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AGRICULTURAL PRODUCTIVITY AND ITS DETERMINANTS: REVISITING INTERNATIONAL EXPERIENCES

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Abstract

This paper makes three contributions to the literature on agricultural productivity. First, we provide estimates of growth in agriculture's total factor productivity (TFP) for a panel of countries using a translog-production function. In contrast to most of the existing literature, the evidence suggests that agricultural TFP growth in developing countries has been positive during the past four decades. Second, the empirical analysis looks at the determinants of agricultural productivity by controlling for infrastructure and other public goods. Third, we pay close attention to international heterogeneity with a special focus on Latin American and Caribbean (LAC) countries. The econometric results suggest that electricity generating capacity per capita has had positive effects on agricultural TFP, whereas roads and credit availability have had negative effects worldwide. Literacy also appears to be important for promoting agricultural productivity. The regression models also control for climactic anomalies and coup d'etat, factors that are rarely found in the literature. Finally, agricultural productivity in LAC countries behaved differently than in other regions: electricity generation was especially relevant before the 1990s, as in the rest of the sample, but its effect declined thereafter; paved roads in LAC appear to influence positively agricultural productivity throughout the period under investigation (1960-1997).

Resumen

Este artículo hace tres contribuciones a la literatura en productividad agrícola. En primer lugar, se estima el crecimiento en la productividad total de factores (PTF) para un panel de países utilizando una función de producción translog.

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Contraria a la mayoría de la literatura existente, la evidencia sugiere que el crecimiento de la PTF agrícola para países en desarrollo ha sido positivo durante las últimas cuatro décadas. Segundo, el análisis empírico examina los determinantes de la productividad agrícola controlando por infraestructura y otros bienes públicos. Tercero, se presta atención a la heterogeneidad internacional, con un enfoque especial en los países de Latinoamérica y El Caribe (LAC). Los resultados econométricos sugieren que la capacidad de generación eléctrica per cápita ha tenido un efecto sobre la PTF agrícola, mientras que los caminos y la disponibilidad de crédito han tenido efectos negativos en toda la muestra. El alfabetismo también aparece como un factor importante para impulsar la productividad agrícola. Los modelos de regresión también controlan por anomalías climáticas y coup d'etat, factores que raramente se encuentran en la literatura. Finalmente, la productividad agrícola en los países LAC se ha comportado distinto con respecto a otras regiones: la generación eléctrica fue especialmente relevante antes de los 1990s, como en el resto de la muestra, pero su efecto ha disminuido desde entonces; los caminos pavimentados en LAC influyen positivamente sobre la productividad agrícola durante el período de investigación (1960-1997).

Keywords: Agriculture, Productivity, Regional study.

JEL Codes: 013, 049, Q19.

Introduction

As highlighted by Martin and Mitra (2001), most economists since Adam Smith have consider that productivity grows more slowly in agriculture than in the manufacturing sector.[1] Smith attributed this alleged weakness of agriculture to a lower potential for labor specialization than that allowed by other industries. Today the extensive literature that has measured growth rates of Total Factor Productivity (TFP) in agriculture remains controversial and provides few guidelines about its potential determinants. This literature has also paid little attention to functional forms and important econometric issues, such as international heterogeneity. In this paper we provide estimates of growth in agriculture's total factor productivity (TFP) for a panel of countries using a translog-production function for the period 1960-2000.[2] We also study the determinants of agricultural productivity by controlling for infrastructure and other variables while also paying close attention to international heterogeneity.

According to Ruttan (2002), research on the rate of productivity growth in agriculture has gone through three stages. Initially, the research focused on the

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1 Martin and Mitra (2001) provide estimates showing the agricultural total factor productivity (TFP) grew faster than manufacturing TFP in most developing and developed countries during 1967-1992.

2 It is worthy to keep in mind that the translog corresponds to a second order approximation to any functional form.

measurement of partial productivity ratios and indexes, such as output per worker or hectare. These early studies showed wide differences in labor and land productivities across the world. Recent studies show that these differences have persisted.

The second stage of the research on technical change in agriculture involved the estimation of cross-country production functions and multifactor productivity estimates. Increasing data availability and improvements in econometric techniques made this approach increasingly reliable. These estimations were mostly carried using Cobb Douglas specifications. International heterogeneity in the use of different technologies for producing similar commodities presents serious challenges to this type of empirical analysis (Mundlak 2000). Hayami and Ruttan (1970) and Kawagoe, Hayami and Ruttan (1985) relied on cross-country meta-production functions (also in Lau and Youtopulus 1989) in accounting exercises that try to identify the sources of differences in land and labor productivities. The results indicated that internal endowments (land and livestock), technical inputs (machinery and fertilizer), and human capital each would account for approximately one fourth of the productivity gap between the developing and developed world. Economies of scale in the developed world account for more than fifteen percent.

More recently, productivity analyses have tested the convergence of growth rates and multifactor productivities by means of non-parametric approaches. The use of the Malmquist index has been widespread in this literature. This research has generally shown a widening of the agricultural productivity gap between developed and developing countries, at least during the period from the 1960s to the early nineties. In fact, developing countries have shown declining total factor productivity in several studies (Fulginity and Perrin 1993, 1997, 1998, and 1999; Arnade 1998; Trueblood 1996; Kawagoe et al. 1985; Lau and Yotoupulus 1989; among others). The result is surprising because the sample of countries included in these studies covers some “green revolution” countries in Asia and agricultural exporters of Latin America and the Caribbean (LAC). However, Nin, Arndt, and Precktel (2003) re-estimate the Malmquist index using a new definition of technology and find that most developing countries also experience positive productivity growth with technical change being the main source of this growth.

The study of the determinants of productivity is strongly rooted in empirical analysis. Griliches (1963a, 1963b) was perhaps the most influential early author in this field. He argued for the use of elasticities derived from empirical production functions in order to calculate productivity. Following Griliches, this paper contributes to the literature on agricultural productivity in three ways. First, we compute agricultural productivities for a panel of countries using a translog-production function for which we carry out different specification tests in order to find the functional form that best fits the data. The results show that, in contrast with recent literature, TFP growth has been positive in the developing world, but there has been a widening in the existing gap between the developed and developing world. Second, the empirical analysis looks at the determinants of agricultural productivity controlling by infrastructure and other variables. The evidence also suggests that electricity generating capacity per capita has a positive effect on TFP, whereas roads and illiteracy tend to hamper productivity growth. Finally, we studied whether LAC behaves differently from the rest of our sample and concluded that these countries' agricultural productivity did behave differently in important ways.

The rest of the paper is structured as follows. Section I reviews previous estimates of agricultural production functions and TFP growth rates. Section II presents the methodology we use for estimating the translog-production function. Section III describes the sources of data used throughout the paper. Section IV presents the main results of our translog estimates and econometric tests concerning TFP estimates, factor elasticities, and returns to scale. We also report average growth rates of: output per worker, agricultural land yields, and total output. Section V studies TFP determinants. Section VI studies whether LAC TFP determinants are different from those in other regions. Finally, section VII summarizes the main findings and discusses policy implications.

I. Production Functions and TFP Estimations: The Existing Evidence

I.1. Production functions[3]

The analysis of agricultural production functions began in 1944 with Tintner (1944), Tintner and Browlnlee (1944), and Heady (1944). These three studies were based on farm data. Subsequent work was extended to cover aggregate data, and in 1955 Bhattacharje provided the first cross-country study. The basic underlying assumption of these studies was that all output observations were generated from the same production function. Heady and Dillon (1961) compared the results from these and other early studies finding that the notion of a homogeneous technology was elusive. The work of Hayami (1969, 1970) and Hayami and Ruttan (1970) gave new impulse to the use of cross-country data to estimate global production functions that also tried to control for cross-country productivity differences. Unfortunately, there were considerable disparities between their results and those obtained in country case studies.

Table 1 presents the results obtained in a series of cross-country studies where the variables have been measured either per worker or as country aggregates, as reported by Mundlak (2000). Studies using a single year of observations correspond to a "between-country" regression for a given year. This is also the case for panel data in which country dummies are not included. Studies with panel data and country dummies provide estimates of "within-country" coefficients.

Table 1 highlights three important patterns in the literature. First, the literature provides low estimates of the output elasticities associated with land. Almost half of the studies yield statistically insignificant land coefficients. Second, most studies find high elasticities associated with labor. Third, in the majority of the studies, the sum of the input elasticities are well below one, suggesting diminishing or constant returns to scale.

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3 This section is based in Mundlak *et al*. (1997).

TABLE 1

CROSS-COUNTRY PRODUCTION FUNCTIONS: COMPARISON OF RESULTS

	Bhattacharjee	Hayami & Ruttan	Evenson & Kislev	Yamada & Ruttan	Antle	Hayami & Ruttan	Nguyen	Evenson & Kislev	Mundlak & Hellinghausen
Date of study	1955	1970	1975	1980	1983	1970	1979	1975	1982
Sample:									
Number of countries	22	37	36	41	43	36	40*	36	58
Time period	1949	1960	1955, 1960, 1965, 1968	1970	1965	1955, 1960	1955, 1960, 1970, 1975	1955, 1960, 1965, 1968	1960, 1965 1970, 1975
Estimation method	OLS	OLS	OLS	OLS	PCR	OLS	OLS	OLS	PCR
Data specification	S; N	M; N	M; N	M; N	S; N	M; PW	M; N	M; N	M; N
Fixed effects included						year	year	country	country#
Elasticities									
Structures and Equipment/machinery/tractors		0.12	0.10	0.11		0.11	0.14	0.06	0.07
Livestock and Orchardsllivestock		0.23	0.30	0.23	0.14**	0.28	0.33	0.35	0.19
Land	0.42	0.08**	0.04**	0.02**	0.16	0.07	0.02**	0.14	0.16
Labor	0.28	0.41	0.23	0.33	0.38	0.40	0.39	0.03**	0.46
Fertilizer	0.29	0.12	0.10	0.24	0.07**	0.14	0.10	0.09	0.11
Irrigation									0.01
Schooling/general education		0.32**		0.08**	0.25**	0.24	0.10**		
Technical Education		0.14	0.04	0.14		0.12	0.17	0.00**	
Research and extension			0.14		0.17			0.07	
Infrastructure					0.21				
Sum of Input elasticities	0.99	0.96	0.77	0.93	0.75	1.00***	0.98	0.67	1.00***

* Sample is not balanced, n=183 for Nguyen study.

