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Technological Backwardness In Agriculture: Is It Due To Lack Of R&D, Human Capital And Openness To International Trade?

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Abstract

In this paper we investigate the relationship between the agricultural technological level and R&D expenditures, human capital and openness to international trade using panel data for a sample of 104 countries and various sub samples over the period 1961-1991. First, we model the unobservable technological level as a dynamic stochastic process whithin a general translog production function framework. Then we relate the implied technological levels to the aforementioned variables. For comparison, alternative specifications of the production and its associated technological process are also considered. We find that the proposed model outperforms all of the alternative specifications. The results suggest that the technological gap between developed and less developed countries in agriculture has increased considerably over this period of time and that, overall, the technological levels are directly related to R&D expenditures, human capital and openness, although this relationship is not robust across the different groups of countries considered.

Resumen

En este artículo se investiga la relación entre el nivel tecnológico agrícola y los gastos en Investigacion y Desarrollo (I&D), capital humano y apertura al comercio internacional en un panel de 104 países durante el periodo 1961-1991. En primer lugar, el nivel tecnológico no observable es modelado como un proceso dinámico estocástico en el contexto de una función de producción translogaritmica. Posteriormente los niveles tecnológicos estimados son relacionados con las variables anteriormente mencionadas. Con fines de comparación también se consideran especificaciones alternativas de la función de producción y del nivel tecnológico, encontrándose que el modelo propuesto es mejor. Los resultados de este estudio sugieren que la brecha tecnológica entre los países desarrollados y en desarrollo se ha incrementado considerablemente durante el periodo de estudio y que en general los niveles tecnológicos se relacionan directamente con los gastos en I&D, capital humano y apertura de las economías, aunque esta relación no es robusta a lo largo de todos los grupos de países considerados.

Palabras Clave: Agricultural production function, Agricultural technology, Dynamic error components models, Non-linear models, R&D expenditures, Human capital, Openness.

Clasificacion JEL: C23, Q16

Introducción

In this paper we investigate the relationship between the agricultural technological level and R&D expenditures, human capital and openness to international trade using cross country information for a sample of 104 countries and various sub samples over the period 1961-1991.

The approach used in this paper differs from most empirical work on the inter country agricultural production function in three important aspects. First, we relax the usual Cobb-Douglas specification and consider the more general translog production function. Second, in this study we attempt to reduce the potential biases due to the heterogeneity among countries by splitting the sample into various sub samples of countries, which in turn will allow us to determine the robustness of the results across different groups of countries. Third, instead of including some available measures of non traditional factors, namely R&D expenditures, human capital and openness, in the production function, we adopt the following empirical strategy. In the first place we model the unobservable technological level as a dynamic stochastic process in the context of a general translog production function specification. Then, in a second stage, we relate the estimated technological levels to R&D expenditures and the other aforementioned factors.

We consider that this empirical strategy avoids potential miss specification of the technological process (and the production function) since in fact this process is not directly observable. Also, it allows the use of a larger time span since the direct inclusion of the non-traditional factors in the production function will severely limit the time span of the sample as some of these variables are only available on a quiquennial basis. For comparison, alternative specifications of the production function and its associated technological process are also considered.

The rest of the paper is organized as follows. In Section 1, we discus various aspects related to the empirics of the inter country agricultural production function and the main determinants of technological progress. In Section 2 we outline the econometric model used to measure the agricultural technological levels as well the testing of some relevant hypothesis. In Section 3 we present the main empirical results. Finally, in Section 4 we conclude.

1.- Background

1.1.- The empirics of the Inter Country Agricultural Production Function

Ruttan (2002) identifies three main stages in the research on international agricultural productivity. In the first stage the focus was mainly on the measurement of partial productivity indexes, such as output per worker or output per acre. In these studies Colin Clark (1940) was a pioneer. We also find the studies by Hayami (1969), Hayami and Inagi (1969), and Hayami, Miller, Wade and Yamashita (1971). In general, they observed the existence of sizeable differences between the less productive countries and the country with the highest productivity.

The second stage is characterized by the estimation of production functions and the construction of multifactor productivity estimates. Based on his previous work, Hayami is also among the first researchers in this stage.[1] Using a Cobb-Douglas specification Hayami and his coauthors estimated an inter country agricultural production function for a sample of 43 countries, divided into two groups: developed and developing countries. They considered five conventional inputs, namely, land, labor, livestock, fertilizers and machinery, and since then these inputs are widely considered in the empirical work on aggregate agricultural production functions. Also, they included two unconventional inputs to proxy for the technological level, which are R&D expenditures and Human Capital. The estimated coefficients were then used to explain the differences between both groups. They found higher input-output elasticities for the developed countries. According to their results, developed countries have increasing returns to scale while developing countries have constant returns to scale. They also make labor productivity comparisons for each group and for each country relative to The United States.

In the third stage, research has dealt with convergence of productivity levels and growth rates among developed and less developed countries and the main results generally indicate a widening of the productivity gaps, although for some particular groups of countries some forms of convergence have been found (Ruttan, 2002).

The present paper is more related to the second stage, although some implications are also derived in terms of convergence of technological levels. The empirical work on the inter country agricultural production function has been considerable and it is worthwhile to mention, in addition to the studies cited before, the contributions of, among others, Evenson and Kislev (1975),

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[1] Hayami and Ruttan (1970) and Kawagoe, Hayami and Ruttan (1985)

Nguyen (1979), Mundlak and Hellihausen (1982), Lau and Yotopoulos (1988), Trueblood (1996), Craig *et al*. (1997) and Mundlak, *et al*. (1997).

It is important to remark, though, that most of the empirical work on aggregate agricultural productivity has relied on the assumption of a Cobb-Douglas production function where the technological levels have been modeled by including the so called non traditional inputs directly into the production function, and generally in addition to a linear time trend.

Given that, in practice, we may have interaction effects among inputs and that the technological process is in fact unobservable, the previous procedure may well suffer from miss specification. It is worth pointing out, though, that in most of the earlier studies the time dimension of the samples is quite limited which in fact has prevented the focusing on dynamic aspects, particularly the dynamics of technology.

Using a data base for 84 countries over the period 1961-1991, Cermeño, Maddala and Trueblood (2003) proposed to model technology as a dynamic stochastic process showing that this model outperforms the usual linear trend representations of the technological levels. However, following the tradition of earlier studies the underlying specification of the production function is Cobb-Douglas which clearly limits the scope of this study, although the authors point out that the approach is compatible with more general specifications of the production function.

In the present study we use a more general approach than in Cermeño *et al.*(2003). In particular, we relax the assumption of a Cobb-Douglas production function using instead the more general translog specification.

1.2.- Productivity and R&D expenditures, Human Capital and Openness

In the earlier studies about productivity and growth, economists have focused on analyzing the role of conventional inputs such as physical capital and labor. However, they found their results unconvincing given that the residual accounted for a large part of the productivity levels. These results motivated the idea of refining the concept and measure of the technological process and introducing other factors as explanatory variables in the production function. Among these factors are investment in research and development (R&D), human capital and openness.[2] Public expenditure on research and development has been used as a proxy variable for technology in the production function. However, as Lydia Zepeda (2001) explains, this variable can have certain limitations since there is not an exact correspondence between research activity on technology and expenditures. Even though technology is produced the scientists could have different goals than the

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[2] Other factors such as social capital, infrastructure or geographic conditions have also been considered.

farmers for developing new inventions and even if the new technology was appropriate the process of adoption can be unequal and take a long time. Nonetheless, some favorable results have been obtained on the technological impact of this measure.

