*, and Y is the GDP of the developed country. Our use of machinery imports rather than the broader class of capital goods imports - machinery and transport equipment - is influenced by the argument of Mayer (2001) over the amount of technology diffused by some of the goods contained in the latter group of imports.

Inefficiency Effects

Equation (1) recognises that countries may differ in their level of productivity through the term η. If a country is 100% efficient (η = 1), it can utilise all frontier knowledge, otherwise impediments to absorption or internal inducements to slack will cause the country to produce below the frontier.
Following Battese and Coelli (1995), the inefficiency effects are obtained as truncations at zero of the normal distribution $N(\mu_{it}, \sigma_{\upsilon}^2)$, where $\upsilon = -\eta$. Inefficiency is thus specified as:

$$\mu_{it} = z_{it}\delta \qquad \textbf{(6)}$$

where μ_{it} are technical inefficiency effects in the SFA framework and are assumed to be independently, but not identically distributed; z_{it} is a vector of variables which may influence the technical efficiency of a country, and δ is a vector of parameters to be estimated.

In determining the set of variables to include in the technical efficiency vector we draw on the previous literature. It is argued that a key determinant of a country's success in adopting foreign technology is the extent to which it invests in 'imitative' or 'adaptive' research activities (see Geroski, 1995). Griffith et al. (2000) using human capital and R&D to capture these effects, find strong empirical support for this argument in the context of OECD countries. As explained earlier, we include human capital in the production function only and base the efficiency scores reported here on this specification of the simultaneously estimated production function and determinants of efficiency. We do, however, include a variable that may capture human capital influences indirectly; namely the agricultural intensity of the country.[11]

Developing countries have relatively little indigenous R&D capacity, but we seek to capture their absorptive capacity for foreign R&D through their importation of capital goods. Machinery imports embody knowledge of foreign technology and production know-how; the greater these imports the greater the scope for direct absorption of foreign innovations by the importing firms and for spillover of this knowledge to other firms. With greater absorption of foreign technology through capital imports the nearer a country can be to the production frontier and the lower the measured inefficiency.

Imports of capital goods is not the only way in which international trade may affect national efficiency. Other measures of international trade have been used in this literature. Generally, the variables employed come in two main forms : indicators of trade policy openness and measures of trade volume. For instance, Kneller and Stevens (2003) using SFA for a cross-country study of developing countries include the Sachs-Warner (1995) measure of policy-openness to international trade amongst the determinants of efficiency. They find that policy-open countries were more efficient than those that were closed to international trade. Mastromarco (2002) on the other hand, also using SFA, considers the effect of the volume of trade (specifically capital good imports) on efficiency. Again evidence is found to suggest that more open countries have greater efficiency.

We also attempt to determine the importance of trade policy openness in explaining deviations from the frontier. To do so, we use the Sachs and Warner (1995) indicator of openness to international trade, as updated by Wacziarg and Welch (2002). The latter two researchers make use of additional data sources to correct some of the perceived misclassifications of countries in the original study and extend the data period up to 1998. It is this augmented Sachs and Warner indicator that we use to capture the pro-competition and reduced input cost effects of policy openness on efficiency. On the import side, trade liberalisation may reduce inefficiency in a number of ways. The reduction or elimination of non-tariff barriers (NTBs) may reduce the opportunity for rent-seeking activity and the

[11] The estimating programme does allow for a variable to be included in both the frontier and inefficiency determinants. We explored the inclusion of human capital in this way, and it did have the expected negative sign with significance. The variable is however collinear with our agricultural intensity variable and may induce over-identification when included as both an explanator of the frontier and efficiency.

diversion of resources away from productive activities. The shift away from NTBs to the use of tariffs only also allows for increases in competition at the margin for domestic producers vis-à-vis imported goods. This increase in competition in the domestic market, combined with greater access and cheaper imported inputs, provides a stimulus and opportunity to increase efficiency. Further the lowering of the relative price of importables post-liberalisation provides an incentive for more domestic resources to be drawn into exportables production, with a resulting greater proportion of a country's production being subject to competition at world prices. The expectation therefore is that increased trade policy openness will reduce aggregate inefficiency.[12]

We next include a dummy variable (TROP) that takes the value of 1 if the developing country has a tropical climate and 0 if it does not. This variable is intended to capture the effects of climate on public health, and by extension the utilisation and productivity of human resources. Increasing empirical evidence has been adduced which shows physical geographical and climatic factors, along with correlates like disease burden and life expectancy at birth, help explain variations in per capita income levels across countries (see Gallup et al., 1999; Hall and Jones, 1999; Gallup and Sachs, 2000). For example, for a cross-section of countries Hall and Jones found per capita income to be positively correlated with the absolute value of latitude. Additionally, Gallup et al. (1999) in stressing the lower levels of per capita GNP in the tropics, argue that human health and agricultural productivity are adversely impacted upon by tropical climate. In a later paper, Sachs (2000) argued that tropical climates are burdened by many infectious diseases (e.g. malaria) which have much lower incidence and prevalence in temperate ecozones and are much easier to control in these zones.