** Not significant at P=0.05 for one-tailed test.

*** Linear homogeneity imposed

\# Country effects on slopes and intercept.

OLS and PCR are ordinary least squares and principal components regressions.

S and M represent a single-year observations and multi-year averages.

PW represents per-worker averages of national aggregated data, N represents national aggregates.

Source: Mundlak (2000).

I.2. TFP estimates

The following paragraph is based on Mundlak (2000) who reviews the TFP estimations for some countries. For the United States Ball (1985) reports an average TFP growth of 1.75% for the period 1948-1979, and the USDA report a similar number of 1.7%. Capalbo and Vo (1988) find an average growth of 1.57% for the period 1950-1982, while USDA reports 1.95%. Ball *et al*. (1997) review the period 1948-94 and find an average rate of growth of 1.94%.

Among the papers that study developing countries Rosegrant and Evenson (1999) find that for India during the period 1957-1985 the TFP growth was approximately 1% per year. For the same period they find a 0.78% TFP growth for Bangladesh and 1.07 for Pakistan. Arnade (1992) finds that for Brazil the average rate of TFP growth for the period 1968-1987 was 1.71%

Angela Lusigi and Colin Thirtle (1997) using Malmquist indexes find that for 47 African countries and the period 1961-1991 the average rate of TFP growth was 1.27%. They also report some evidence of convergence in productivity levels across countries in their sample. Martin and Mitra (2001) find that for a sample of approximately 50 countries and over the period 1967-92, technical progress seems to have been faster in agriculture than in manufacturing. Moreover they find evidence of convergence in levels and growth rates of TFP in agriculture, suggesting relatively rapid international dissemination of innovations. In their sample, the average TFP growth for agriculture lies between 2.34% and 2.91%. For developing countries the range goes from 1.76% to 2.62%.

More recently Nin, Arndt and Preckel (2003) compute Fare indexes using a sequential production set as a definition of technology. They find that most developing countries experienced positive productivity growth with technical change being the main source of this growth. These results are in contrast with the ones derived using a contemporaneous reference production set as in Arnade (1998) and Fulginity and Perrin (1997, 1998, 1999). According to the Nin *et al*. results, the agricultural productivity of developing countries grew at an average rate of 1.3% during 1961-1994. The following section provides new estimates of productivity growth across countries since the early 1960s.

II. The Empirical Translog Production Function

Following Kawagoe, Hayami and Ruttan (1985) and Lau and Yotoupoulos (1988) we assume that developed and developing countries exhibit different production functions. In particular, Lau and Yotoupoulos (1988) show that estimating a meta-production function based on international data requires paying close attention to differences in the quality of the inputs. To consider international heterogeneity in the quality of inputs, first assume that input *j* of a developed country in terms of the input in a developing country *r* can be expressed as $X_j{}^* = A_{jr} \cdot X_j$, where a A_{jr} is a conversion factor. Then the translog function is expressed as follows:

$$\ln(Y) = \alpha_0' + \textstyle\sum_i \alpha_i' \ln(A_{ir} X_i) + \frac{1}{2}\sum_i \sum_j \beta_{ij} \cdot \ln(A_{ir} X_i) \cdot \ln(A_{jr} X_j), \tag{1}$$

which is equivalent to:

(2) $\ln(Y)=\alpha_0'+\sum_i \alpha_i' \ln(A_{ir})+\sum_i \alpha_i' \ln(X_i)+\frac{1}{2}\sum_i\sum_j \beta_{ij}\cdot\left[\left(\ln(A_{ir})+\ln(X_i)\right)\cdot\left(\ln(A_{jr})+\ln(X_j)\right)\right].$

the previous expression can be simplified to:

$$(3) \qquad \ln(Y)=\alpha_0+\sum_i \alpha_i \ln(X_i)+\frac{1}{2}\sum_i\sum_j \beta_{ij}\cdot\ln(X_i)\cdot\ln(X_j),$$

where $\alpha_0=\alpha_0'+\sum_i \alpha_i' \ln(A_{ir})+\sum_i\sum_j \beta_{ij} ln(A_{ir})\cdot\ln(A_{jr})$, and $\alpha_i=\alpha_i'+\sum_k \ln(A_{kr})(\beta_{ij}+\beta_{ji})$.

Note that for a country in the reference group, all A_{ir} coefficients are equal to 1, and equation (3) reduces to the regular translog. To capture the factor-augmentation parameters for all the countries not included in the reference group, the econometric model needs to include a variable defined as the interaction between a group-identifying dummy variable and the corresponding factor of production.

This paper provides estimates of two regression models, one using as a group of reference the developing countries and another using the developed countries. In this manner we avoid the dubious interpretation of the coefficients expressed without tilde, which indeed would allow us to recover elasticities and returns to scale with respect to a reference group. By changing the reference group we can recover *true* elasticities and *true* returns to scale for each group. The empirical section of this paper follows this approach and reports *true* factor elasticities and returns to scale for each group of countries.

In addition, we are interested in capturing the evolution of technical progress, ideally in a differentiated manner for each country. Following Kim (1992) we add a time trend and its quadratic term to model (3), so that we can capture the average rate of growth of the TFP, which is the portion of output growth that is not explained by the utilized stock of factors of production. Finally, we add the interaction of the time trend variable and the natural logarithm of each factor. This allows us to recover different rates of technical progress for each country associated with changes in the endowments of each factor of production. Therefore our empirical production function is specified as follows:

$$(4) \quad \ln(Y)=\alpha_0+\sum_i \alpha_i \ln(X_i)+\frac{1}{2}\sum_i\sum_i \beta_{ij}\cdot\ln(X_i)\cdot\ln(X_j)+\sum_i \gamma_{iT}\cdot\ln(X_i)+\delta_T T+\frac{1}{2}\delta_{TT}T^2.$$

This production function reduces to a Cobb-Douglas technology if $\beta_{ij}=0$, $\gamma_{iT}=0$ and $\delta_{TT}=0$. If $\sum_i \beta_{ij}=0$ and $\sum_i \alpha_i=1$, then there is linear homogeneity in production. The Kmenta approximation of a CES function is obtained if $\sum_i \beta_{ij}=0$. Finally, if $\gamma_{iT}=0$ there is Hicks neutral technical change.

By differentiating equation (4) with respect to T we obtain the TFP growth rate: $TFPgrowth=\delta_T+\sum_i \gamma_{iT}\cdot\ln(X_i)+\frac{1}{2}\delta_{TT}T$. In sum, for each specification of (4), our estimates provide tests for:

1. whether (4) reduces to a Cobb-Douglas production technology;
2. whether (4) is linear homogeneous across countries;

3. whether (4) corresponds to the Kmenta approximation of the CES production function; and
4. whether (4) is characterized by Hicks-neutral technical change.

III. Data and Variable Definitions

The main source of the data used in our estimations is FAOSTAT 2002, and therefore our period of study covers 1961-2000. We consider countries whose agrarian labor forces were greater or equal to 300 thousand people; this sample includes 86 countries. Our measure of output was obtained from Nin's *et al*. (2003), and their agricultural output from 1980 (collected from a ERS/USDA database) was expanded using the rates of growth implicit in the FAOSTAT output indexes. The base years are 1979-81 period. The latter are indexes of agricultural and livestock-related production net of feed and seeds used as inputs. Nin's *et al*. database does not have data for the 86 countries whose agrarian labor forces were greater or equal to 300 thousand people, therefore the final sample is reduced to 77 countries. We consider six inputs entering in the agricultural production function: rural labor, capital, permanent crops land, permanent pastures land, livestock, and fertilizer.

The rural labor corresponds to the economically active population. We interpolate the figures for rural economically active population reported by FAOSTAT, because these data have a periodicity of 10 years. We use a constant rate of growth between each one of the reported points. Agricultural capital is proxied by the number of tractors available in each economy as has been done in previous research.[4]

The construction of the livestock series followed Sere and Steinfeld (1996). That is, we express the livestock in cow-equivalent units, correcting for differences in body sizes across different geographical regions. Finally, we use the total metric tons of fertilizer used each year.

Section V, which explores the determinants of TFP, adds to the previous data sources and variables the following ones. The data on irrigated land (ha), total population, literacy rate (%) and domestic credit to private sector (% of GDP) were obtained from the World Development Indicators 2003 of the World Bank. The data on main telephone lines, electricity generating capacity (in kilowatts), paved roads and roads (in Km) were taken from Calderon and Serven (2003). The temperature anomalies were obtained from NASA (0.01C). The data on coups d'etat was taken from Easterly and Levine databse which are available through the CID-World Bank data surfer.

IV. Agricultural Productivity Growth: New International Evidence from Translog Production Functions

Table 2 reports the results of our translog estimation. We must remark that in our estimations we do not instrument the independent variables due to lack of suitable instruments. Regression (1) has as reference group the low-income

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4 See Nin *et al*. (2003) among others.