One of the main contributions in this area was probably made by Griliches (1964) who introduced a variable that reflected the contribution of public expenditures in agricultural investment and its effects on productivity, for 39 states of United States and for three different years. He used raw data but the results were surprisingly significant. Later studies have found high return rates to investment in research (above 15%) in many regions and internationally. These are the cases of Evenson and Kislev (1976), Pray and Evenson (1991) for Asia, Rosegrant and Evenson (1992) for India, Block (1994) for Africa, and Alston *et al.* (1995) and Huffman (1998) for United States.

The adoption and expansion of technology are processes that affect research and innovation, so they have also been investigated. The studies on adoption behavior analyze the factors that affect this process once the individual begins to use a new technology. The studies about expansion analyze the penetration of new technology in its potential market. In this respect we can mention the studies of Griliches (1957) and Rogers (1962) about hybrid corn in Iowa.

Another important non traditional factor is, no doubt, human capital. The theoretical foundations of the modern empirical studies related with human capital have their origins in Friedman and Kuznets (1945), Mincer (1958), Miller (1960), Becker (1962) and Ben-Porath (1967), among others. These studies highlight the role of education on the individual income distribution and analyze the process of investment in education and its determinants.

Schultz (1960) was one of the first researchers that related human capital with the "(Solow) residual" in growth accounting studies. Since then, different approaches have been developed to measure the contribution of education to growth. We will mention three of the most important. The first is based on a weighted measure of labor, weighting the type of labor for each education level by its relative market income. The first implementation of this approach was in the context of wage differentials and can be found in Kendrick (1956), where he implied the existence of disequilibrium in the use of labor between industries and a gain in productivity because of changes of low wage to high wage employment.

The second approach is based on the construction of quality indexes of labor which are based on information on work force distribution by educational level and average income. In this approach we emphasize the work of Griliches (1963) for the U.S. manufacturing industry and Jorgenson and Griliches (1967) for the U.S. economy as a whole, as well as the more recent study by Jorgenson, Ho and Fraumeni (1994). These studies find that educational improvement accounts for around a third of total productivity.

The third approach to estimate human capital is developed by Jorgenson and Fraumeni (1992). It is based on the present value of the increments in future income flows produced by education. This approach provides a relevant measure of output and the possibility of computing changes in productivity over time. It is also pointed out that when education is incorporated to gross domestic product, as investment in human capital, labor quality becomes an internal input and it is not possible to use it to measure growth in total productivity, except when the social returns of such investment become greater that the private returns, because of the constraints to capital and the indirect externalities created by education.

Jamison and Lau (1982) analyzed the role of education in agriculture economic efficiency and found that, in countries such as Thailand, Korea and Malaysia, rural education is important to increase production while the role of physical capital was insignificant. However, some studies have reported evidence of low returns to education, especially in those countries that have remained dedicated to agricultural activities. This is the case of the study by López and Valdés (2000) on the determinants of rural poverty in six countries.

Besides R&D and human capital, openness has also been considered an important factor to explain productivity. It has been argued that openness, through international trade, plays an important role for technology transfer between countries. First, it allows technology to be imported thus improving inputs and transmitting knowledge. Second, it opens export markets allowing competition through comparative advantage. Third, it increases the set of available technologies contributing to the process of adoption and diffusion (Hoppe, 2005). In the empirical long term studies openness has been shown to be one of the most important determinants of the speed at which a country adopts technology (Comin, 2003).

It is important to notice, however, that the impact of openness in each country or region is significantly different from the impact found in overall samples. Even though in the world taken as a whole openness has a positive impact this is not always the case for every region as argued, for example, by Miller and Upadhyay (2002). Also, Dodzin and Vamvakidis (2004) have shown that in developing countries technology transfer through openness has a positive effect on the share of production of industrial value added, which happens at the expenses of agricultural share.

2.- Econometric model for agricultural production and technology

Consider the following general specification of the production function:

$$y_{it} = f\left(x_{1,it},\ldots,x_{k,it}\right) + v_{it} \tag{1}$$

Where $y_{it} = \ln\left(\frac{Y_{it}}{X_{0,it}}\right)$ is the natural logarithm of output (Y_{it}) per unit of labor ($X_{0,it}$), $x_{j,it} = \ln\left(\frac{X_{j,it}}{X_{0,it}}\right)$ is the natural logarithm of the quantity of each input $X_j (j = 1, \cdots, k)$ per unit of labor. The term v_{it} represents the technological level, which is assumed to evolve stochastically according to the following process:[3]

$$v_{it} = \mu_i + \theta t + \phi v_{it-1} + \varepsilon_{it}, \tag{2}$$

Where $\varepsilon_{it} \sim iid(o, \sigma_\varepsilon^2)$. The term μ_i represents the individual effects which are assumed fixed, and θt is a common linear time trend.[4] Also, we assume that technology is a trend stationary process; that is $|\phi| < 1$.[5]

The function $f(\cdot)$ in (1) is quite general and needs to be specified explicitly in order to obtain an estimable model. Following the pioneering work by Bernt and Christensen (1973) and Christensen, Jorgenson and Lau (1970, 1971, 1972, 1973, 1975),[6] this function can be approximated by a second order Taylor's series expansion around a given vector of input quantities to obtain the well known translogarithmic production function.[7]

$$y_{it} = \alpha_0 + \sum_j \alpha_j x_{j,it} + \frac{1}{2}\sum_j \beta_j x_{j,it}^2 + \sum_j \sum_{h \neq j} \beta_{jh} x_{j,it} x_{h,it} + v_{it} \tag{3}$$

It is important to note that according to (3) the input-elasticities are not constant and will include both direct and indirect effects. Specifically, for the j_{th} input the elasticity can be expressed as:

$$\eta_{x_j}^y = \alpha_j + \beta_j x_{j,it} + \sum_{h \neq j} \beta_{jh} x_{j,it} x_{h,it} \tag{4}$$

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[3] It is important to note that equation (1) implies that technological progress is disembodied.

[4] Notice that if   = 0, we will have the usual deterministic representation of technology.

[5] In the case   = 1 the technological process will have a unit root with the theoretical implication that the growth rate of *per capita* output will trend over time. We will be back to this point later in this section.

[6] We should also mention two important earlier contributions. One is due to Earl Heady and John Dillon (1961), who introduced a second order polynomial in logarithms thus adding quadratic terms and cross-products to the Cobb-Douglas specification. The other is due to Jan Kmenta (1967), who used a similar specification as an approximation of the CES production function. See Berndt (1990).

[7] This specification does not rely on homogeneity assumptions and does not require *a priori* knowledge of a specific functional form among the levels of inputs and output. Also, it is the most reliable among various alternative specifications. See Guilkey, Lovell and Sickles (1983).

The first two terms in (4) are the direct effects while the last one is indirect and includes the sum of the interactive effects of input j_{th} with all other inputs.[8]

Solving for v_{it} in (3) and substituting in (2) we can obtain:

$$\begin{aligned} y_{it} &= \phi y_{it-1} + (1-\phi L)\sum_{j} \alpha_j x_{it}^{j} + (1-\phi L)\frac{1}{2}\sum_{j} \beta_j x_{jit}^{2} + \\ &(1-\phi L)\sum_{j}\sum_{h \neq j} \beta_{jh} x_{jit} x_{hit} + \tilde{\mu}_i + \theta t + \varepsilon_{it} \end{aligned} \qquad (5)$$

Where $\tilde{\mu}_i = (1-\phi)\alpha_0 + \mu_i$. It is important to remark that this is a non linear dynamic panel specification.[9] Also, notice that estimation of (5) will enable us to identify the parameters of both the translog production function (3) and the technological process (2). The model will be estimated by non linear least squares, which is equivalent to maximum likelihood estimation in this particular case. Estimation will be made using numerical optimization procedures.