Finally, it is argued that developing countries may face special problems of agricultural management and are characterised by lower average food output per unit input. There is likely to be greater dependence on subsistence or relatively backward agriculture as agricultural intensity increases. This is likely to involve agriculture activity which is less likely to use fertilisers and new seed varieties. Of course this does not necessarily mean that

[12] Following Rodriguez and Rodrik (2000) we recognise that the Sach and Warner openness variable may capture other elements of policy liberalisation in addition to trade policy. This is of some advantage in the current context, given that capital goods imports might well not be exogenous to trade policy openness. Dealing with endogeneity of explanatory variables within an SFA estimating framework is problematic. The broader policy liberalisation nature of our openness variable may help to reduce the endogeneity problem. By retaining both trade variables we are able to try to distinguish between the foreign technology absorption effect and the domestic efficiency effect.

individual, small farmers are 'inefficient', given the technology and resources available (see Schultz, 1964). Poverty restricts access to alternative technologies and mechanisation etc. Nonetheless, aggregate output for given national resources may be increased through the wider domestic diffusion of existing know-how and by greater commercialisation of agricultural activity. By increasing efficiency and productivity in agriculture the scope for an agricultural surplus and for releasing resources from agriculture to higher productivity activities increases. To test these arguments, as well as account for the fact that for many of the countries in our sample (particularly those from SSA) the agricultural sector has the highest share in GDP, we include this sector's share in GDP as our final determinant of efficiency.[13] Higher agricultural intensity is expected, *ceteris paribus*, to increase 'distance' from the production frontier.[14]

We thus specify the mean level of inefficiency as:

$$\mu_{it} = \delta_0 + \delta_1 AY_{it} + \delta_2 SW_{it} + \delta_3 KM_{it} + \delta_4 TROP_j \qquad \textbf{(7)}$$

where AY refers to the share of agriculture in GDP; SW the Sachs-Warner openness index ; KM is machinery imports ; and TROP the tropical index discussed above.

In summary, if capital imports promote the absorption of technology and openness increases competition, we would expect to find negative coefficients on δ_2 and δ_3, respectively; that is they reduce the distance from the frontier. In contrast, if a higher share of agriculture in GDP as well as having a tropical climate increase inefficiency (or the distance from the frontier) then δ_1 and δ_4 would be positive.

[13] If this variable and the variable TROP are found to be statistically significant, we can reasonably argue that the tropical dummy is not solely picking up factors related to agricultural productivity but is also capturing effects related to the health of the population. As noted in the later discussion of the results, we also explored the use of an alternative input-based measure of agricultural intensity.

[14] Of course this measured 'distance' may be some mixture of aggregate under-utilisation of productive potential and of measurement error. Measurement errors in both inputs and output is no doubt an issue in the present analysis. It is, however, potentially more important where agricultural and in particular subsistence activity is relatively important, since non-marketed output increases in importance.

Data

Data on GDP, the share of agriculture in GDP, labour force and physical capital investment were taken from the World Bank's World Development Indicators (WDI) CD ROM 2000 for the period 1960 to 1998. This data is in constant 1995 US \$. The capital stock data were constructed using the perpetual inventory method. To avoid the problem of initial conditions, initial capital stocks were constructed for 1960 (or the earliest available year). Appendix A provides greater detail of the construction of variables used in the empirical exercise, as well as full data sources. Human capital is measured by mean years of schooling in the population aged 25 and over and is taken from Barro and Lee (2000).[15]

R&D investment data on machinery for the 15 OECD countries were taken from the OECD's ANBERD Database. This data covers the period 1970-1995. Like the physical capital stock, the stock of R&D was computed using the perpetual inventory method. Data on machinery imports for our sample of developing countries were extracted from the United Nations COMTRADE database.

The Sachs-Warner and the tropical indexes were obtained from Wacziarg and Welch (2002) and the World Bank, respectively. Summary statistics of the variables used for our empirical exercise is shown in Table A1 of Appendix A.