TABLE 2
TRANSLOG ESTIMATIONS.
(1961-2000)

	(1)	(2)		(1)	(2)		(1)	(2)
	Ly	Ly		Ly	Ly		Ly	Ly
Lani	0.0259	–0.1918	Lfertltract	0.0149	0.015	**hi_lani**	–0.3063	
	(0.13)	(0.15)		(0.0032)***	(0.0032)***		(0.0456)***	
Llndp	–0.0177	–0.1104	**Lfertlani**	–0.0206	–0.0202	**hi_llndp**	0.1231	
	(0.11)	(0.09)		(0.0050)***	(0.0052)***		(0.0559)**	
Llndc	–0.0146	0.1633	**Lanillndp**	–0.0185	–0.0056	**hi_llndc**	0.2275	
	(0.11)	(0.10)		(0.0082)**	(0.01)		(0.0431)***	
Llabor	0.3604	0.2054	**Lanillndc**	–0.0489	–0.0339	**hi_llabor**	–0.0953	
	(0.1292)***	(0.14)		(0.0079)***	(0.0075)***		(0.0379)**	
Ltract	–0.1127	–0.1247	**Lanillabor**	–0.0055	0.0046	**hi_ltract**	–0.0255	
	(0.0538)**	(0.0528)**		(0.01)	(0.01)		(0.02)	
Lfert	0.3267	0.2558	**Laniltract**	0.0199	0.0143	**hi_lfert**	–0.069	
	(0.0493)***	(0.0535)***		(0.0054)***	(0.0053)***		(0.0213)***	
llndp2	–0.0023	0.0037	**Llndpllndc**	0.0113	0.0026	**lowlac_lani**		0.1435
	(0.01)	(0.01)		(0.01)	(0.01)			(0.0322)***
llndc2	0.0203	0.0201	**Llndpllabor**	0.0449	0.0445	**Lowlac_llndp**		–0.0907
	(0.0040)***	(0.0040)***		(0.0094)***	(0.0093)***			(0.06)
lani2	0.0237	0.0177	**Llndpltract**	0.0032	0.0048	**Lowlac_llndc**		–0.2174
	(0.0075)***	(0.0077)**		(0.00)	(0.00)			(0.0428)***
llabor2	–0.0176	–0.021	**Llndcllabor**	0.0601	0.0519	**Lowlac_llabor**		0.129
	(0.0095)*	(0.0093)**		(0.0087)***	(0.0085)***			(0.0376)***
ltract2	–0.005	–0.003	**Llndcltract**	–0.0022	–0.0039	**Lowlac_ltract**		0.0455
	(0.0021)**	(0.00)		(0.00)	(0.00)			(0.0201)**
lfert2	0.008	0.0083	**Llaborltract**	–0.025	–0.0236	**lowlac_lfert**		0.067
	(0.0016)***	(0.0016)***		(0.0061)***	(0.0060)***			(0.0216)***
T	–0.0339	–0.0321	**Tllndp**	–0.0004	–0.0005	Observations	3038	3038
	(0.0035)***	(0.0036)***		(0.00)	(0.0003)**	R-squared	1	1
T2	0.0001	0.0001	**Tllndc**	0.0012	0.0013			
	(0.0000)***	(0.0000)**		(0.0003)***	(0.0003)***			
Lfertllabor	–0.0174	–0.0175	**Tllabor**	–0.0016	–0.002			
	(0.0049)***	(0.0049)***		(0.0003)***	(0.0003)***			
Lfertllndp	–0.0069	–0.0077	**Tltract**	–0.0001	–0.0005			
	(0.0028)**	(0.0028)***		(0.00)	(0.0003)*			
Lfertllndc	–0.0112	–0.0118	**Tlani**	0.0035	0.0038			
	(0.0033)***	(0.0033)***		(0.0004)***	(0.0004)***			
			Tlfert	0.0002	0.0004			
				(0.00)	(0.00)			

Robust standard errors in parentheses.
significant at 10%; ** significant at 5%; *** significant at 1%.

TABLE 2 (b)

VARIABLE DEFINITIONS FOR TABLE 2 (a)

Lani: ln(livestock)
Llndp : ln(pasture lands)
Llndc: ln(crop lands)
Llabor: ln(labor force)
Ltract: ln(tractors)
Lfert: ln(fertilizers)
llndp2: [ln(pasture lands)]^2
llndc2: [ln(crop lands)]^2
Lani2: [log(livestock)]^2
Llabor2: [ln(labor force)]^2
Ltract2: [ln(tractors)]^2
Lfert2: [ln(fertilizers)]^2
T : time trend
T2 :time trend squared
Lfertllabor: ln(fertilizers)*ln(labor force)
Lfertllndp: ln(fertilizers)*ln(pasture lands)
Lfertllndc: ln(fertilizers)*ln(crop lands)
Lfertltract: ln(fertilizers)*ln(tractors)
Lfertlani: ln(fertilizers)*ln(livestock)
Lanillndp: ln(livestock)* ln(pasture lands)
Lanillndc: ln(livestock)* ln(crop lands)
Lanillabor: ln(livestock)* ln(labor force)
Laniltract: ln(livestock)* ln(tractors)
Llndpllndc: ln(pasture lands)* ln(crop lands)
Llndpllabor: ln(pasture lands)* ln(labor force)
Llndpltract: ln(pasture lands)* ln(tractors)
Llndcllabor: ln(crop lands)* ln(labor force)
Llndcltract: ln(crop lands)* ln(tractors)
Llaborltrac: ln(labor force)* ln(tractors)
Tllndp: time trend* ln(pasture lands)
Tllndc : time trend* ln(crop lands)
Tllabor: time trend* ln(labor force)
Tltract: time trend* ln(tractors)
Tlani: time trend* ln(livestock)
Tlfert: time trend* ln(fertilizers)
hi_lani: high income countries dummy* ln(livestock)
hi_llndp: high income countries dummy* ln(pasture land)
hi_llndc: high income countries dummy* ln(crop land)
hi_llabor: high income countries dummy* ln(labor force)
hi_ltract: high income countries dummy* ln(tractors)
hi_lfert: high income countries dummy* ln(fertilizers)
lowlac_lani: low income and Latin America countries dummy* ln(livestock)
Lowlac_llndp: low income and Latin America countries dummy* ln(pasture land)
Lowlac_llndc: low income and Latin America countries dummy* ln(crop land)
Lowlac_llabor: low income and Latin America countries dummy* ln(labor)
Lowlac_ltract: low income and Latin America countries dummy* ln(tractors)
lowlac_lfert : low income and Latin America countries dummy* ln(fertilizers)

countries and regression (2) has as a reference group the high-income countries. As mentioned, for both regressions we test whether our model: (1) reduces to a Cobb-Douglas technology; (2) is linear homogeneous; (3) corresponds to the Kmenta approximation of the CES production function; and (4) exhibits Hicks-neutral technical change. The four tests are rejected for both specifications with p-values equal to zero. Therefore, we conclude that the translog function as specified is the most appropriate for carrying out parametric TFP growth estimations. In the same spirit, we test the joint significance of the variables used in the computations of the TFP, the null hypothesis of coefficients equal to zero is rejected with p-value equal to zero. Finally, we carried out Dickey-Fuller tests on the errors' correlation structure given the time series nature of the data. For both specifications the existence of unit root was rejected.

Regression models (1) and (2) provide estimates of TFP growth. Table 3 reports estimates for the three groups of countries, namely LAC, non-LAC developing countries, and high-income countries.[5] The table shows the results of our first specification for LAC and the other poor countries and the second specification for the high-income countries. Besides TFP growth rates Table 3 also reports the rate of growth of output per worker, output per hectar and total output.

In LAC, the country with the highest TFP growth is Brazil, which averaged 1.93% per year during 1960-2000. We must recall that Arnade (1992) finds for Brazil a TFP growth of 1.71% for the period 1968-1987. Mexico follows Brazil with an average increase of 1.85%. In the third position and very close to Mexico's average we find Argentina with an increase of 1.84%. On the last spot of our sample we find El Salvador with an average increase of 0.53%. The previous-to-last spot is occupied by Paraguay with an average increase of 0.74% per year.

Regarding the high-income countries, the highest TFP growth was Australia with 2.17% per year, followed by the U.S. with an average increase in TFP of 2.04%. We must recall that USDA reported a TFP growth of 1.95% for USA for the period 1950-1982. The third spot is occupied by France with a TFP increase of 1.74% per year. The last spot is occupied by Finland with a very low 0.21%. The previous-to-last last position is occupied by Denmark with a 0.68% per year. Among the non-LAC developing countries, India[6] led the group with an average TFP increase of 1.98% followed by China with an increase of 1.67% and South Africa with 1.64%. Among the lowest TFP growth in the full the sample is Papua New Guinea with a reduction of 0.36% per year. The arithmetic average for the TFP growth of the high-income countries is 1.36% per year followed by LAC with an average increase of 1.2%. The rest of the poor countries show an average of 0.74%.[7]

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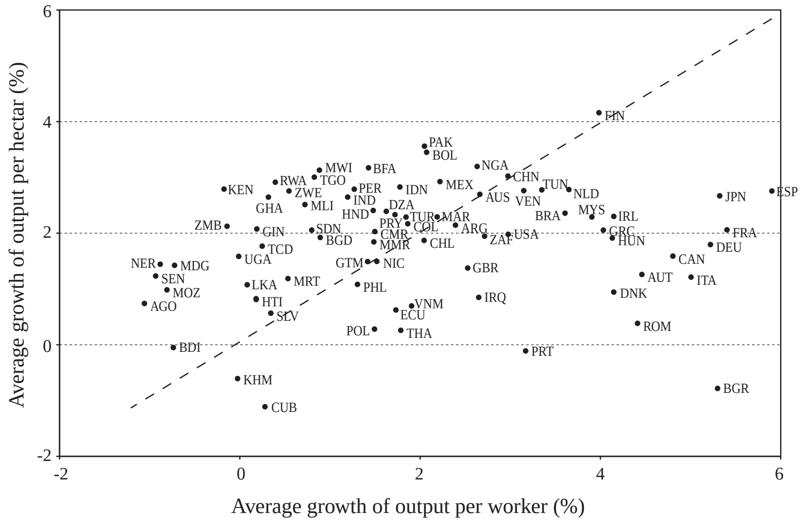
5 A cursory look over the results suggests that there are no significant differences in the TFP rates of growth across both specifications.

6 Rosegrant and Evenson (1999) provide and estimate for TFP growth of approximately 1% per year for the period 1957-1985.

7 We must recall that Nin *et al*. (2003) find and average TFP growth for developing countries close to 1.3%.

FIGURE 1

AVERAGE RATE OF GROWTH OF OUTPUT PER HECTAR AND PER WORKER (1961-2000)



Source: Faostat 2003.

Figure 1 complements the results shown in Table 3. Figure 1 is a scatter plot between the rate of growth of output per worker and output per hectar. We add a 45 degree line in order to distinguish the fastest rate of growth. This graph shows that, in general, the developed world has experienced a faster growth of output per worker relative to the growth of agricultural yields, whereas the opposite has occurred in the developing world.