Using the estimation results from (5) it is possible to test some relevant hypothesis. First, we can verify whether the translog specification is appropriate or not by evaluating the joint null hypothesis $H_0 : \beta_{jh} = 0; (\forall j, h = 1, \cdots, k)$. If this hypothesis is valid then the usual Cobb-Douglas specification will be appropriate. If not, the interaction effects are significant and the translog specification should be used.

Second, we can evaluate the null hypothesis $H_0 : \phi = 0$, which implies that the technological process does not follow a dynamic process as postulated in this paper, in which case the usual linear trend representation of technology will be appropriate.

Third, we can test for individual specific effects by evaluating the joint null hypothesis $H_0 : \tilde{\mu}_1 = \tilde{\mu}_2 = \cdots = \tilde{\mu}_N$. In all previous cases we can use a Wald test statistic which will be distributed χ^2 with $k(k+1)/2$, 1, and $N-1$ degrees of freedom respectively.

Finally, it is also possible to evaluate if the technological process given by (2) is indeed trend stationary by testing the null hypothesis $H_0 : \phi = 1$ against the alternative hypothesis $H_1 : |\phi| < 1$. However, this test can not be implemented in the usual way since v_{it} has to be estimated from a non linear model and the distribution of the test will be non standard under the null

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[8] Given that the elasticities vary with each observation it is conventional to evaluate them on the mean values of inputs and we will follow this approach.

[9] See Greene (2000), Chapter 10, for a discussion of non linear regression models and the nonlinear least squares estimator.

hypothesis. Cermeño, Maddala and Trueblood (2003) evaluate this hypothesis using critical values tabulated from Monte Carlo simulations and find rejection in most cases.[10] Given this result and the fact that the observed growth rates of *per capita* output do not trend over time, we consider that the assumption $|\phi| < 1$ is justified. As it will be seen later, the estimation results for this parameter will be consistent with this assumption.

3.- Empirical Results

In what follows we briefly describe the empirical strategy, the data and its sources and present the main empirical findings. These include results on the agricultural production technology as well as on the relationship between technological levels and its proposed determinants.

3.1.- Empirical Strategy

In this paper we use the following two-step procedure. First, we estimate model (5) and use the results to make a characterization of the aggregate agricultural production function as well as its associated technological process. Then, in a second stage, we relate the estimated technological level to proposed key variables: R&D expenditures in agriculture, human capital and openness to international trade.

This strategy differs from most studies that include various proxies of the technological levels directly in the estimation of the production function under the name of “non traditional” inputs which. As we argue before, such a procedure can lead to a miss specification of the production function since technology is not directly observable and the question on its determinants can not be solved *a priori* or on the basis of available information. In fact, our procedure attempts to avoid this potential problem by first identifying the unobserved technological levels using a quite general specification of the production function. Once we obtain a measure of the technological levels we proceed to investigate to which extent this process is driven by the aforementioned factors

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[10] An alternative would be to follow a panel cointegration approach as described, for example, in Baltagi (2001) and Baltagi and Kao (2000). However, this approach may require imposing *a priori* the assumption that the relationship between inputs and output is linear, i.e. assuming a Cobb-Douglas production function. Although implementing this approach is beyond the scope of this paper it would be interesting to consider in future research.

3.2.- The data

We use aggregate data for a panel of 104 countries over the period 1961-1991. These data includes price and quality adjusted information on output and the inputs land, labor, fertilizers, livestock and capital, all of which are commonly used in the estimation of inter-country agricultural production functions.[11] We will consider the complete sample as well as the sub-samples: OECD, Centrally Planned Economies (CPE), Latin America (LA), Africa (AF), South East Asia (SEA) and Middle East (ME).[12] The data on R&D Agricultural Expenditures has been obtained from the USDA and is the same used in Tueblood (1996); and the data on human capital is due to Barro and Lee (1993). The data on openness to international trade has been obtained from the Penn World Table Version 6.1 by Heston, Summers and Aten (2002).

3.3.- Brief description

In Table 1 we present the average growth rates of agricultural output and inputs. First of all, while the OECD, CPE and SEA countries experienced the highest growth rates of *per capita* agricultural output, the ME, LA and AF, in that order, experienced the lowest average growth rates. It is interesting to note that overall the inputs Land, Labor and Livestock show slow or even negative patterns of growth, while Fertilizers and Capital show quite faster rates of growth, particularly in those groups of countries with higher average growth rates in *per capita* output.

3.4.- Estimating the inter-country agricultural production function

Tables A1 through A7 in the Appendix show the estimation results for the proposed model. For comparison, we considered various alternative specifications. These are:

(i) Cobb-Douglas with a linear technology trend and common intercept.
(ii) Cobb-Douglas with a linear technology trend and individual specific effects.
(iii) Cobb-Douglas with dynamic technology and individual effects.
(iv) Translog with a linear technology trend and individual effects.
(v) Translog with dynamic technology and individual effects.

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[11] See Trueblood (1996) and Cermeño, Maddala and Trueblood (2003) for details on this data set.

[12] We split the sample in several groups in order to avoid potential biases due to heterogeneity across countries, which in turn will help to evaluate the robustness of the results across different groups of countries. See the Appendix for a list of the countries in each group.

Table 1
Average growth rates of p*er capita* output and inputs, 1961-1991

Group	*Per capita* output	Labor	Land	Fertilizers	Livestock	Capital
OECD	4.23	-2.71	2.79	4.92	2.40	10.62
CPE	3.86	-1.93	1.92	5.88	2.39	10.82
LA	1.80	0.44	0.48	5.63	1.02	7.63
AÁF	0.97	1.24	-0.57	6.17	0.60	7.98
SEA	3.01	0.05	-0.80	7.00	-1.37	17.83
ME	1.82	0.70	-0.04	10.80	-0.10	11.65
WORLD	2.38	-0.25	0.70	6.37	1.06	9.79

It should be mentioned that the specifications (i) and (ii) have been used widely in the empirical literature on the inter-country agricultural production function with the main difference being that in this literature various non conventional inputs such as education, research and infrastructure are also included directly in the production function.[13] As we mentioned before, in this paper we follow instead a two step approach to avoid a potential miss specification of the technological process.

The specification given by (v) is certainly the most general and corresponds to our proposed model. It is important to note that the specifications listed before are nested in various ways. For example, specification (i) is a restricted version of (ii), and model (iii) is a restricted case of (v). Also (iv) is a particular case of (v) when $\phi = 0$, in which case our proposed model for technology will not be valid. The same relationship holds between specifications (iii) and (ii). In terms of estimation, it is important to remark, once again, that models (iii) and (v) are non linear and consequently they will be estimated by non linear least squares using numerical optimization procedures. Models (i), (ii) and (iv) are linear and will be estimated by OLS or LSDV. We also report goodness of fit measures for each model as well as the well known Durbin-Watson test for first order residual autocorrelation.