3. Results

The parameters of the models defined by (2) and (7) were estimated simultaneously by maximum likelihood (ML) using FRONTIER Version 4.1 (Coelli, 1996) for 57 developing countries over the period 1970-1998. The log-likelihood function for this model is presented in Battese and Coelli (1993) as are the first partial derivatives of this function with respect to the different parameters of the model.[16]

Rather than report each of the coefficients of the translog production function, we report instead the elasticities of output with respect to each of the inputs, E_m. These were calculated in the following manner:

[15] The data in Barro and Lee (2000) are in five-year averages, which we annualised by linear interpolation.
[16] This parameterisation originates in Battesse and Corra (1977).

$$\mathrm{E}_m = \frac{\partial y}{\partial x_m} = \beta_m + \sum_n \beta_{mn} x_{nit} \quad , m = k, l, h, rd^m \qquad \textbf{(8)}$$

The full set of parameters used to determine these elasticities are reported in Table B1 of the Appendix B. Returns to scale (elasticity of scale) is calculated from the sum of the input elasticities as:

$$RTS = \sum_m \mathrm{E}_m \qquad \textbf{(9)}$$

The input elasticities vary both over time and countries, we therefore present the input elasticities and returns to scale calculated for different groups of countries in Table 1. The first row of the table reports the elasticities evaluated at the mean of the data for the entire period and all countries; while rows 2-5 report them for various regional groups. The results appear plausible and compare well with those from the previous literature. At the mean for the entire period the elasticity of output with respect to physical capital is 0.47, for labour 0.24 and for human capital 0.11. The estimated capital elasticity is within the range estimated for developing countries by Koop et al. (1999) using SFA, while the three input elasticities are close to that found by Miller and Upadhyay (2000) for a group of developed and developing countries based on a Cobb-Douglas production function. Finally, the combined elasticity of physical and human capital (0.58) is of a similar magnitude to that found in MRW (1992).

One interesting result in Table 1 relates to the estimated output elasticity of human capital. The estimated elasticity passes through zero; varying between –0.04 in Sub-Saharan Africa and 0.20 in Latin American and the Caribbean, and Asia respectively. This finding is consistent with Pritchett (1996). As argued by Pritchett, the effect of human capital on the economy depends in part upon the institutional and social environment. If the institutional and social structure is such that the returns to education are greater for 'rent-seeking' than 'entrepreneurial' activities, then increases in human capital induce wealth transfer rather wealth creation and increases in GDP. The result for Sub-Saharan Africa is consistent with the presence of a relatively weak institutional environment.

Table 1 : Mean Estimates of Input (K, L, H, R&D) and Elasticity of Scale (RTS)					
VARIABLES					
	K	L	H	R&D	RTS
All countries	0.47*** (0.022)	0.24*** (0.015)	0.11*** (0.035)	0.05*** (0.013)	0.87
Latin America	0.47*** (0.022)	0.31*** (0.017)	0.20*** (0.042)	0.03** (0.013)	1.01
Sub-Saharan Africa	0.39*** (0.024)	0.22*** (0.020)	-0.04 (0.036)	0.06*** (0.015)	0.63
Asia	0.61*** (0.032)	0.11*** (0.023)	0.20*** (0.047)	0.04** (0.018)	0.96
Others	0.40*** (0.019)	0.32*** (0.018)	0.05 (0.034)	0.08*** (0.017)	0.85

Notes: standard errors in parentheses . *** significant at 1%; **significant at 5%.

As expected, foreign R&D contributes positively to the level of output in developing countries. The coefficient indicates that, ceteris paribus, a 1 per cent increase in the stock of foreign R&D will raise the level of output by 0.05 per cent. This elasticity is of a similar magnitude to that found by CHH (1997) for developing countries based on their preferred specification, and Xu and Wang (1999) for OECD countries based on the weighting scheme adopted in this study. The estimates for those two studies are based on TFP growth regressions and employ a different methodology from the one employed in this paper. Our finding thus indicates that technologies embodied in capital goods (machinery) imports are an important source of output growth in developing countries and by extension, trade is an important channel for transferring these technologies from R&D performing countries to these (developing) economies.

In terms of regional country groupings, OTHERS (comprising countries mainly from the Middle East & North Africa) is shown to receive the largest contribution to output (on average) from foreign R&D, followed by the SSA countries. Though these two groups have a higher foreign R&D elasticity than the ASIA group, which comprises the South East Asian NICs that are known to have invested heavily in imitating and adapting technologies embodied in foreign capital goods, the group is not restricted to these economies. It also contains some of the poorer and less technologically advanced developing countries (certainly for the period under review) from South Asia such as Bangladesh, Sri Lanka and Pakistan among others. This will be clearly reflected in our profile below of the most efficient and inefficient countries at different points over the sample period.