Table 3 corroborates the conclusions that can be derived from the scatter plot. In Latin America the average rate of growth of the output per worker is 1.17%, whereas in the high income countries is 4.23%, showing a very significant difference. This result seems to indicate that in developed countries labor has been substituted by other inputs.[6] This gap increases once the poor non-LAC countries are considered; this group has an average rate of growth of 1.07%. With respect to the growth of the agricultural yields, we observe again that the high-income countries have the fastest growth, 1.97%; Latin America has average rate of growth of 1.82% and the group of poor non-LAC countries 1.60%. Therefore, the gap existing between regions yields' growth are not as significant as in the case of output per worker. Finally, the evolution of total agricultural output behaves differently to the previous pattern. The green revolution seems to have had a larger impact in LAC that shows an average output growth

8 Indeed, this prediction is corroborated in the labor estimations of the translog-function.

TABLE 3
AGRICULTURAL TFP GROWTH AND OTHER MEASURES OF PRODUCTIVITY.
PARAMETRIC ESTIMATES: SUMMARY STATISTICS

	Average TPF Growth (%)	TPF Growth over 40 years (%)	Average Growth Output per worker (%)	Output per worker growth over 40 years (%)	Average Growth Output per ha (%)	Output per ha growth over 40 years (%)	Average Output Growth (%)	Output growth over 40 years (%)
Latin America								
Argentina	1.84	107.61	2.39	151.51	2.14	128.65	2.07	122.55
Bolivia	1.18	60.13	2.07	122.58	3.45	275.31	3.90	344.87
Brazil	1.93	114.44	3.61	298.44	2.36	148.14	3.46	276.67
Chile	1.20	61.32	2.04	120.19	1.87	105.96	2.68	180.08
Colombia	1.43	76.65	1.86	105.46	2.17	130.83	2.58	170.17
Cuba	1.17	59.10	0.28	11.49	–1.11	–35.34	–0.05	–1.88
Ecuador	1.28	66.23	1.73	95.34	0.62	27.39	2.65	176.98
El Salvador	0.53	23.31	0.34	14.35	0.57	24.62	1.37	70.29
Guatemala	0.79	36.83	1.42	73.18	1.49	78.02	3.36	262.38
Haití	0.97	46.95	0.18	7.30	0.82	37.74	0.81	36.92
Honduras	0.78	36.38	1.48	77.39	2.41	152.70	2.68	180.00
México	1.85	108.54	2.22	135.56	2.92	207.71	3.15	234.81
Nicaragua	0.79	36.98	1.52	80.10	1.49	78.28	2.10	124.68
Paraguay	0.74	34.34	1.72	94.59	2.33	145.60	3.55	290.29
Peru	1.36	71.81	1.27	63.59	2.79	192.21	2.72	184.57
Venezuela	1.35	70.97	3.15	235.26	2.76	189.32	3.18	238.68
Average	1.20	63.22	1.71	105.40	1.82	117.95	2.51	180.75
High Income								
Australia	2.12	131.84	2.66	178.71	2.69	182.11	2.53	164.98
Austria	0.69	31.79	4.46	448.49	1.26	62.92	0.82	37.39
Canada	1.23	62.95	4.80	523.50	1.59	84.90	2.70	183.13
Denmark	0.66	30.28	4.15	388.10	0.94	44.21	1.04	49.53
Finland	0.25	10.50	3.98	358.95	4.16	389.86	0.50	21.25
France	1.77	101.76	5.41	679.20	2.06	121.41	1.32	67.04
Germany	1.39	73.37	5.22	627.94	1.80	100.15	1.00	47.26
Greece	1.62	89.85	4.03	367.40	2.05	121.07	1.91	109.21
Ireland	0.72	33.50	4.15	388.22	2.30	142.74	1.81	100.97
Italy	1.73	98.59	5.01	572.03	1.21	59.93	1.03	49.01
Japan	1.40	74.31	5.32	656.09	2.67	179.29	0.99	46.58
Netherlands	1.16	58.55	3.65	304.99	2.78	191.45	2.17	130.83
Portugal	1.41	75.02	3.17	237.93	–0.11	–4.26	1.06	50.60
Spain	1.89	111.50	6.10	908.42	2.74	187.28	2.64	176.56
United Kingdom	1.67	93.64	2.53	164.79	1.37	70.29	1.04	49.51
USA	2.11	130.77	2.98	213.99	1.98	114.69	1.72	94.12
Average	1.36	75.51	4.23	438.67	1.97	128.00	1.52	86.12
Poor Countries (Non-LA)								
China	1.67	94.10	2.97	213.65	3.02	219.40	4.46	447.88
India	1.98	119.17	1.20	59.04	2.65	176.87	2.61	172.66
Papua New Guinea	–0.36	–13.41	0.00	0.00	0.00	0.00	0.00	0
Sierra Leone	–0.18	–7.06	0.18	7.34	0.81	37.02	0.83	38.00
South Africa	1.64	91.43	2.72	184.36	1.94	111.96	1.79	99.86
Zambia	–0.26	–9.85	–0.14	–5.37	2.12	126.93	2.12	127.02
Average	0.74	37.55	1.07	76.71	1.60	101.73	1.98	141.19

of 2.51%, poor non-LAC have 1.98%, whereas the high income countries experienced an average growth of 1.52%.

In LAC the group of the fastest growing countries regarding output per worker is not very different to the ones that experienced the fastest TFP growth. The same happens with the countries with the slowest rate of growth. Indeed, the Spearman rank correlation is 0.68. The null hypothesis that both variables are independent is rejected with a p-value equal to zero.

For the high-income countries there seems not to exist a structural relationship between the rates of growth of output per worker and TFP growth. The rankings are significantly different, as can be seen by noting that the Spearman rank correlation is –0.05. The null hypothesis of independence between variables is accepted with a p-value of 0.85. Finally, for the group of poor non-LAC countries the Spearman rank correlation is even higher than for Latin America reaching 0.73, although the top three and bottom three countries do change. The null hypothesis of independence is rejected with a p-value equal to zero.

In LAC the group of the fastest growing countries regarding agricultural yields is relatively different to the ones that experienced the fastest FTP growth. The same happens with the countries with the slowest rate of growth. Indeed, the Spearman rank correlation is 0.45, a lower correlation than the one existing between TFP growth and output per worker growth. The null hypothesis of independence between these two variables has a p-value equal to 0.10.

For the high-income countries again there seems not to be a structural relationship between the rates of growth of agricultural yields and TFP growth. The rankings are significantly different, as can be seen by noting that the Spearman rank correlation is 0.06. The null hypothesis of independence can not be rejected and has a p-value equal to 0.83. Finally, for the group of poor non-LAC countries the Spearman rank correlation is significantly lower than for Latin America reaching 0.23. The null hypothesis of independence between both variables is accepted with a p-value of 0.15.

In LAC the group of the fastest growing countries agricultural output is significantly different to the ones that experienced the fastest FTP growth. The same happens with the countries with the slowest rate of growth. Indeed, the Spearman rank correlation is 0.15, a lower correlation than the one existing between TFP growth and output per worker growth. The null hypothesis of independence between both variables has a p-value equal to 0.57.

For the high-income countries there seems to be a structural relationship between the rates of growth of output and TFP growth. The rankings are not very different, as can be seen by noting that the Spearman rank correlation is 0.43. The null hypothesis of independence has p-value equal to 0.10. Finally, for the group of poor non-LAC countries the Spearman rank correlation is significantly higher than for Latin America reaching 0.44. The null hypothesis of independence is rejected with a null equal to zero.

Table 4 presents the results of our estimations of returns to scale and factor elasticities based in our translog estimations. In LAC, the average return to scale is 0.94. With Brazil, Argentina and Mexico having scale coefficients of

TABLE 4
RETURNS TO SCALE AND FACTORS ELASTICITIES. TRANSLOG ESTIMATIONS

	Returns to Scale	Tractors Elasticity	Labor Elasticity	Pasture Land Elasticity	Crops Land Elasticity	Animal Stock	Fertilizer
Latin America							
Argentina	1.09	0.09	0.77	–0.04	–0.03	0.21	0.08
Bolivia	0.95	0.06	0.64	–0.02	–0.06	0.28	0.04
Brazil	1.15	0.08	0.74	0.06	0.11	0.11	0.07
Chile	0.89	0.09	0.55	–0.05	–0.10	0.25	0.15
Colombia	1.01	0.08	0.66	0.02	0.03	0.14	0.08
Cuba	0.90	0.08	0.53	–0.02	–0.06	0.20	0.18
Ecuador	0.93	0.07	0.60	0.00	–0.01	0.16	0.10
El Salvador	0.83	0.05	0.46	0.01	–0.02	0.16	0.17
Guatemala	0.89	0.05	0.52	0.02	0.02	0.15	0.13
Haití	0.85	0.03	0.49	0.05	0.02	0.24	0.01
Honduras	0.86	0.06	0.52	–0.01	–0.03	0.19	0.13
México	1.02	0.10	0.64	0.01	0.00	0.20	0.08
Nicaragua	0.85	0.08	0.57	–0.04	–0.06	0.17	0.13
Paraguay	0.93	0.05	0.60	–0.04	–0.07	0.27	0.11
Peru	0.91	0.09	0.58	–0.02	–0.05	0.23	0.08
Venezuela, BR	0.96	0.09	0.65	–0.04	–0.05	0.18	0.13
Average	0.94	0.07	0.59	–0.01	–0.02	0.20	0.10
High Income							
Australia	0.98	0.14	0.58	0.06	–0.04	0.16	0.08
Austria	0.75	0.04	0.32	0.04	0.07	0.08	0.20
Canada	0.86	0.08	0.41	0.06	0.04	0.11	0.17
Denmark	0.54	0.06	0.14	–0.01	–0.05	0.14	0.25
Finland	0.44	0.04	0.00	0.00	–0.08	0.20	0.28
France	0.94	0.07	0.44	0.10	0.15	0.05	0.13
Germany	0.86	0.05	0.34	0.10	0.12	0.08	0.16
Greece	0.89	0.05	0.45	0.09	0.16	0.06	0.09
Ireland	0.59	0.09	0.19	0.01	–0.12	0.21	0.22
Italy	0.96	0.03	0.44	0.12	0.21	0.04	0.11
Japan	0.79	0.01	0.22	0.14	0.19	0.10	0.13
Netherlands	0.65	0.07	0.25	0.02	–0.02	0.14	0.19
Portugal	0.80	0.03	0.36	0.08	0.17	0.06	0.10
Spain	1.00	0.05	0.51	0.12	0.22	0.02	0.08
United Kingdom	0.79	0.10	0.35	0.05	–0.02	0.16	0.15
USA	1.09	0.10	0.55	0.13	0.13	0.08	0.11
Average	0.81	0.06	0.35	0.07	0.07	0.11	0.15
Poor Countries (Non-LA)							
China	1.14	0.04	0.57	0.16	0.21	0.13	0.02
India	1.05	0.04	0.48	0.15	0.15	0.20	0.03
Papua New Guinea	0.95	–0.06	0.47	0.12	0.19	0.07	0.16
Sierra Leone	0.86	0.00	0.49	0.04	0.06	0.19	0.08
South Africa	1.00	0.10	0.66	–0.03	–0.06	0.21	0.12
Zambia	0.85	0.02	0.43	0.01	0.00	0.22	0.16
Average	0.92	0.04	0.51	0.03	0.02	0.22	0.09
World Average	0.91	0.05	0.52	0.02	–0.01	0.22	0.09

1.15, 1.09 and 1.02 respectively. For the high-income countries our estimations imply an average scale coefficient of 0.81. This low mean is mostly due to the low scale coefficients of Finland and Denmark. The highest scale coefficients are those of the U.S. with 1.09, Spain with 1.0, and France with 0.94. In the sample of non-LAC developing countries, India had a scale coefficient 1.05, China had a scale coefficient of 1.14, South Africa had a corresponding estimate of 1.00.