Clearly the proposed specification, model (v), is the best on the basis of the adjusted-R^2, sum of squared residuals, and the values of the Durbin-Watson statistic, which are relatively close to 2. The test for the null hypothesis of a Cobb-Douglas specification is rejected implying that the relationship between inputs and output is more properly captured by a translog specification. Also, the parameter ϕ is found highly statistically significant and is positive but less than one in all cases, which is consistent

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[13] See Trueblood (1991).

with our assumption that the technological process is trend stationary. It is important to remark that except under our proposed dynamic specifications of technology, given by models (iii) and (v), in all other cases there are serious autocorrelation problems, even when the translog specification (iv) is considered. We therefore conclude that the results widely support model (v) and we use this model to characterize the inter country agricultural production function and its associated technological level.

In Table 2, we present estimates of the input elasticities which have been calculated using equation (4). Notice that in all cases the elasticities were evaluated at the mean values of the inputs.[14] For the complete sample (WORLD), the elasticities of land and fertilizers resulted negative which is consistent with the negative interactive effects of these inputs. Livestock and Capital have positive elasticities (0.28 and 0.41). The same calculations vary considerably by groups of countries being worthwhile to mention that the input elasticities are all positive for the OECD and Middle East (ME) countries.

Table 2
Estimated Input Elasticities

Group	Land	Fertilizers	Livestock	Capital
OECD	0.2562	0.0505	0.3672	0.7062
CPE	2.3830	-0.3833	-0.4888	-0.2967
LA	-0.0520	-0.0327	0.2455	0.2167
AAF	3.0628	-0.1112	-1.1751	0.5460
SEA	10.9559	-0.4841	-2.3076	0.9630
ME	2.3022	0.6284	0.4762	0.2004
WORLD	-0.1664	-0.0580	0.2792	0.4095

Overall, we find that Land is positively related to output in all groups of countries but Latin America. Fertilizers have a positive elasticity only in the cases of the OECD and Middle Eastern countries (ME). Similarly, Livestock is positively related to output only in the cases of OECD, LA and ME. Finally, the elasticity of Capital is positive in all cases except the Centrally Planned Economies (CPE).

It is important to highlight the finding that Land and Capital each consistently has in all cases but one a positive effect on Output, implying that changes in arable land per worker or in its quality, along with the mechanization of agriculture have had important effects on agricultural productivity.

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[14] In interpreting these eleasticities it is important to take into account that (i) They have been evaluated at the mean values of inputs for each group of countries and (ii) The output and all inputs are *per capita*.

3.5.- Characterizing the technological levels

Regarding technology, we have obtained highly significant estimates of the parameter ϕ, which validates the dynamic specification proposed in this paper. In particular, the results allow us to characterize the technological process as trend stationary. We observe that the SEA group shows the highest level of persistence of technology while the lowest levels correspond to the CPE and ME groups. Also, the hypothesis of no individual specific effects is rejected in all cases implying heterogeneity in the levels of technology within each group of countries due to unobserved country specific factors.

Another interesting finding is that the time trend is not always significant but overall it ranges between -0.002 in the case of ME (but not significant) and 0.0039 for the CPE. The results suggest that the common autonomous technological growth process has been considerably slow over the period under study.

In Figure 1, we plot the average estimates of the technological levels for each of the samples.[15] The most striking results are that the technological gap between the OECD group and all other groups is considerable and that the patterns over time suggest divergence of technological levels rather than convergence.

3.6.- Are technological levels related to R&D, human capital and openness?

Once we have estimated the inter-country agricultural production function and its associated technological level we investigate to which extent the R&D expenditures in agriculture, human capital and openness, which are usually considered to be the key determinants of technological progress, can explain or at least be related to technology. Unfortunately, the data on R&D expenditures in agriculture and human capital is available on a quinquennial basis and only for the period 1970-1985 which leaves us with only four observations over time. Also, data for the proposed variables is available only for 76 countries out of the 104 countries considered originally, which has forced us to exclude all Centrally Planned Economies as well as several

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[15] The results are derived as follows. Adding over the cross-sectional dimension of equation (2) and dividing by *N* we can obtain the following expression for the average technological level at time *t*: $\bar{v}_t = \bar{\mu} + \theta t + \phi \bar{v}_{t-1} + \bar{\varepsilon}_t$. Where $\bar{v}_t = (1/N)\sum_{i=1}^{N} v_{it}$ and $\bar{\mu} = (1/N)\sum_{i=1}^{N} \mu_i$. Assuming that $\bar{\varepsilon}_t = 0$, since this is an average of random disturbances and using the corresponding parameter estimates we can obtain the estimated average technological levels shown in Figure 1.

countries from Africa from the regressions on the determinants of technological levels.

In Table 3 below we present the estimation results. We have estimated panel regressions for each of the groups and for the complete sample. In all cases we have included individual specific fixed effects.

Table 3
Determinants of Technology, 1970-1985

Sample	OECD	LA	AF	SEA	ME	WORLD
R&D	0.0062 (0.010)	0.0416*** (0.015)	0.0586*** (0.019)	0.1368** (0.048)	-0.0645*** (0.011)	0.0284*** (0.006)
Human Capital	-0.0096** (0.004)	0.0249** (0.012)	-0.0272 (0.018)	0.1012*** (0.026)	0.0202* (0.010)	0.0134*** (0.003)
Openness	0.0042*** (0.001)	0.0003 (0.001)	-0.0010*** (0.000)	0.0012 (0.002)	0.0008** (0.000)	0.0005*** (0.000)
N of Countries	22	21	18	6	9	76
Adjusted R^2	0.99	0.99	0.99	0.99	0.99	0.99
Durbin-Watson	2.04	1.85	2.11	1.75	2.42	1.73

The results are based on panel regressions with country specific fixed effects of the technological levels estimated in the first stage on the specified variables. We use the two-step FGLS estimator under groupwise heteroskedasticity. All of the samples consist of only 4 quinquennial observations.

For the complete sample (WORLD) the evidence supports a positive relationship between the estimated technological levels and the three main determinants considered in this paper. Clearly R&D expenditures, Human Capital and Openness, all have a positive impact on the technological levels. When the sample is divided into groups we find some important differences. It is worth mentioning that in the cases of Latin America (LA) and South East Asia (SEA) we find positive coefficients for all three factors. However, only R&D and Human Capital resulted significant in the cases of LA, SEA and ME groups of countries.

R&D expenditures resulted significant for LA, AF and SEA while surprisingly it did not resulted significant for the OECD and is negative in the case of the ME sample. The measure of human capital resulted positive and significant in the cases of LA, SEA, ME and WORLD while for AF it does not seem related to technology and for the case of the OECD a weakly significant negative relationship is found. Finally, we can see that in all groups of countries but AF openness is positively related to the technological levels but only in the cases of OECD and ME this relationship is significant. In the case of AF, we have found a negative and significant relationship which may be indicating a perverse effect of openness on agricultural technological development in this region.

An important implication of the preceding results is that there seem to be important differences among groups of countries, both in terms of sign and magnitude, regarding the forces that may have driven their technological processes. This suggests that care should be taken when making generalizations based on regressions fitted to wide samples of countries. On the other hand, it is important to remark that the time span of the sample for the regressions shown in Table 3 consists of only 4 quinquennial observations and, therefore, the results may change sensibly if a longer time span is considered. Further investigation over wider time spans is certainly necessary in order to evaluate the robustness of the results found in this paper in order to derive more reliable forecasts and/or policy implications.