Table 1 also shows that the elasticity of scale (RTS) for the group of developing countries as a whole is below 1, i.e. there are decreasing returns to scale. In the case of individual country groupings however, the Latin American and Caribbean grouping exhibit constant returns to scale. Of the country specific time trends (not reported in Table B1), the majority are negative and significant, suggesting technical regression over the period.[17] The robustness of this finding was explored by varying the reference country and by including common periods against which the country time trends could be considered. The finding of generally negative time trends persists. Duffy and Papageorgiou (2000) find similar negative trends for a sample of developed and developing countries over the period 1960-87. Given that the contribution of foreign R&D has tended to be positive over the period, this result seems somewhat surprising. To explain this, we turn to a similar result in Koop et al. (1999). They interpret this result as suggesting that large negative shocks to the economies close to the frontier will tend to move the frontier inwards over time, and in the SFA methodology this will be interpreted as inward shifts of the frontier (or technical regress) [see Koop et al., 1999]. Recall, the estimated production frontier does not measure the position of the global frontier, only the frontier for developing countries. It is likely that the global frontier moved outward over this period. Given the increase in efficiency identified below, this result is also consistent with the bunching of developing country GDP found by Quah (1997).

Efficiency Levels

Table 2 presents efficiency scores across all countries and for the respective regions at four points in time (1970, 1980, 1990 and 1998) as well as the average (and standard deviation) for the entire time period. More detailed information on the countries that make up the sample are presented in Table B2 of Appendix B.

[17] Only Cameroon, Mauritius, Rwanda, Singapore, Tunisia, Uganda and Uruguay have been found to have a positive and significant time trend coefficient. While Hong Kong, Jordan and Senegal also have positive time trends, these are not significantly different from zero.

The table shows a marked increased in the average level of efficiency for the entire group of countries for the period 1970-98, with improvements being higher in the post-1980 period. The average efficiency level increased from 0.76 in 1970, to 0.78 in 1980 through to 0.92 in 1998. This pattern of convergence in efficiency scores is demonstrated clearly in Figure 1. For instance, in 1980 only 36% of the sample had an efficiency score between 0.90 and 1. This increased to 53% in 1990. By 1998, however, 84% of the sample of countries had an efficiency score between 0.90 and 1.[18]

The findings for the entire group of countries mask some country and region specific trends, however. As a regional group, the largest average efficiency gain over the entire period has been in LAC countries. In 1970, the average efficiency level for the LAC group of countries was below the average for all countries (0.73 against 0.76). By 1998 the efficiency level for this group rose to 0.93. Of the countries that make up this group (i.e. LAC) three distinct trends are evident. First, for some countries there were large increases in efficiency over the period; albeit from initially low levels. Honduras, Jamaica, Dominican Republic and Ecuador are included in this group. For a second group of countries, there was a large increase in efficiency between 1970 and 1980 and then small increases thereafter. Brazil, Chile and Paraguay are included in this group. In the final group of Latin American countries, efficiency levels were high on average and remained high. Peru, Uruguay, Venezuela and Mexico form this group (efficiency declined slightly in Mexico and Uruguay).

In contrast to LAC countries, much of the increase in efficiency levels in the Sub-Saharan African group occurred between 1990 and 1998. In fact, at the average, this latter group of countries has recorded the biggest improvement in efficiency levels between 1980 and 1998 compared to the other groups. However, this sharp increase is against the background of a decline in average efficiency level between 1970 and 1980 for the Sub-Saharan Africa group as a whole. Again there is large variation in performance within the group. For example, there were large increases in efficiency in Gambia, Zambia, Mozambique and Niger but falls in efficiency in Zimbabwe, the Democratic Republic of the Congo (formerly Zaire) and Rwanda. In the case of Rwanda, the decline was catastrophic with the efficiency level falling from 0.93 in 1970 to 0.51 in 1998.

[18] Although the degree of convergence is fashioned by how technical progress is modelled, overall convergence is clearly identified for alternative specifications to that reported.

Table 2: Average Efficiency Scores

	1970	*1980*	*1990*	*1998*	*mean*	*s.d.*
All countries	0.76	0.78	0.86	0.92	0.83	0.15
Latin America & Caribbean	0.73	0.82	0.90	0.93	0.85	0.13
Sub-Saharan Africa	0.78	0.63	0.75	0.91	0.74	0.19
Asia	0.78	0.83	0.92	0.96	0.88	0.12
Others	0.83	0.87	0.89	0.88	0.88	0.10

Additionally, the Sub-Saharan countries in which efficiency levels rose did not have high initial levels of efficiency.[19] Indeed as a group, even accounting for the general improvement in efficiency, the Sub-Saharan African countries are much less efficient than the average developing country. For example Gambia, Malawi, Niger and Mozambique all have a mean efficiency score of less than 65 per cent; amongst the lowest of all developing countries in the sample. Finally, across all regions the countries that consistently recorded the highest efficiency scores are concentrated in Asia; the average efficiency score in Korea, Singapore, India, Hong Kong, Indonesia and China being over 90 per cent. As such, while there were notable increases in average efficiency for this group over the period, these changes are less marked than the other regions.[20]

The most efficient and inefficient countries in our sample are shown in Table 3 at four distinct time periods.[21] In 1970 and 1980 respectively, Latin American (e.g. Mexico, Uruguay, Peru) and Asian (e.g. Korea, Singapore, India) countries dominate the group of most efficient countries. Middle East and North African countries (Algeria, Tunisia and Jordan) are also represented, while the Democratic Republic of the Congo (formerly Zaire) is the only SSA country amongst the list of efficient economies.