In general, given the large standard errors implied by a translog estimation our scale coefficients and factor elasticities should be considered only as reference. The bottomline is that for most of the world, we cannot reject the possibility that agricultural production exhibits constant returns to scale. From a policy viewpoint, it is perhaps more interesting to understand why some countries had better TFP performances than others. This is the topic of Section V.

Finally, Table 5 shows the marginal products of the inputs used in the translog specification. The table reports the average marginal products by region based on the elasticities reported in Table 4. This was done by multiplying the elasticities by the mean of the ratio between the agricultural output and the respective input. In reading this table is worth to keep in mind that output is measured in million of 1979-1981 US$, labor is measured in thousand workers, tractors in units, crop and pasture land are measured in thousand hectares, livestock is measured in cow units and fertilizer in metric tons. This table also includes upper and lower bounds for our estimates. These bounds were computed using the average variation coefficient by region on the ratio between output and inputs used in computing the marginal effects.

TABLE 5

MARGINAL PRODUCTS DERIVED FROM THE TRANSLOG PRODUCTION FUNCTION

(Elasticities Evaluated at variable mean; 1961-2000)

	Labor	Tractors	Crop Land	Pasture Land	Livestock	Fertilizer
Lower bound	1.3355	0.0161	–0.2899	0.0022	0.0004	0.0024
LAC	1.6820	0.0278	–0.2335	0.0029	0.0005	0.0068
Upper bound	2.0285	0.0395	–0.1771	0.0036	0.0006	0.0111
Lower bound	3.3940	0.0011	–16.9456	0.2587	0.0007	0.0010
High Income	6.0355	0.0020	–13.6258	0.3552	0.0008	0.0013
Upper bound	8.6770	0.0030	–10.3061	0.4516	0.0010	0.0016
Lower bound	0.3712	0.0066	–0.8555	0.1427	0.0006	–0.1203
Poor (non_LAC)	0.4748	0.0180	–0.6865	0.1960	0.0007	0.2926
Upper bound	0.5784	0.0294	–0.5175	0.2493	0.0009	0.7056

The marginal effects for each variable assume keeping all else constant. For LAC countries in the sample an extra worker produces in average US$ 1,682. For the high-income countries this figure increases to US$ 6,035, whereas for poor non-LAC countries this figure decreases to US$ 474. An extra tractor produces in LAC about US$ 27,800, while in high-income countries US$ 2,000 and in poor non-LAC US$ 18,000. An extra hectare of crop land decreases output by US$ 233 in LAC, by US$ 13,625 in high income countries and by US$ 686 in poor non-LAC. Whereas an extra unit of pasture land increases output by US$ 2,9 in LAC, by US$ 355 in high income countries and by US$ 196 in poor non-LAC countries. An extra cow unit increases output by US$ 500 in LAC, by US$ 800 in high income countries and by US$ 700 in poor non-LAC. Finally, an extra metric ton of fertilizer increases output in LAC by US$ 2,400, by US$ 1,300 in high-income countries and by US$ 292,000 in poor non-LAC countries. We believe that these estimates do not provide an exact figure of the marginal products, but show the feasibility of the translog function as a representative function for our sample and should be used only as reference and with caution. The results, however, also reveal some of the disadvantages of the translog production function in form of implausible coefficients over certain range of the key variables. We believe this is the case for fertilizer use in poor non-LAC countries, crop land in high-income countries, and pasture land in LAC. In any case, we also believe that the region rankings in the reported marginal effects are reliable.

A negative marginal product for crop land might be surprising for some readers, but it is not an unlikely scenario. Indeed, by increasing crop land without increasing none other factor implies not just a decrease in the inputs devoted to each hectare but also a decrease in managerial resources; all these effects might indeed cause a drop in the yields per hectare. In contrast, an increase in pasture land implies more feed for each animal consistent with a positive marginal effect.

V. The Determinants of TFP

For the study of the determinant of TFP across countries is easier to estimate a Cobb-Douglas production function because the analysis needs to control for the contribution of agricultural factors of production as well as factors that influence the context in which agricultural production is taking place. For example, infrastructure coverage and the depth of domestic financial markets might affect not only the stock of the factors of production that are available within each economy, but also these variables might influence the efficiency in the use of the production factors. This section follows the alternative Cobb-Douglas approach because in this case we have suitable instruments for our variables of interest. In the estimations reported in Table 6 we use as instruments the lags 5 through 19 of the input variables. This reduces our sample, but allows us to recover appropriated Hansen tests for the validity of instrumental variables. An additional consideration is that in this case our estimation is comparable to some of the existing literature. A fully specified Translog production function was not feasible due to the large number of explanatory variables that would be required.[9] The list of contextual determinants of TFP to be examined includes irrigated land per worker, the number of telephone lines per capita, national electricity generating capacity per capita, the extent (in kilometers) of paved roads and roads in general (in per capita terms), temperature anomalies measured as deviations from long-run averages, coups d'etat (a measure of institutional volatility), the illiteracy rate, and credit to the private sector. We estimate a Cobb Douglas specification using factors in per worker terms. In our estimates we use fixed effects and time dummies given the time series nature of the data. For this reason we carried out Dickey-Fuller tests on the serial correlation of the errors. In all our specification we reject the null hypothesis of unit root.

Table 6(a) presents the estimation results. Our results show a positive and significant coefficient associated with irrigated land per worker up to regression (10), from then on this variable is not significant due to the inclusion of other controls (illiteracy); electricity generating capacity per capita enters significantly with a positive sign; telephone density also enters with a positive sign although it is not significant. Surprisingly, road coverage per capita (paved or total) has a negative and significant effect on agricultural productivity. As expected, the illiteracy rate is significant with a negative coefficient in regressions (11) trough (13).

Regressions (9) to (11) include two measures of temperature anomalies. In specification (9) we use simply temperature anomalies, in specifications (10) and (11) we use positive temperature anomalies in order to test the impact of global warming. In regressions (9) and (10) these variables are significant at 10%, whereas in regression (11) positive temperature anomalies are marginally insignificant due to the inclusion of illiteracy as explanatory variable. We speculate that this might be due to the significant correlation between both variables.

In specifications (7) through (13) we add our credit measure, which results significant but with negative sign in regressions (10) through (13). In specifications (8) to (12) we add our coup d'etat variable which is significant and with negative sign up to regression (11) in which illiteracy is added. Again we speculate that countries with higher illiteracy might experience more coups and therefore by including illiteracy coups looses its significance.

With respect to the elasticities of the inputs of the production function we have the following results for the instrumented regressions: the elasticity of animal stock fluctuates between 0.14 y 0.19 depending on the specification; the elasticity of pasture land goes from 0.21 to 0.41; the elasticity of crop land moves from 0.12 to 0.15; the tractors' elasticity fluctuates between 0.15 y 0.18 and the fertilizants's elasticity between 0 and 0.04. Under the assumption of constant returns to scale the labor elasticity fluctuates between 0.15 and 0.25. The most unstable elasticity is the pasture elasticity. In particular this elasticity jumps once illiteracy is added.

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[9] Note that the translog production function requires interacting the contextual variables with the country-group dummies and with all the relevant factors of production. Thus the model quickly becomes unidentifiable.
Another alternative was to use the estimated translog-TFP growth rates as dependent variable explained by the contextual variables. However, we believe that the underlying orthogonality assumption too strong and therefore inappropriate.

TABLE 6 (A)

AGRICULTURAL PRODUCTIVITY PER WORKER AND ITS DETERMINANTS.