Conclusions

In this paper we investigated the relationship of R&D expenditures, human capital and openness with the technological levels in agriculture. We have proposed a two step empirical strategy that consists of first identifying technology as a dynamic process and then relating this process to the aforementioned variables which are considered to be the key determinants of technological progress. We have shown that the translog specification of the inter country agricultural production function outperforms the traditional Cobb Douglas specification finding some evidence that mechanization and, particularly, changes in land per worker, which includes changes in land quality have had important effects in agricultural productivity. The results of this study also suggest that the technological levels can indeed be modeled as trend stationary dynamic processes, although the technological gaps between the OECD group and the other groups of countries seem to have widened over time. In terms of the forces that have driven the technological process, for the overall sample we have found the expected positive relationship between technological levels and R&D, human capital and openness to international trade. However, when looking at individual groups of countries this relationship is not robust which suggests that care should be taken when making inferences on the basis of wide samples of countries. One of the most striking finding is that R&D expenditures and openness may have been negatively related to technological levels in the cases of the Middle East and Africa respectively. However, given that the time dimension of the samples is very limited, additional research considering longer time spans is necessary in order to formulate more reliable policy implications.

References

Alston J.M., G.M.Norton and P.G. Pardey (1995), *Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*, Cornell University Press, Ithaca, NY.

Adelman, Irma and C. Morris (1988), *Contributions to economic analysis: Interactions between Agriculture and Industry during the nineteenth Century, The Agrotechnological System Towards 2000*, North Holland.

Baltagi, B.H. (2001), *Econometric Analysis of Panel Data*, Second Ed., John Wiley.

Baltagi, B.H. and C. Kao (2000), "Nonstationary panels, cointegration in panels and dynamic panels: A survey" *Advances in Econometrics*, 15, pp.7-51.

Barro, R.J. and Jong-Wha Lee (1993), "International Comparisons of EducationalAttainment," *Journal of Monetary Economics*, 32, pp.363-394.

Becker G.S. (1962), "Investment in Human Capital: A Theoretical Analysis", *Journal of Political Economy*, 70, pp. 9-49.

Ben-Porath, Y. (1967), "The production of Human Capital and the Life Cycle of Earnings", *Journal of Political Economy*, 75, pp. 352-65

Berndt, E., (1991*), The Practice of Econometrics, Classic and Contemporary*, Addison-Wesley.

Berndt, E. and L. Christensen (1973), "The Translog Function and the Substitution of Equipment, Structures and Labor in U.S. Manufacturing, 1929-1968," *Journal of econometrics*, 1, pp. 81-114.

Block, S. (1994), "A new view of agricultural productivity in Sub-Saharan Africa," *American Journal of Agricultural Economics*, 76, pp. 619-624.

Cermeño Rodolfo, G.S. Maddala and M. Trueblood (2003), "Modeling Technology as a Dynamic Error Components Process: The case of the Inter-country Agricultural Production Function," *Econometric Reviews*, 22(3), pp. 289-306.

Chambers, Robert G. (1988), *Applied Production Analysis: a dual approach*, Cambridge University Press.

Christensen, L.R., D.W. Jorgenson and L. J. Lau (1970), "Conjugate Duality and the Trascendental Logaritmic Production function", unpublished paper presented at the Second World Congress of the Econometric Society, Cambridge, England.

________ (1971), "Conjugate Duality and the Trascendental Logaritmic Production function", *Econometrica*, 39(4), pp. 255-256.

________ (1972), "Conjugate Duality and the Trascendental Logaritmic Production Frontiers", Discussion Paper 238, Cambridge, Mass., Harvard Institute of Economic Research.

________ (1973), "Trascendental Logaritmic Production Frontiers", *The Review of Economics and Statistics*, 55(1), pp. 28-45.

________ (1975), "Trascendental Logaritmic Utility Functions," *The American Economic Review*, 65, pp. 367-383.

Comin, D., B. Hobijn (2003), "Cross-Country Technology Adoption: Making the Theories Face the Facts", C.V. Starr Center for Applied Economics, New York University working papers.

Craig, B., Pardey, P. and J. Roseboom (1997), "International productivity patterns: accounting for input quality, infrastructure and research", *Amer. J. of Agricultural Economics*, 79, 4, pp. 1064-1076.

Dodzin, S., A. Vamvakidis (2004), "Trade and Industrialization in Developing Economies", *Journal of Development Economics*, 75(1), pp. 319-28.

Evenson R.and Y. Kislev (1976), "A stochastic model of applied research," *Journal of Political Economy*, 84(2), pp. 265-281.

________ (1975), *Agricultural Research and Productivity*, New Haven: Yale University Press.

Färe Rolf, S. Grosskopf y M. Norris (1994), "Productivity Growth, technical progress, and Efficiency Change in Industrialized countries", *The American Economic Review*, 84(1), pp. 66-83.

Fawson, Chris, C. R. Shumway y R. L. Basmann (1990), "Agricultural Production Technologies with Systematic and Stochastic Technical Change", *American Journal of Agricultural Economics*, 72, 1, pp. 182-199.

Friedman M. and S. Kuznets (1945), *Income from independent Professional Practice*, New York: National Bureau of Economic Research.

Greene, William H.(2000), *Econometric Analysis*, 4th Edition, Prentice Hall.

Griliches Zvi (1957), "Hybrid Corn: An Exploration in the Economics of technological change", *Econometrica*, 25(4), pp. 501-522.

________ (1963), "The sources of Measured Productivity Growth: United States Agriculture 1940-1960", *Journal of Political Economy*, 71(4), pp. 331-346.

________ (1964), "Research Expenditures, Education and the Aggregate Agricultural Production Function", *American Economic Review*, 54(6), pp. 961-974.

________ (1997), "Education, Human Capital and Growth: "A personal perspective", Journal of Labor Economics, 15(1), S330-S344

________ (1970), "Notes on the role of education in production functions and growth accounting", in Lee Hansen ed. *Education and Income*, National Bureau of Economic Research Studies in Income and Wealth, Vol 35, Columbia University Press, Columbia.

Guilkey, D.K., Lovell, C.A.K., and R.C. Sickles (1983), "A Comparison of the Performance of Three Flexible Functional Forms", *International Economic Review*, 24(3), pp. 591-616.

Hayami, Yujiro, (1969), "Industrialization and Agricultural Productivity: An International and Comparative Study", *Developing Economies*, 7, pp. 3-21.

Hayami, Yujiro y Kinuyo Inagi (1969), "International Comparisons of Agricultural Productivity", *Farm Economist*, 11, pp. 407-419.

Hayami, Miller, Wade y Yamashita (1971), "An International Comparison of Agricultural Production and Productivities", University of Minnesota Agricultural Experiment Station Technical Bulletin 277.

Hayami Y. and V. Ruttan (1985), "The intercountry agricultural production function and productivity differences among countries", *Journal of Development Economics*, 19, pp. 113-132.

________ (1991), *Agricultural Development, an International Perspective*, Johns Hopkins University Press.

Heady, Earl O. y John L. Dillon (1961), *Agricultural Production Functions*, Iowa State University Press.

Heston, Alan, Robert Summers and Bettina Aten (2002), *Penn World Table Version 6.1,* Center for International Comparisons at the University of Pennsylvania (CICUP), October.

Hoppe, M. (2005), "Technology Transfer Through Trade", Fondazione Eni Enrico, Mattei working paper No. 19.