In 1990 Asian countries overwhelmingly dominate the list of most efficient developing countries; Colombia and Chile are the only two Latin American countries listed. As was indicated earlier and is demonstrated in Fig. 1, the post 1990 period witnessed a general rise

[19] One exception within Sub-Saharan Africa is Mauritius which started with a reasonably high level of efficiency in 1980 (the first decadal value available) and increased it over the period.

[20] The exceptions to this are Bangladesh and Sri Lanka which had efficiency levels of less than 60 per cent in 1980 (51 and 58 respectively) but rose to 97 per cent in 1998.

in the average efficiency scores of developing countries. This convergence in efficiency levels is evidenced by the fact that in 1995 Iran, with an efficiency level of 0.98, is shown to be the most efficient country while Malaysia and Korea with a slightly lower efficiency score of 0.94 are ranked 27th. Additionally, Latin American countries now make up the overwhelming majority of the ten most efficient countries; Singapore and Thailand are the only two countries from ASIA.

Among the countries from the LAC grouping are some (such as Costa Rica, Brazil and Argentina) that never previously featured amongst the most efficient producers.

Among countries listed as the most inefficient in Table 3, SSA countries (e.g. Niger, Mali, Malawi, Rwanda, Mozambique, Togo) dominate this group in all time periods bar one- 1970 - when countries from the LAC region (Honduras, Jamaica, Ecuador, Nicaragua, the Dominican Republic and Paraguay) made up the majority. Indeed since 1970, SSA countries account for at least seven of the ten countries listed as most inefficient in Table 3. This, despite the fact that by 1995 most countries within this regional grouping – Rwanda being the notable exception - had significantly increased their efficiency levels relative to the earlier periods.

Determinants of Technical Efficiency

Turning to the factors used to explain technical inefficiency in Table B1. First, all four variables have the expected sign and are statistically significant at a level below 1% and thus offer significant power in explaining variations in aggregate inefficiency.
Note that the coefficients on the dummy variables can be directly interpreted as the impact on the inefficiency score of a change in country status, holding other things equal; being open reduces the inefficiency score by 0.60 and being a tropical country raises the inefficiency score by 0.57, ceteris paribus. These are substantial intercept effects. In the case of the other two variables we need to consider the estimated coefficient alongside information on the spread of the variable. A doubling of the agricultural share at the mean (9.84% of GDP) and of machinery imports (c. \$330,000 per annum) would respectively

[21] Due to the absence of data on the share of agriculture in GDP in 1998 for Korea, Malaysia and Singapore among others, we use 1995 instead of 1998 for the purpose of making individual country comparisons of efficiency scores.

increase or reduce the inefficiency score by about 0.14, *ceteris paribus*. But the actual spread of the two variables differs. A one standard deviation increase in the agricultural share increases the inefficiency score by 0.18, while a one standard deviation increase in machinery imports reduces the inefficiency score by 0.37.

The results point to a strong influence of international trade on the absorption and efficiency with which foreign technology is utilised. Specifically, a greater orientation towards trade and policy openness as well as increases in actual levels of machinery imports are shown (as expected) to increase national efficiency scores. This result is consistent with those of Griffith et al. (2000), Kneller (2002) and Kneller and Stevens (2002) for OECD countries and Mastromarco (2002) for developing countries.

In terms of the impact of climate and associated factors on inefficiency, our estimation shows that tropical countries are more technically inefficient relative to non-tropical countries. This finding thus lends support to those researchers that argue that aspects of geography and their correlates negatively affect output growth in particular groups of countries. It also mirrors earlier findings by Bloom et al. (2002) and Hall and Jones (1999) of the importance of geography in determining the level of productivity. More interesting in our case is the significance of this variable despite controlling for the share of agriculture in GDP.[22] This result indicates that the TROP variable is not solely capturing the effects on agricultural productivity.

Finally, the positive correlation between the share of agriculture in GDP and the inefficiency variable indicates that increases in the former is associated with higher levels of technical inefficiency. This finding is consistent with the view that the agricultural sector in many developing countries is characterised by both constrained and unconstrained slack in the use of the available technology.

[22] In order to check on the robustness of this finding we experimented with the use of an input-based measure (share of the agricultural labour force in the total labour force). Similar positive and significant coefficients were obtained on both the tropical and agricultural intensity variables.