(Dep. var. = output per worker; 1961-1997; fixed effects)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	lyw	lyw	lyw	lyw	lyw	lyw	lyw	lyw	lyw	lyw	lyw	lyw	lyw
	OLS	OLS	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
ln(animals/w)	0.2993 (0.0155)***	0.2521 (0.0147)***	0.3654 (0.0306)***	0.2668 (0.0279)***	0.1851 (0.0456)***	0.2143 (0.0463)***	0.2248 (0.0475)***	0.2408 (0.0474)***	0.2397 (0.0489)***	0.2397 (0.0489)***	0.1464 (0.0543)***	0.1476 (0.0543)***	0.1351 (0.0528)**
ln(pasture/w)	0.4042 (0.0179)***	0.5286 (0.0213)***	−0.0018 (0.0319)	0.2507 (0.0333)***	0.2634 (0.0460)***	0.2529 (0.0436)***	0.244 (0.0458)***	0.2108 (0.0490)***	0.2074 (0.0501)***	0.2074 (0.0501)***	0.4066 (0.0647)***	0.4038 (0.0647)***	0.4154 (0.0627)***
ln(crops/w)	0.0704 (0.0183)***	0.0378 (0.0192)**	0.1239 (0.0362)***	0.0895 (0.0361)**	0.1455 (0.0475)***	0.1185 (0.0464)**	0.1165 (0.0462)**	0.1213 (0.0479)**	0.1169 (0.0504)**	0.117 (0.0504)**	0.1455 (0.0579)**	0.1417 (0.0578)**	0.1409 (0.0578)**
ln(tractors/w)	0.093 (0.0072)***	0.0423 (0.0070)***	0.1507 (0.0185)***	0.1075 (0.0167)***	0.179 (0.0228)***	0.1661 (0.0238)***	0.1552 (0.0237)***	0.1571 (0.0238)***	0.1544 (0.0240)***	0.1544 (0.0240)***	0.1551 (0.0236)***	0.154 (0.0235)***	0.1526 (0.0235)***
ln(fert/w)	0.0785 (0.0052)***	0.0504 (0.0050)***	0.0828 (0.0162)***	0.0803 (0.0157)***	0.0279 (0.0215)	0.0357 (0.0219)	0.0408 (0.0222)*	0.047 (0.0219)**	0.0487 (0.0217)**	0.0487 (0.0217)**	0.0308 (0.0239)	0.0326 (0.0236)	0.0312 (0.0238)
Trend		0.01 (0.0005)***		0.011 (0.0007)***									
Lac*Trend		0.0005 −0.0007		−0.0027 (0.0013)**									
ln(irriga/w)	0.1178 (0.0096)***	0.029 (0.0097)***	0.2884 (0.0327)***	0.0257 (0.0361)	0.1124 (0.0414)***	0.0746 (0.0427)*	0.1289 (0.0459)***	0.137 (0.0450)***	0.1527 (0.0452)***	0.1524 (0.0452)***	0.055 (0.0512)	0.0515 (0.0513)	0.047 (0.0518)
ln(electric/p)					0.0367 (0.0140)***	0.0232 (0.0141)*	0.0248 (0.0137)*	0.0247 (0.0138)*	0.0216 (0.0144)	0.0217 (0.0144)	0.0442 (0.0160)***	0.0448 (0.0161)***	0.0454 (0.0162)***
ln(telecom/p)					0.0225 (0.0192)	0.0133 (0.0197)	0.0307 (0.0198)	0.0289 (0.0199)	0.0315 (0.0200)	0.0316 (0.0200)	0.037 (0.0235)	0.0361 (0.0236)	0.037 (0.0236)
ln(proad/p)						−0.0937 (0.0407)**	−0.1012 (0.0496)**	−0.114 (0.0499)**	−0.1164 (0.0506)**	−0.1166 (0.0506)**	−0.0851 (0.0502)*	−0.0856 (0.0503)*	−0.0802 −0.0511
Credit (%)							−0.0003 (0.0002)	−0.0004 (0.0002)*	−0.0002 (0.0003)	−0.0002 (0.0003)	−0.0008 (0.0003)**	−0.0008 (0.0003)**	−0.0007 (0.0003)**
Illiteracy (%)											−0.0123 (0.0025)***	−0.0121 (0.0025)***	−0.0125 (0.0025)***
Coups								−0.0927 (0.0304)***	−0.0923 (0.0304)***	−0.0923 (0.0304)***	−0.054 (0.0330)	−0.0529 (0.0330)	
T_anom_p										−0.0004 (0.0002)*	−0.0005 (0.0003)		
T_anom									−0.0004 (0.0002)*				
ln(road/p)					−0.1694 (0.0273)***								
Constant	−1.3574 (0.1058)***	−0.3571 (0.1150)***	−2.0758 (0.1514)***	−2.6799 (0.3281)***	−2.6118 (0.4915)***	−2.5186 (0.5250)***	−1.5489 (0.6527)**	−3.1084 (0.5506)***	−2.1499 (0.6570)***	−2.158 (0.6571)***	0.2824 −0.5898	−2.3646 (0.5446)***	0.4405 −0.5704
Hansen's test (p-value)			0	0	0.47	0.45	0.69	0.56	0.51	0.5	0.14	0.14	0.16
Observations	2993	2993	1480	1480	1153	1153	1105	1095	1051	1051	886	886	886

Robust standard errors in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Instruments: lags 1-19

Regressions 5-13 include timme dummies

w: workers

p: population

TABLE 6 (b)
VARIABLE DEFINITIONS FOR TABLE 6 (a)

Ln(irriga/w) : ln(irrigated land per worker)
Ln(animals/w) : ln(livestock per worker)
Ln(pasture/w) : ln(pasture land per worker)
Ln(crops/w) : ln(crop land per worker)
Ln(tractors/w) : ln(tractors per worker)
Ln(fert/w) : ln(fertilizer per worker)
Ln(electric/p) : ln(electricity generating capacity per capita)
Ln(telecom/p) : ln(main phone lines per capita)
Ln(proad/c) : ln(km paved roads per capita)
Ln(road/c) : ln(km roads per capita)
Illiteracy : illiteracy rate
t_anom : temperature anomalies
t_anom_p : positive temperature anomalies
Coups : Copus d'etat
Credit : credit to the private sector (%GDP)
Trend : Time trend
Lac_Trend : Latin America * time trend

From Table 1 that summarizes previous studies we know that: animal stock elasticity fluctuates between 0.14 and 0.30, close to the range we obtain for our estimates; tractors elasticity moves between 0.06 and 0.14, also in the range we obtain for our elasticities; finally, labor elasticity fluctuates between 0.03 and 0.46, thus our estimates are in the middle of this range; land ranges from 0 to 0.42, therefore the sum of the crops and pasture's elasticities we estimate is higher than this reference interval. Unfortunately we are not aware of any other study that has added pasture land as an input different from crop land, therefore we have no reference for the sum of their elasticities.

We take the ranges of the elasticities of the translog as a reference for the Cobb Douglas function. The most striking result is the differences between the estimated land elasticities and labor elasticities. Despite the fact that land elasticities fluctuate significantly in the translog specification they show very low averages. Indeed, almost all the difference in the values of the labor elasticity between the Cobb Douglas specification and the translog is due to the differences in the values of the elasticities of the two types of land we use. For the other three inputs both functional specifications do not show significant deviations. However, what is clear from the differences between the translog and Cobb Douglas elasticities is that most likely pasture land as input interacts with other factors of production, either as a complements or substitutes, mechanism that is not captured by the Cobb Douglas specification.

VI. Is Latin America different?

Tables 7(a)-7(c) shows whether Latin America behaves differently and whether have been differences in its productivity determinants through the nineties decade. Table 7(a) reports the estimated regression. Table 7(b) shows the effects of the infrastructure variables for Latin America during the nineties and for the whole sample during the period 1960-2000. Table 7(c) shows the effects of each input for Latin America during the nineties and for the whole sample during the period 1960-2000. For this estimation we use as instruments the lags 5 through 19 of the input variables, and our estimates include fixed effects and time dummies. As in all the previous specifications we carried out the Dickey-Fuller test rejecting its null hypothesis.

From Tables 7(a)-(c) we note that once we interact LAC and nineties dummies all infrastructure variables recover its significance for the whole sample and the whole period. However, the effect of irrigation on productivity is no longer significant. Illiteracy has a slightly negative coefficient in Latin America up to the end of the eighties, however during the nineties decade illiteracy increases its importance for productivity but its effect is still not significantly different from zero. In Latin America the effect of electricity generating capacity over the period different from the nineties is positive as in the whole sample, however during the nineties this effect decreased loosing its significance. Regarding paved roads Latin America appears to be different to the rest of the sample having this variable a positive and significant impact in productivity which seems to have kept constant through the nineties decade. The number of phone lines is significant for Latin America as for the whole sample, however in LAC this effect changes during the nineties decade, loosing its significance. For the whole sample, credit has a negative impact, whereas for Latin America this effect is positive, however this effect vanishes during the nineties decade.[8]

Illiteracy is not significantly different from zero for LAC, this result does not mean that this variable does not have and indirect effect through other variables or factors of production. Indeed, for LAC Figure 2 shows a strong and significant relationship between illiteracy and fertilizer during the nineties. This relationship might be indicative that higher levels of education imply a higher degree of sophistication on the usage of agricultural techniques. Finally, is worth to keep in mind that even if illiteracy or education does not play a significant role in a production function it might play an important role in the allocation of resources and therefore in the costs structure. The former should be analyzed by studying added value functions and not production function.[9]

Table 7(c) shows the effects of inputs in the production function for LAC during the nineties. In LAC the largest elasticity is associated to animal stock with a coefficient of 0.32; it is followed by the crop land coefficient equal to 0.24; fertilizer has a coefficient of 0.07. The remaining two coefficients are associated to pasture land and tractors, but both are not significant at a 10% confidence level. Nevertheless, pasture land has a p-value of 0.16. If we add the coefficients and we

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10 The significance of each variable during the nineties decade was determined carrying out the corresponding F-test.

11 See Huffman (2001) for a full discussion on the role of education on agriculture.

TABLE 7 (a)
IS LATIN AMERICA DIFFERENT?

	lyw		lyw
ln(irrigate/w)	–0.0316	lac90*ln(fert)	–0.0136
	(0.0564)		(0.0276)
ln(animals/w)	0.1111	Illiteracy	–0.0179
	(0.0515)**		(0.0026)***
ln(pasture/w)	0.6587	ln(electric/p)	0.0418
	(0.0755)***		(0.0242)*
ln(crops/w)	0.0555	ln(proad/p)	–0.238
	(0.0638)		(0.0557)***
ln(tractors/w)	0.1979	ln(telecom/p)	0.0596
	(0.0246)***		(0.0299)**
ln(fert/w)	0.0109	Credit	–0.0011
	(0.0248)		(0.0003)***
lac* ln(irriga/w)	0.0044	lac*illiteracy	0.0169
	(0.0991)		(0.0071)**
lac* ln(animals/w)	0.2991	lac* ln(electric/p)	0.0237
	(0.1466)**		(0.0340)
lac* ln(pasture/w)	–0.5572	lac* ln(proad/p)	0.6376
	(0.1342)***		(0.0925)***
lac* ln(crops/w)	0.1601	lac* ln(telecom/p)	0.0003
	(0.1087)		(0.0579)
lac* ln(tractors/w)	–0.1345	lac*credit	0.0013
	(0.0804)*		(0.0006)**
lac* ln(fert/w)	0.0729	lac90*illiteracy	–0.0073
	(0.0340)**		(0 .0036)**
lac90*ln(irriga/w)	0.0406	lac90* ln(electric/p)	–0.0522
	(0.0316)		(0.0394)
lac90*ln(animals/w)	–0.0906	lac90* ln(proad/p)	–0.0232
	(0.0661)		(0.0410)
lac90*ln(pasture/w)	0.0475	lac90* ln(telecom/p)	–0.0015
	(0.0393)		(0.0424)
lac90*ln(crops/w)	0.0214	lac90*credit	0.0004
	(0.0233)		(0.0006)
lac90*ln(tractors/w)	–0.0208	Observations	886
	(0.0368)	Hansen's (p-value)	0.22

Robust standard errors in parentheses.
* significant at 10%; ** significant at 5%; *** significant at 1%.
Lac: indicates Latin America dummy.
90: indicates nineties dummy.
Instruments: lags 5/19.