Huffman W.E. (1998), "Finance, organization and impacts of U.S. agriculturalresearch: future prospects", document prepared for the conference Knowledge Generation and transfer: implications for agriculture in the 21st Century, University of California, Berkley, june 18-19.

Jamison D.and Lau, L. (1982), Farmer education and farm efficiency. The World Bank.

Jorgenson D.W. and Z. Griliches (1967), "The explanation of productivity change", *Review of Economic Studies*, 34, pp. 249-283.

Jorgenson D.W. and Fraumeni B. (1992), "Investment in Education and U.S. Economic Growth", *Scandinavian Journal of Economics*, 94, S51-S70.

Kaneda, Hiromitsu (1982), "Specification of Production functions for analyzing technical change and factor inputs in agricultural development", *Journal of Development Economics*, 11, pp. 97-108.

Kmenta, Jan (1967), "On Estimation of the CES Production Function", *International Economic Review*, 8(2), pp. 180-189.

Kendrick, J.W. (1956), *Productivity Trends: Capital and Labor*, National bureau of Economic Research, New York.

Lopez, R. and Valdes, A. (2000), *Rural poverty in Latin America: Analytics, new empirical evidence, and policy*, Macmillan Press, Londres.

Mincer, J. (1958), "Investment on Human Capital and Personal Income Distribution", *Journal of Political Economy*, 66, pp. 281-302.

Miller, H.P. (1960), "Annual and Lifetime income in relation to education", American, *Economic Review*, 50, pp. 962-986.

Miller,S., M. Upadhyay, (2002), "Total Factor Productivity, Human Capital and Outward Orientation: Differences by Stage of Development and Geographic Regions", University of Connecticut, Dep. of Economics working papers No. 33.

Mundlak Yair and R. Hellinghausen (1982), "The Intercountry Agricultural Production Function: Another view", *Amer. J. of Agricultural Economics*, 64, 4, pp. 664-672

Mundlak (2000), Agriculture and Economic Growth, Theory and Measurement, Cambridge University Press.

Nguyen, Dung (1979), "On Agricultural Productivity Differences among Countries," *American Journal of Agricultural Economics*, 61, 3, pp. 565-570.

Pray, C.E. and Evenson, R.E. (1991), “Research effectiveness and the support base for national and international agricultural research and extension programs”, in R.E. Evenson & C.E. Pray, Eds. *Research and productivity in Asian agriculture*, Cornell University Press, Ithaca.

Rogers, E. (1962), *Diffusion of Innovation*, Free Press of Glencoe, New York.

Rosegrant, M.W. and Evenson, R.E. (1992), “Agricultural productivity and sources of growth in South Asia”, *Amer. J. of Agricultural Economics*, 74, pp. 757-761.

Ruttan Vernon (2002), “Productivity Growth in World Agriculture: Sources and Constraints”, *Journal of Economic Perspectives*, 16, 4, pp. 161-184.

Schultz (1960), “Capital formation by education,” *J. of Pol. Economy*, 68, pp. 571-583.

________ (1964), *Transforming traditional agriculture*, Yale University Press, New Haven.

Trueblood, M. A. (1996), “An Intercountry Comparisson of Agricultural Efficiency and Productivity”, *Ph.D. dissertation*, University of Minnesota.

________ (1991), “Agricultural Production Functions estimated from aggregate inter-country observations: a selected survey”, United States Department of Agriculture, Economic Research Service, Washington D.C.

Zepeda L. (2001), “Agricultural Investment, Production Capacity and Productivity” in Lydia Zepeda ed. *Agricultural Investment and Productivity in Developing Countries*, FAO, Economic and Social Development Paper No. 148.

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APPENDIX

GROUPS OF COUNTRIES

OECD. 23 countries: Australia, Austria, Belgium-Luxemburg, Canada, Denmark, Finland, France, Germany, Greece, Island, Ireland, Italy, Japan, Holland, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States of America

CENTRALLY PLANNED ECONOMIES (CPE). 10 countries: Albania, Bulgaria, China, Cuba, Czechoslovakia, Hungary, Popular Republic of Korea, Poland, Rumania, Soviet Union and Yugoslavia.

LATIN AMERICA (LA). 23 countries: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Surinam, Trinidad y Tobago, Uruguay and Venezuela.

AFRICA (AF). 29 countries: Algeria, Angola, Benin, Botswana, Burkina Faso, Cameroon, Côte d'Ivoire, Egypt, Ethiopia, Ghana, Lesotho, Kenya, Madagascar, Malawi, Mali, Mauritania, Morocco, Mozambique, Nigeria, Senegal, Sierra Leona, South Africa, Sudan, Tanzania, Zaire, Zambia and Zimbabwe.

SOUTH EAST ASIA (SEA) Includes 6 countries: Korean Republic, Malaysia, Philippines, Singapore, Thailand and Indonesia.

MIDDLE EAST (ME) Includes 13 countries: Afghanistan, Bangladesh, India, Iran, Iraq, Israel, Jordan, Myanmar, Nepal, Pakistan, Saudi Arabia, Sri Lanka and Syria.

Table A1
World

Model:	**(i)**	**(ii)**	**(iii)**	**(iv)**	**(v)**
Constan**t**	4.3400 (48.63)				
ϕ	-		0.8782 (101.42)		**0.7842** **(70.53)**
θ	-0.0079 (-8.95)	0.0051 (6.71)	0.0018 (7.45)	0.0040 (6.18)	**0.0010** **(2.96)**
α_L	0.3229 (27.69)	0.4920 (13.97)	0.1878 (6.35)	0.7708 (8.31)	**0.6543** **(4.26)**
α_F	0.1960 (18.85)	0.0370 (5.77)	0.0131 (2.59)	-0.1402 (-4.31)	**0.0149** **(0.44)**
α_{LS}	0.1274 (8.93)	0.1017 (2.86)	0.0765 (3.76)	-0.7448 (-8.65)	**-0.4699** **(-4.43)**
α_K	0.1484 (19.01)	0.1111 (12.24)	0.0395 (3.18)	0.2664 (9.88)	**0.0316** **(0.79)**
β_L				0.0458 (2.04)	**-0.0066** **(-0.15)**
β_F				0.0285 (7.86)	**0.0169** **(4.42)**
β_{LS}				0.1661 (12.59)	**0.0960** **(5.92)**
β_K				0.0041 (2.13)	**0.0244** **(7.42)**
β_{LF}				-0.0574 (-7.76)	**-0.0279** **(-3.50)**
β_{LLS}				-0.0946 (-7.70)	**-0.0559** **(-2.75)**
β_{LK}				0.0678 (11.43)	**0.0266** **(2.37)**
β_{FLS}				0.0183 (3.71)	**-0.0036** **(-0.70)**
β_{FK}				0.0078 (3.61)	**0.0007** **(0.22)**
β_{LSK}				-0.0417 (-9.56)	**-0.0126** **(-1.88)**
Adjusted R^2	0.8769	0.9860	0.9963	0.9920	**0.9965**
RSS	703.3991	77.3259	20.1076	44.2080	**18.8101**
DW statistic	0.0487	0.3145	2.4101	0.5605	**2.3469**
Test for no indiv. effects $H_0 : \tilde{\mu}_i = \tilde{\mu}_j$		-	269.31 (0.0000)	-	**414.55** **(0.0000)**
Test Cobb-Douglas $H_0 : \beta_j = \beta_{jh} = 0$				1755.16 (0.0000)	**310.50** **(0.0000)**

Models (i), (ii) and (iv) are estimated by conventional linear panel data techniques. Models (iii) and (v) are non linear and they are estimated by NLS which are equivalent to MLE, using numerical optimization procedures.