Table 3: The Ten Most Efficient & Inefficient Countries 1970-95

1970				1980				1990				1995			
Efficient	**Score**	**Inefficient**	**Score**	**Efficient**	**Score**	**Inefficient**	**Score**	**Efficient**	**Score**	**Inefficient**	**Score**	**Efficient**	**Score**	**Inefficient**	**Score**
Korea	0.99	Honduras	0.34	Mexico	0.971	Niger	0.30	Hong Kong	0.97	Malawi	0.55	Iran	0.98	Rwanda	0.39
Mexico	0.982	Zambia	0.40	Jordan	0.97	Malawi	0.33	Korea	0.96	Niger	0.55	Singapore	0.97	Malawi	0.76
Algeria	0.981	Jamaica	0.45	Hong Kong	0.96	Gambia	0.34	Syria	0.96	Rwanda	0.60	Chile	0.97	Togo	0.78
Singapore	0.97	Ecuador	0.47	Tunisia	0.95	Mali	0.47	Malaysia	0.96	Mozambique	0.60	Egypt	0.97	Algeria	0.80
Uruguay	0.962	Nicaragua	0.48	Korea	0.95	Bangladesh	0.51	Singapore	0.95	Gambia	0.67	Ecuador	0.96	Mozambique	0.71
Dem. Rep. of Congo	0.961	Sri Lanka	0.49	Singapore	0.95	Zambia	0.52	Colombia	0.95	Togo	0.68	Thailand	0.96	Cameroon	0.80
Venezuela	0.96	Papua New Guinea	0.56	Uruguay	0.94	Togo	0.53	India	0.95	Papua New Guinea	0.70	Costa Rica	0.96	Niger	0.82
India	0.941	Dom. Repub.	0.59	Peru	0.94	Honduras	0.54	Chile	0.95	Benin	0.71	Brazil	0.96	Dem. Rep. of Congo	0.83
Peru	0.94	Thailand	0.59	Dem. Rep. of Congo	0.94	Mozambique	0.56	Thailand	0.95	Congo Rep.	0.71	Argentina	0.96	Zimbabwe	0.84
Tunisia	0.87	Paraguay	0.65	Colombia	0.93	Jamaica	0.57	Philippines	0.95	Mali	0.72	Venezuela	0.962	Congo Rep.	0.86

4. Conclusions

We use stochastic frontier analysis to examine the role played by international trade, both in determining the position of the technical frontier (through technology transfer) and in explaining deviations from the frontier. The focus on the latter role is a particularly distinctive feature of the work, given the relatively limited recognition in the literature that countries differ in the efficiency with which they use the available technology. This analysis is undertaken for a sample of 57 developing countries over the period 1970-98.

Trade is shown to contribute positively to technology transfer, technology absorption and efficiency. There is also evidence that differences in efficiency levels between the developing countries in our sample have narrowed considerably over time; the narrowing of the efficiency gap coinciding with improvements in the policy environment and trade liberalisation.

In terms of the other traditional inputs determining the technical frontier, human capital is shown not to impact output positively for all countries (notably the SSA countries). Consequently, this possibility should be recognised rather than omitting it from the production function. This finding with respect to human capital suggests support for the interpretation of Pritchett (1996) regarding the role played by this factor in the economic development of developing countries.

With respect to factors other than trade that explains distance from the frontier, geography (specifically climate) as well as agricultural intensity are found to be significant explanatory factors.

Finally, our findings demonstrate that studies which consider only technology transfer or efficiency in explaining productivity differences are likely to be mis-specified.

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APPENDIX A

Data Construction

Gaps in the data were evident for six countries, Chad, Guyana, Madagascar, Mauritania, Pakistan and Syria. We chose to exclude Chad completely from the sample because of this missing data and excluded observations for Guyana (data period now 1976-1983), Madagascar (time period now 1984-1998) and Syria (time period now 1975-1998). Missing observations for Pakistan in 1982 and Mauritania in 1994 were interpolated using surrounding years as a guide.

Physical Capital and R&D Stocks

Estimates of the physical capital stock are generated based on the perpetual inventory method using the pair of equations immediately below. *K* refers to the physical capital stock, Δ the depreciation rate, *I* is investment and g^K the average annual growth rate of investment over the sample period. To overcome problems regarding the assumptions about initial capital stocks, this value was estimated for the first available observation. For most countries this was 1960. This also informed our choice about the depreciation rate, which we set equal to 10 per cent.

$$K_{it} = (1 - \Delta)K_{it-1} + I_{it-1}$$
$$K_{i0} = \frac{I_0}{(g^K + \Delta)}$$

Data on physical capital investment for the developing countries in our sample were obtained from World Bank's World Development Indicators CD ROM 2000.