TABLE 7 (B)
THE EFFECT OF PUBLIC GOODS ON AGRICULTURAL-SECTOR PRODUCTIVITY GROWTH IN LAC AND THE REST OF THE WORLD
(Effect of a 1% increase of each variable on the average annual growth of Agricultural Total Factor Productivity)

	Effect in LAC in the 1990s	Effect in the Rest of the World during 1960-2000
Illiteracy	–0.008 0.330	–0.018 0.000
Irrigation	0.013 0.880	–0.032 0.580
Roads	0.376 0.000	–0.238 0.000
Telephone Density	0.058 0.160	0.060 0.050
Credit to Private Sector	0.001 0.210	–0.001 0.000
Electricity Generation	0.013 0.740	0.042 0.085

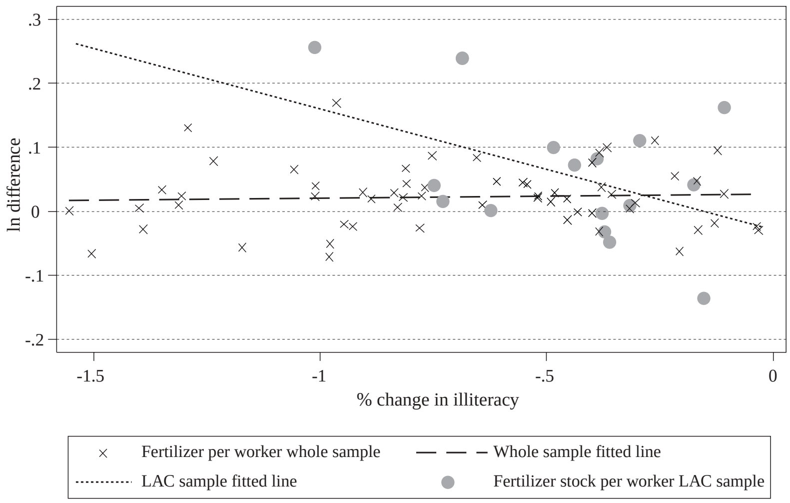
p-values below coefficients.

TABLE 7 (c)
THE EFFECT OF INPUTS IN LAC AND THE REST OF THE WORLD
(Effect of a 1% increase of each variable on the average annual growth of Agricultural Total Factor Productivity)

	Effect in LAC in the 1990s	Effect in the Rest of the World during 1960-2000
Animal Stock	0.32 0.01	0.11 0.03
Crop Land	0.24 0.00	0.06 0.39
Pasture Land	0.15 0.16	0.66 0.00
Tractors	0.04 0.44	0.20 0.00
Fertilizer	0.07 0.00	0.01 0.66

p-values below coefficients.

FIGURE 2
ILLITERACY AND FERTILIZER PER WORKER
(Change 2000-1980 whole sample; change 2000-1990 LAC sample)



consider constant returns to scale we obtain an implied elasticity of labor of about 0.18. However, we must keep in mind that the role of labor might be higher by giving up the coefficients that are not significant, under this assumption the role of labor greatly increases to an implied coefficient of 0.37.

Finally, Table 8 studies heterogeneity within Latin America in the effects of the variables studied in Table 7(a) on productivity and also for nineties decade. The first row shows the total effect for Latin America in each infrastructure variable during the nineties period. The remaining rows show the total effects of each variable for each country during the nineties decade at a significance level of 10%. For paved roads we also test whether the coefficients are different to the ones estimated for LAC. For this variable all the reported coefficients are different to the one reported for LAC, with the exception of Paraguay. The countries that show a higher degree of heterogeneity with respect to the average Latin American country are: Chile and Colombia and Ecuador. The countries with the higher homogeneity with respect to the average results are Honduras and Mexico. Regarding the impact of illiteracy on productivity, this variable has the most negative effect in Chile, whereas it has a positive effect in the case of Colombia and Venezuela. Electricity has the most positive effect in the case of Colombia and the most negative for Chile. Paved roads have a positive impact for the region however it has some important degree of heterogeneity. The country with the most negative effect for this variable is Brazil, whereas El Salvador shows the most positive deviation. Phone lines have its largest effect for the case of Brazil, and the smallest and negative for Ecuador. Credit has its greatest effect in the case of Venezuela and the most negative effect in the case of El Salvador. Irrigation has its largest effect for El Salvador and the most negative effect in the case of Peru.

TABLE 8
DETERMINANTS OF AGRICULTURAL PRODUCTIVITY IN THE 1990S:
HETEROGENEITY ACROSS LAC COUNTRIES

	Illiteracy	Electricity	Paved roads	Phone lines	Credit	Irrigation
LAC Effect	0.000	0.0000	0.3764	0.0000	0.0000	0.0000
Difference with respect to LAC Effect						
arg	ns	ns	ns	0.396	ns	ns
bol	ns	ns	ns	ns	ns	ns
bra	ns	ns	–1.388	1.800	0.001	–1.608
chl*	–2.329	–3.832	–1.205	ns	–0.081	–3.467
col	0.633	2.764	–1.615	1.458	ns	1.000
ecu*	–0.490	–1.001	–0.504	–1.442	ns	–2.150
slv	ns	ns	1.066	1.170	–0.464	2.947
hnd*	ns	ns	ns	ns	ns	ns
mex*	ns	ns	ns	ns	ns	ns
nic	–0.167	ns	ns	ns	ns	ns
pry	Ns	ns	0.857	ns	ns	ns
per	Ns	ns	ns	ns	ns	–10.488
ven	0.152	ns	ns	1.439	0.012	ns

Note: Reported coefficients are significantly different from 0 at 10%.
* Indicates that a different set of instruments has been used in order to make possible the computation of the coefficients; either because of computational feasibility or in order to get appropriated Hansen's tests.

VII. Concluding remarks

This paper provided three contributions to the literature on agricultural productivity. First, we computed agricultural TFP growth for a panel of countries using a translog-production function. We find substantial international heterogeneity in agricultural TFP growth rates, most developing countries have exhibited positive rates during 1960-2000. In some instances, agricultural TFP growth was actually higher in developing countries, such as Brazil, Mexico, and Argentina, than in some advanced countries that had transformed their economies in earlier time periods, such as Denmark and Finland (see Johnston and Mellor, 1961). However, on average, the agricultural productivity gap between developed and developing countries did increase during the period under investigation.

In turn, we explored the determinants of agricultural productivity. The evidence suggests that electricity generating capacity per capita has a positive impact on TFP. Surprisingly, roads had a negative effect on TFP growth. Among the other findings, illiteracy tends to hamper productivity growth, thus stressing the importance of basic skills in promoting technical progress in agriculture.

We also found some evidence that positive temperature anomalies are damaging for TFP growth, a result that poses a question about the impact that global warming will have on agriculture during the next decades. We also find some evidence that coups also hamper productivity. However, the significance of both variables vanishes once illiteracy is included in the regressions.

Finally, we studied whether LAC behaves differently from the rest of our sample and concluded that these countries' agricultural productivity did behave differently in some important ways. For example the effect of electricity generating capacity in LAC was important until only until the end of the 1980s, while during the nineties this effect decreased substantially loosing its statistical significance. Regarding paved roads, LAC appears to be different. This variable had an economically significant impact on agricultural productivity, and this effect did not change for LAC during the nineties decade. Credit also has a different effect in Latin America when compared to the rest of the sample. For the whole sample credit has a negative effect whereas for Latin America this effect is not significantly different from zero. Phone lines have a positive impact in LAC previously to the nineties, whereas during this period its effect is positive but not significant. In our final analysis we also test for heterogeneity within Latin America in the effects of the different determinants of productivity during the nineties decade. The results show that there are significant departures from the average effects for the region.

References

Arnade, Carlos (1998). "Using a Programming Approach to Measure International Agricultural Efficiency and Productivity". *Journal of Agricultural Economics*, 49: 1, pp. 67-84.

Basu, Susanto and John Fernald (1997). "Returns to Scale in U.S. Production: Estimates and Implications". *Journal of Political Economy*, 105 (2), pp. 249-283, April.

Binswanger, Hans and Vernon Ruttan eds (1978). *Induced Innovation: Technology, Institutions and Development.* Baltimore, MD: Johns Hopkins University Press.

Bernard, Andrew and Charles Jones (1996). "Comparing Apples to Oranges: Productivity Convergence Across Industries and Countries". *American Economic Review*, 86 (5), pp. 1216-38, December.

Bernard, Andrew and Charles Jones (1996). "Productivity Across Industries and Countries: Time Series Theory and Evidence". *Review of Economic and Statistics*, 78 (1), pp.1535-46, February.

Bhalla, Surjit (1988). "Mis-Sopecification in Farm Productivity Analysis: The Role of Land Quality". *Oxford Economic Papers*, 40 (1), pp. 55-73, March.

Crego, Al, Donald Larson, Rita Butzer and Yair Mundlak (1998). "A new database on Investment and Capital for Agriculture and Manufacturing". *World Bank Working Paper* 2013, World Bank.

Chavas, Jean Paul; Michael Aliber and Thomas Cox (1997). "An Analysis of the Source and Nature of Technical Change: The Case of U.S. Agriculture". *Review of Economics and Statistics*, 79 (3), pp. 482-92, August.

CID - World Bank Data Surfer: http://paradocs.pols.columbia.edu:8080/datavine/MainFrameSet.jsp

Coelli, Tim (1996). "Measurement of Total Factor Productivity Growth and Biases in Technological Change in Western Australian Agriculture". *Journal of Applied Econometrics*, 11 (1), pp. 77-91, Jan-Feb.

Datt, Gaurav and Martin Ravallion (1988). "Farm Productivity and Rural Poverty in India". *Journal of Development Studies*, 34 (4), pp. 62-85, April.

Fulginiti, Lilyan and Richard Perrin (1993). "Prices and Productivity in Agriculture," *Review of Economics and Statistics*, 75 (3), pp. 471-82, August.