Table A2
OECD

Model:	**(i)**	**(ii)**	**(iii)**	**(iv)**	**(v)**
Constant	3.2889 (36.06)				
ϕ			0.8497 (44.69)		**0.7429** **(28.48)**
θ	0.0095 (5.03)	0.0186 (13.39)	0.0027 (4.10)	-0.0047 (-2.65)	**0.0008** **(0.93)**
α_L	0.145 (14.33)	0.050 (2. 25)	0.0110 (0.42)	(0.7707) (3.56)	**(0.5973)** **(1.97)**
α_F	0.5363 (18.46)	(0.1682) (6.45)	0.0559 (2.57)	-0.0924 (-0.75)	**-0.2500** **(-1.79)**
α_{LS}	0.2027 (11.30)	0.3499 (9.95)	0.2779 (5.19)	-0.5528 (-4.10)	**-0.5472** **(-2.27)**
α_K	-0.0239 (-1.28)	0.0452 (3.83)	0.1358 (4.38)	-0.2136 (-3.37)	**-0.1036** **(-0.99)**
β_L				0.2821 (7.46)	**0.1065** **(1.89)**
β_F				-0.1171 (-4.22)	**-0.0011** **(-0.03)**
β_{LS}				0.1322 (9.48)	**0.1009** **(2.75)**
β_K				0.0076 (0.94)	**0.0318** **(1.56)**
β_{LF}				-0.0932 (-4.64)	**-0.0546** **(-2.44)**
β_{LLS}				-0.0864 (-3.57)	**-0.0799** **(-2.33)**
β_{LK}				0.0276 (2.25)	**0.0429** **(2.55)**
β_{FLS}				0.0238 (1.07)	**0.0305** **(1.42)**
β_{FK}				0.1022 (6.33)	**0.0179** **(0.79)**
β_{LSK}				-0.0401 (-3.68)	**-0.0214** **(-1.31)**
Adjusted R^2	0.8965	0.9874	0.9966	0.9937	**0.9968**
RSS	72.1599	8.5128	2.1697	4.1619	**2.0463**
DW statistic	0.0644	0.3139	2.4158	0.6703	**2.3111**
Test for no indiv. effects $H_0 : \tilde{\mu}_i = \tilde{\mu}_j$			74.06 (0.000)	-	**103.50** **(0.000)**
Test Cobb-Douglas				742.7011 (0.000)	**71.99** **(0.000)**

$H_0 : \beta_j = \beta_{jh} = 0$					

See Note on Table 1A

Table A3
Centrally planned economies (cpe)

Model:	**(i)**	**(ii)**	**(iii)**	**(iv)**	**(v)**
Constan**t**	3.9171 (20.88)		-	-	-
ϕ			0.7428 (18.11)	-	**0.5589** **(11.08)**
θ	0.0029 (1.03)	0.0125 (4.11)	0.0025 (2.38)	0.0121 (3.92)	**0.0039 (2.64)**
α_L	0.4396 (8.38)	0.5763 (9.72)	0.4532 (4.94)	3.1769 (3.19)	**3.8073 (2.87)**
α_F	0.3066 (13.46)	0.0946 (5.39)	0.0652 (4.35)	0.2169 (0.74)	**0.0842 (0.33)**
α_{LS}	0.1795 (7.62)	0.2111 (3.10)	0.3700 (3.72)	-0.8781 (-0.85)	**-1.7026** **(-1.14)**
α_K	0.0102 (0.52)	0.0387 (2.51)	0.0563 (2.18)	-0.1150 (-0.52)	**0.0155** **(0.052)**
β_L				0.59 (4.93)	**0.7183 (3.82)**
β_F				0.0714 (3.69)	**0.0412 (1.79)**
β_{LS}				0.2219 (1.19)	**0.3963 (1.45)**
β_K				0.0333 (2.60)	**0.0301 (1.50)**
β_{LF}				-0.0552 (-0.98)	**-0.0766** **(-1.65)**
β_{LLS}				-0.2836 (-1.86)	**-0.4125** **(-1.96)**
β_{LK}				-0.0662 (-1.50)	**-0.0432** **(-0.76)**
β_{FLS}				-0.0474 (-1.05)	**-0.0364** **(-0.85)**
β_{FK}				-0.0139 (-0.80)	**0.0137** **(0.77)**
β_{LSK}				-0.0045 (-0.13)	**-0.0388** **(-0.82)**
Adjusted R^2	0.9538	0.9933	0.9968	0.9957	**0.997**
RSS	13.26	1.88	0.85	1.17	**0.78**
DW statistic	0.14	0.56	2.4	0.91	**2.22**
Test for no indiv. effects $H_0 : \tilde{\mu}_i = \tilde{\mu}_j$			46.82 (0.000)		**70.91** **(0.000)**

Test Cobb-Douglas $H_0 : \beta_j = \beta_{jh} = 0$			-	265.763 (0.000)	**47.37** **(0.000)**

See Note on Table 1A

Table A4
Latin America (LA)

Model:	**(i)**	**(ii)**	**(iii)**	**(iv)**	**(v)**
Constan**t**	3.5729 (41.05)				
ϕ			0.8668 (46.78)		**0.8300** **(41.88)**
θ	-0.0038 (-3.58)	0.0078 (5.34)	0.0010 (2.62)	0.0066 (4.14)	**0.0011** **(2.29)**
α_L	0.2816 (12.24)	0.2824 (6.92)	0.4408 (5.17)	1.4043 (4.79)	**1.19** **(1.73)**
α_F	0.0079 (0.91)	0.0882 (8.84)	-0.0010 (-0.16)	0.2653 (2.96)	**0.0348** **(0.52)**
α_{LS}	0.2723 (22.60)	0.2310 (5.43)	0.0353 (1.56)	-1.34 (-5.27)	**-0.5376** **(-1.86)**
α_K	0.1994 (20.93)	0.0085 (0.46)	0.0407 (1.53)	-0.2740 (-2.51)	**-0.4232** **(-2.23)**
β_L				0.1122 (1.32)	**0.0403** **(0.21)**
β_F				0.0328 (3.93)	**0.0027** **(0.40)**
β_{LS}				0.2092 (5.32)	**0.057** **(1.27)**
β_K				0.0287 (2.60)	**0.0325** **(2.15)**
β_{LF}				-0.005 (-0.23)	**-0.0041** **(-0.23)**
β_{LLS}				-0.1631 (-4.07)	**-0.0611** **(-0.77)**
β_{LK}				0.009 (0.52)	**-0.0437** **(-1.11)**
β_{FLS}				-0.0231 (-1.75)	**-0.0063** **(-0.67)**
β_{FK}				-0.0135 (-1.59)	**0.0020** **(0.32)**
β_{LSK}				0.0166 (0.98)	**0.0338** **(1.23)**
Adjusted R^2	0.9081	0.9778	0.9938	0.9826	**0.9939**
RSS	36.10	8.46	2.26	6.52	**2.21**
DW statistic	0.087	0.418	2.119	0.541	**2.108**
Test for no indiv. effects $H_0 : \tilde{\mu}_i = \tilde{\mu}_j$			66.08 (0.000)		**72.96** **(0.000)**
Test Cobb-Douglas $H_0 : \beta_j = \beta_{jh} = 0$				311.34 (0.000)	**19.75** **(0.032)**