Estimates of the stock of machinery R&D (R_{it}) in OECD countries necessary to measure technology transfer were calculated in a similar manner (i.e. based on the perpetual inventory method) to the stock of physical capital. The corresponding pair of equations for computing the R&D stock is shown below:

$$R_{it} = (1-\Delta)R_{it-1} + RD_{it-1}$$
$$R_{i0} = \frac{RD_1}{(g^{RD} + \Delta)}$$

In this instance, R refers to the machinery R&D stock, Δ to the depreciation rate (again set at 10%), RD machinery R&D investments and g^{RD} is the average annual growth rate of R&D over the period. Initial R&D stock was also computed in a manner analogous to initial physical capital.

Individual country R&D stocks in US $ PPP were calculated and then aggregated across the 15 available OECD countries. Machinery R&D investments were taken from the OECD ANBERD database for Australia, Canada, Denmark, Finland, France, Germany, Italy, Ireland, Japan, Netherlands, Norway, Spain, Sweden, UK and US. The German data were adjusted to take account of German reunification. This data was available for most countries for the period 1970/3 to 1995. This investment data were extrapolated forward (and in some cases backwards) for missing years by assuming that the rate of growth of R&D was the same in these missing years as the average over the sample period.

The cumulative R&D stock was then weighted by the ratio of the developing countries' machinery imports from developed countries to the GDP of the 15 OECD countries.

Capital Goods Imports

Capital goods import data, Machinery and Transport Equipment (SITC Rev. 2, Sec 7) imports, for 89 developing countries were extracted from the United Nations COMTRADE Database. The data covers the period 1970-2001. The machinery data is also disaggregated by type (e.g. Agricultural; Textile and Leather Making; Metalworking etc.) and is in current US $.

Human Capital

Data on human capital measured as average years of schooling for the population twenty-five and over were obtained from Barro and Lee (2000).

Table A1: Summary Statistics of Variables used in Estimation of Stochastic Production Frontier					
Variable	No. of Obs.	Mean	Std. Deviation	Minimum	Maximum
GDP	1414	23.302	1.695	19.088	27.526
K	1414	23.803	1.719	17.906	28.130
L	1414	15.402	1.510	12.560	20.426
H	1414	1.150	0.637	-1.073	2.326
RD^m (foreign R&D stock weighted by machinery imports)	1414	15.985	1.789	10.134	20.706
KM (Machinery Imports)	1414	12.706	1.759	7.055	17.166
SWOPEN	1414	0.383	0.486	0	1
TROP	1414	0.708	0.455	0	1
AY (% Share of Agriculture in GDP)	1414	2.826	0.914	-2.149	4.192

Note: All variables are in logs except SWOPEN and TROP.

Appendix B

Table B1 : Maximum-Likelihood Estimates for Stochastic Translog Production Function with Inefficiency Component[a]

	Coeff.	*std. error*	*t-stat.*
Production Function			
Constant	19.61	1.50	13.11
k	-1.26	0.23	-5.57
l	0.83	0.18	4.52
h	-1.17	0.35	-3.39
rd^m	0.49	0.16	3.14
k^2	0.05	0.03	1.85
l^2	-0.15	0.02	-9.78
h^2	0.21	0.05	4.56
$(rd^m)^2$	0.06	0.01	6.75
$k*l$	0.08	0.02	4.18
$k*h$	0.09	0.03	3.34
$k* rd^m$	-0.05	0.01	-3.59
$l* h$	-0.02	0.02	-0.92
$l*rd^m$	-0.01	0.01	-0.76
$h* rd^m$	-0.05	0.02	-2.53
LAC	0.78	0.04	19.34
SSA	-0.09	0.04	-2.12
ASIA	0.78	0.05	16.37
Inefficiency Effects			
Constant	1.31	0.20	6.58
SW	-0.60	0.07	-8.63
KM	-0.21	0.02	-12.33
TROP	0.57	0.07	8.40
AY	0.20	0.03	6.34
σ^2	0.13	0.01	9.68
γ	0.96	0.01	108.88
Log-likelihood	662.10		
Countries	57		
Years	29		
Observations	1414		

[a] The dependent variable is the log of GDP. All other variables except SW, TROP and the Regional Dummies are in logs. Country specific time trends not reported.