See Note on Table 1A

Table A5
Africa (AF)

Model:	**(i)**	**(ii)**	**(iii)**	**(iv)**	**(v)**
Constan**t**	5.4551 (74.28)				
ϕ			0.7251 30.06		**0.7009** **(27.99)**
θ	-0.0067 (-4.72)	0.0096 (8.24)	0.0021 (3.09)	0.0055 (4.640)	**0.0014** **(1.97)**
α_L	0.379 (18.50)	0.7493 (14.37)	0.6745 (7.08)	1.1924 (4.74)	**0.6798** **(1.68)**
α_F	0.1282 (11.81)	0.0157 (2.39)	0.0078 (0.97)	-0.0669 (-1.59)	**0.0838** **(1.43)**
α_{LS}	0.0044 (0.37)	0.1343 (5.73)	0.0937 (2.12)	0.6085 (4.11)	**0.60** **(2.08)**
α_K	0.1008 (12.53)	-0.0041 (-0.35)	0.0252 (0.97)	0.1114 (2.76)	**0.0183** **(0.21)**
β_L				0.2608 (4.32)	**0.3243** **(2.76)**
β_F				0.0367 (3.30)	**0.0148** **(1.93)**
β_{LS}				-0.065 (-2.82)	**-0.0683** **(-1.55)**
β_K				0.008 (1.14)	**0.0152** **(1.53)**
β_{LF}				-0.065 (-4.47)	**-0.0164** **(-1.2)**
β_{LLS}				-0.1261 (-3.40)	**-0.0525** **(-0.92)**
β_{LK}				0.0906 (5.57)	**0.0659** **(2.96)**
β_{FLS}				0.013 (1.93)	**-0.01** **(-1.1)**
β_{FK}				-0.009 (-1.32)	**-0.006** **(-1.05)**
β_{LSK}				-0.018 (-2.32)	**-0.0074** **(-0.5)**
Adjusted R^2	0.722	0.963	0.982	0.968	**0.983**
RSS	115.94	14.98	6.95	12.95	**6.77**
DW statistic	0.093	0.564	2.315	0.676	**2.297**
Test for no indiv. effects $H_0 : \tilde{\mu}_i = \tilde{\mu}_j$			131.88 (0.000)		**134.99** **(0.000)**
Test Cobb-Douglas $H_0 : \beta_j = \beta_{jh} = 0$				118.89 (0.000)	**23.88** **(0.008)**

See Note on Table 1A

Table A6
South East Asia (SEA)

Model:	**(i)**	**(ii)**	**(iii)**	**(iv)**	**(v)**
Constan**t**	7.2867 (21.15)				
ϕ			0.8941 (29.39)		**0.8896** **(24.16)**
θ	-0.0358 (-6.60)	0.0046 (1.17)	0.0031 (2.24)	0.0054 (1.11)	**0.0018** **(1.33)**
α_L	-0.1255 (-1.86)	0.380 (4.1)	0.1655 (1.48)	0.3765 (0.38)	**0.6187** **(0.67)**
α_F	0.2977 (10.17)	0.1387 (4.02)	0.0532 (1.32)	-0.2319 (-0.55)	**0.8884** **(2.18)**
α_{LS}	-0.3861 (-8.33)	-0.2031 (-3.3)	0.0542 (0.75)	1.5145 (2.51)	**0.8668** **(1.47)**
α_K	0.2568 (7.550	0.1144 (8.27)	-0.0347 (-1.81)	1.2619 (5.10)	**-0.0869** **(-0.32)**
β_L				0.5089 (1.05)	**1.1815** **(2.84)**
β_F				0.1604 (3.42)	**-0.0353** **(-0.95)**
β_{LS}				-0.1425 (-1.7)	**-0.0337** **(-0.42)**
β_K				0.0586 (4.37)	**0.007** **(0.53)**
β_{LF}				0.2003 (1.6)	**0.0961** **(0.94)**
β_{LLS}				-0.005 (-0.03)	**-0.1319** **(-0.80)**
β_{LK}				-0.088 (-1.23)	**0.0863** **(1.19)**
β_{FLS}				0.0239 (0.37)	**-0.1407** **(-2.2)**
β_{FK}				-0.086 (-2.92)	**0.013** **(0.47)**
β_{LSK}				-0.185 (-4.98)	**0.0062** **(0.14)**
Adjusted R^2	0.856	0.962	0.99	0.982	**0.991**
RSS	20.046	5.16	1.24	2.24	**1.05**
DW statistic	0.12	0.37	2.27	0.73	**2.14**
Test for no indiv. effects $H_0 : \tilde{\mu}_i = \tilde{\mu}_j$			18.44 (0.0024)		**14.5** **(0.013)**
Test Cobb-Douglas $H_0 : \beta_j = \beta_{jh} = 0$				278.55 (0.000)	**33.014** **(0.0003)**

See Note on Table 1A

Table A7
Middle East (ME)

Model:	**(i)**	**(ii)**	**(iii)**	**(iv)**	**(v)**
Constan**t**	4.3576 (18.41)				
ϕ			0.6735 (18.01)		**0.5010** **(11.33)**
θ	-0.0242 (-9.86)	0.0116 (3.25)	0.0004 (0.23)	0.0011 (0.31)	**-0.002** **(-0.92)**
α_L	0.417 (11.59)	0.601 (8.45)	0.6435 (6.61)	0.7977 (1.05)	**0.3226** **(0.40)**
α_F	0.179 (7.26)	0.019 (1.14)	0.0344 (1.63)	0.5784 (3.02)	**0.335** **(1.46)**
α_{LS}	0.101 (3.09)	0.3448 (4.63)	0.0846 (1.19)	-1.4102 (-1.4)	**-0.627** **(-0.82)**
α_K	0.2024 (12.25)	0.0568 (1.77)	0.1432 (2.99)	-0.3374 (-1.83)	**-0.0631** **(-0.25)**
β_L				0.4345 (2.57)	**0.2482** **(1.24)**
β_F				0.0172 (0.74)	**0.0959** **(3.22)**
β_{LS}				0.2612 (1.74)	**0.1342** **(1.12)**
β_K				0.0142 (0.77)	**0.0619** **(2.59)**
β_{LF}				0.0762 (1.67)	**0.0731** **(1.58)**
β_{LLS}				-0.1574 (-1.4)	**-0.0608** **(-0.49)**
β_{LK}				-0.005 (-0.14)	**-0.0016** **(-0.04)**
β_{FLS}				-0.0856 (-2.98)	**-0.0411** **(-1.28)**
β_{FK}				0.0002 (0.01)	**-0.0575** **(-2.35)**
β_{LSK}				0.048 (1.79)	**0.0053** **(0.16)**
Adjusted R^2	0.863	0.976	0.987	0.984	**0.988**
RSS	55.49	9.24	4.86	5.94	**4.30**
DW statistic	0.12	0.70	2.31	1.09	**2.14**
Test for no indiv. effects $H_0 : \tilde{\mu}_i = \tilde{\mu}_j$			68.051 (0.000)		**91.42** **(0.000)**
Test Cobb-Douglas $H_0 : \beta_j = \beta_{jh} = 0$				210.56 (0.000)	**71.14** **(0.000)**

See Note on Table 1A

FIGURE 1: Technological Level by group of countries