Table B2: Average efficiency scores and Standard Deviation by Country and Year[1] (1970-1998)

	1970	1980	1990	1995	mean	Std. Dev.	obs
Algeria	0.98	0.91	0.83	0.80	**0.890**	**0.060**	29
Argentina	0.89	0.90	0.88	0.96	**0.915**	**0.039**	29
Bangladesh		0.51	0.81	0.95	**0.783**	**0.157**	19
Bolivia			0.87	0.95	**0.878**	**0.075**	13
Brazil	0.76	0.93	0.93	0.96	**0.913**	**0.046**	29
Cameroon		0.85	0.84	0.80	**0.883**	**0.051**	24
Sri Lanka	0.49	0.58	0.78	0.95	**0.700**	**0.153**	29
Chile	0.74	0.89	0.95	0.97	**0.877**	**0.091**	29
China		0.89	0.95	0.95	**0.937**	**0.020**	24
Colombia	0.89	0.93	0.95	0.94	**0.923**	**0.021**	29
Congo, Rep.			0.71	0.86	**0.773**	**0.130**	14
Congo, Dem. Rep.	0.96	0.94	0.84	0.83	**0.913**	**0.052**	28
Costa Rica	0.76	0.84	0.91	0.96	**0.866**	**0.059**	29
Benin			0.71	0.87	**0.706**	**0.184**	17
Dominican Republic	0.59	0.75	0.83	0.94	**0.805**	**0.105**	29
Ecuador	0.47	0.69	0.90	0.96	**0.769**	**0.147**	29
El Salvador	0.88	0.87	0.87	0.94	**0.869**	**0.069**	29
Gambia, The		0.34	0.67	0.93	**0.592**	**0.218**	24
Ghana	0.72	0.69	0.86	0.94	**0.775**	**0.118**	29
Guatemala	0.66	0.83	0.92	0.94	**0.833**	**0.085**	29
Honduras	0.34	0.54	0.88	0.92	**0.670**	**0.205**	28
Hong Kong		0.96	0.97	0.94	**0.956**	**0.016**	18
India	0.94	0.92	0.95	0.94	**0.933**	**0.015**	29
Indonesia		0.90	0.95	0.95	**0.925**	**0.041**	19
Iran, Islamic Rep.		0.85	0.92	0.98	**0.908**	**0.050**	20
Jamaica	0.45	0.57	0.90	0.95	**0.710**	**0.182**	29
Jordan		0.97	0.93	0.91	**0.933**	**0.046**	23
Kenya		0.64	0.85	0.93	**0.815**	**0.113**	20
Korea, Rep.	0.99	0.95	0.96	0.94	**0.961**	**0.016**	28
Malawi		0.33	0.55	0.76	**0.487**	**0.214**	26
Malaysia	0.79	0.91	0.96	0.94	**0.906**	**0.053**	28
Mali		0.47	0.72	0.88	**0.701**	**0.167**	20
Mauritius		0.86	0.91	0.93	**0.922**	**0.023**	23
Mexico	0.98	0.97	0.93	0.87	**0.943**	**0.043**	29
Mozambique		0.56	0.60	0.88	**0.640**	**0.163**	18
Nicaragua	0.48	0.62	0.78	0.95	**0.705**	**0.124**	27
Niger		0.30	0.55	0.82	**0. 558**	**0.223**	19
Pakistan		0.69	0.91	0.95	**0.782**	**0.144**	27
Panama		0.82	0.90	0.93	**0.890**	**0.045**	19
Papua New Guinea	0.56	0.62	0.70	0.94	**0.712**	**0.107**	28
Paraguay	0.65	0.90	0.95	0.94	**0.870**	**0.091**	29
Peru	0.94	0.94	0.85	0.94	**0.933**	**0.026**	22
Philippines	0.67	0.85	0.95	0.95	**0.865**	**0.078**	29
Rwanda	0.93	0.79	0.60	0.39	**0.683**	**0.166**	29
Senegal	0.88	0.79	0.85	0.88	**0.857**	**0.034**	29
Singapore	0.97	0.95	0.95	0.97	**0.957**	**0.012**	28
Zimbabwe		0.92	0.93	0.84	**0.874**	**0.063**	24
Syrian Arab Republic		0.87	0.96		**0.869**	**0.078**	17

Thailand	0.59	0.81	0.95	0.96	**0.832**	**0.133**	28
Togo		0.53	0.68	0.78	**0.679**	**0.106**	19
Trinidad &Tobago			0.94	0.93	**0.926**	**0.030**	14
Tunisia	0.94	0.95	0.94	0.95	**0.945**	**0.013**	29
Uganda			0.83	0.92	**0.861**	**0.050**	17
Egypt, Arab Rep.		0.92	0.93	0.97	**0.921**	**0.039**	24
Uruguay	0.96	0.94	0.94	0.94	**0.927**	**0.046**	29
Venezuela	0.96	0.80	0.93	0.96	**0.892**	**0.077**	29
Zambia	0.40	0.52	0.76	0.91	**0.656**	**0.190**	29
	0.756	**0.774**	**0.856**	**0.910**	**0.830**	**0.154**	**1414**

1. The mean, standard deviation and number of observations for each country are for the entire period 1970-1998.

Figure 1: Percentage of Countries Within Each Efficiency Decile, 1970-1998