Fulginity, Lilian and Richard Perrin (1998). "Agricultural Productivity in Developing Countries". *Agricultural Economics*, 19, 45-51.

Fulginity, Lilian and Richard Perrin (1999). "Have Prices Policies Damaged LDC agricultural Productivity?" *Contemporary Economic Policy*, 17, 469-475.

Gardner Bruce (2001). How U.S. Agriculture Learned to Growth: Causes and Consequences. Draft University of Maryland, January.

Griliches, Zvi (1963a) "The Sources of Measured Productivity Growth: United States Agriculture, 1940-1960". *Journal of Political Economy,* 71 (4): 331-46.

Griliches, Zvi (1963b) "Estimates of the Aggregate Agricultural Production Function from Cross-Sectional Data". *Journal of Farm Economics,* 45: 419-28.

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

Hayami, Yujiro (1970). "On the use of the Cobb-Douglas Production Function on the Cross-Country Analysis of Agricultural Production". *American Journal of Agricultural Economics,* 52: 327-9.

Hayami, Yuyiro and Vernon Ruttan (1970). "Agricultural Productivity Differences among Countries". *American Economic Review*, 60 (5), pp. 895-911.

Hayami, Yuyiro and Vernon Ruttan (1985). *Agricultural Development. An International Perspective*. The Johns Hopkins University Press, Baltimore and London.

Heady, E.O. (1944). "Production Functions from a Random Sample of Farms". *Journal of Farm Economics,* 26: 989-1004.

Henrichsmeyer, W. ; Ostermeyer-Schloder (1988). "A Productivity Growth and Factor Adjustment in EC Agriculture". *European Review of Agricultural Economics*, 15 (2/3), pp: 137-54.

Huffman, Wallace (2001). "Human Capital: Education and Agriculture". In *Handbook of agricultural economics.* Bruce L. Gardner and Gordon C. Rausser eds. Amsterdan-New York, Elsevier.

Jorgenson, D.W. Gollop, F.M. (1992). "Productivity growth in U.S. agriculture: A postwar perspective". *American Journal of Agricultural Economics*, 74 (3), 745-750, pp.

Richard Just, David Zilberman, and Eithan Hochman. "Estimation of Multicrop Production Functions". *American journal of Agricultural Economics*, 65 (4): 745-750.

Kawagoe, Tishihico, Yuyiro Hayami and Vernon Ruttan (1985). "The Inter-country Agricultural Production Function and Productivity Differences among Countries". *Journal of Development Economics*, 19, pp. 113-132.

Kim, H. Youn (1992). "The Translog Production function and Variable Returns to Scale". *Review of Economics and Statistics*, 74 (3), pp. 546-52, August.

Lau, Lawrence and Pan Yotopoulus (1989). "The Meta Production Function Approach to Technological Change in World Agriculture". *Journal of Development Economics*, 31, pp. 241-269.

Lewis, Arthur (1954) "Economic Development with Unlimited Supply of Labor". *Manchester School of Economic and Social Studies*, 22, pp. 139-91.

Lusigi, Angela and Colin Thirtle (1997). "Total Factor Productivity and the Effects of R&D in African Agriculture". *Journal of International Development*, 9 (4), pp. 529-538.

Lopez, Ramon and Alberto Valdes (2000). "Fighting Rural Poverty in Latin America: New Evidence of the Effects of Education, Demographics and Access to Land". *Economic Development and Cultural Change*, 49 (1), pp. 197-211.

Mankiw, Gregory, David Romer and David Weil (1992). "A Contribution to the Economics of Economic Growth". *Quarterly Journal of Economics*, 107 (2): 407-438.

Martin, Will and Devanish Mitra (2001). "Productivity Growth and Convergence in Agriculture and Manufacturing". *Economic Development and Cultural Change*, 49 (2), pp. 403-21.

Mundlak, Yair (2001). *Agriculture and Economic growth. Theory and Measurement*. Harvard University Press.

Mundlak Yair, Donald Larson, Rita Butzner (1997). "The Determinants of Agricultural Production Function: A Cross Country Analysis". Draft September.

Murgai, Rinku Mubarik Ali, and Derek Byelee (2001). Productivity Growth and Sustaintability in Post Green Revolution Agriculture: The case of the Indian and Pakistan Punjabs. *The World Bank Research Observer* 16 (2), pp. 199-218, Fall.

NASA http://www.giss.nasa.gov/data/update/gistemp/ZonAnn.Ts.txt accessed on 12/12/2003.

Newll Andrew; Kiran Pandya; James Symons (1997). "Farm Size and the Intensity of Land Use in Gujarat'" *Oxford Economic Papers*, 49 (2), pp. 307-15, April.

Nin, Alejandro Channing Arndt, Paul Preckel (2003). "Is agricultural productivity in developing countries really shrinking? New evidence using a modified nonparametric approach". *Journal of Development Economics*, 71, pp. 395-415, August.

Olmstead, Alan and Paul Rhode (2002). The Red Queen and the hard reds: Productivity growth in American Wheat, 1800-1940. *NBER WP* 8863, April.

Pingali, Prabhu and Paul Hesey (1999). "Cereal Crop Productivity in Developing Countries: Past Trends and Future Prospects". *CIMMYT Economics Working Paper* 99-03.

Radwan, Ali Shaban (1987). “Testing Between Competing Models of Share-cropping”. *Journal of Political Economy*, 95 (5), pp. 893-920, October.

Rosegrant, Mark and Evenson Robert (1999). “Agricultural Productivity Growth in Pakistan and India”. *Pakistan Development Review*, 32 (4): 433-48.

Rostow, Walt (1956). “The take of into self sustained growth”. *Economic Journal*, March, 66, pp. 25-48.

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

Schultz, Theodore (1964). *Transforming Traditional Agriculture.* New Heaven, Conn: Yale University Press.

Thirtle, Colin, Lin Lin and Jenifer Piesse (2003). “The Impact of Research Led Agricultural Productivity Growth on Poverty Reduction in Africa, Asia and Latin America”. *World Development*, 31(12), pp. 1959-1975.

Tintner, G. (1944) “A note on the Derivation of Production Functions from Farms Records”. *Econometrica*, 12: 26-34.

Tintner, G. and O.H. Browlee (1944). “Production Function Derived from Farm Records”. *Journal of Farm Economics*, 26: 566-71.

Trueblood, M.A. (1996). “An intercountry Comparison of Agricultural Efficiency and Productivity”. Ph.D. dissertation, University of Minesota.

Yao, Shujie (2000). “How Important is Agriculture in China’s Economic Growth?” *Oxford Development Studies*, 28 (1).

APPENDIX

Our livestock equation is given by:
Livestock = cattle+buffaloes+asses+horses+mules+0.125*(sheeps+goats)+
+0.01*(ducks+chickens+geese+turkeys)
The factors used in correcting for body sizes across regions and countries are:

S.Saha.Africa		Madagascar	0.46	**Asia**		Taiwan	0.42	Jamaica	0.75	Lebanon	0.42	Italy	1
Angola	0.46	Malawi	0.46	Bangladesh	0.42	Thailand	0.42	Martinique	0.75	Libya	0.42	Japan	1
Benin	0.46	Mali	0.46	Bhutan	0.42	Viet Nam	0.42	Mexico	0.75	Morocco	0.42	Netherlands	1
Botswana	0.46	Mauritania	0.46	Brunei	0.42	**C. and S. Am.**		Nicaragua	0.75	Oman	0.42	New Zealand	1
Burkina Faso	0.46	Mauritius	0.46	Cambodia	0.42	Argentina	0.75	Panama	0.75	Qatar	0.42	Norway	1
Burundi	0.46	Mozambique	0.46	China	0.42	Bahamas	0.75	Paraguay	0.75	Saudi Arabia	0.42	Portugal	1
Cameroon	0.46	Namibia	0.46	Timor-Leste	0.42	Barbados	0.75	Peru	0.75	Syria	0.42	Spain	1
Cape Verde	0.46	Niger	0.46	Fiji Islands	0.42	Belize	0.75	Puerto Rico	0.75	Tunisia	0.42	Sweden	1
C.African R.	0.46	Nigeria	0.46	India	0.42	Bolivia	0.75	St. Lucia	0.75	Turkey	0.42	Switzerland	1
Chad	0.46	Réunion	0.46	Indonesia	0.42	Brazil	0.75	Suriname	0.75	U. A. Emirates	0.42	United Kingdom	1
Congo	0.46	Rwanda	0.46	Kampuchea	0.42	Chile	0.75	Trinidad &Tobago	0.75	Yemen	0.42	United States of America	1
Comoros	0.46	Senegal	0.46	Laos	0.42	Colombia	0.75	Uruguay	0.75	**OECD**		Yugoslavia	1
Cote D Ivoire	0.46	Sierra Leone	0.46	Malaysia	0.42	Costa Rica	0.75	Venezuela	0.75	Australia	1	**E. Europe**	
E.l Guinea	0.46	Somalia	0.46	Mongolia	0.42	Cuba	0.75	**W. Asia N.Africa**		Austria	1	Albania	0.73
Ethiopia	0.46	Sudan	0.46	Myanmar	0.42	Dominican R.	0.75	Afghanistan	0.42	Belgium-L	1	Bulgaria	0.73
Gabon	0.46	Swaziland	0.46	Nepal	0.42	Ecuador	0.75	Algeria	0.42	Canada	1	Czechoslovakia	0.73
Gambia	0.46	Tanzania	0.46	Noirth Korea	0.42	El Salvador	0.75	Bahrain	0.42	Denmark	1	Hungary	0.73
Ghana	0.46	Togo	0.46	Pakistan	0.42	French Guyana	0.75	Cyprus	0.42	Finland	1	Poland	0.73
Guinea	0.46	Uganda	0.46	P.N.Guinea	0.42	Guadeloupe	0.75	Egypt	0.42	France	1	Romania	0.73
Guinea Bissau	0.46	Zaire	0.46	Philippines	0.42	Guatemala	0.75	Iran	0.42	Germany	1	USSR	0.73
Kenya	0.46	Zambia	0.46	Singapore	0.42	Guyana	0.75	Iraq	0.42	Greece	1	Other Developed	
Lesotho	0.46	Zimbabwe	0.46	South Korea	0.42	Haití	0.75	Jordan	0.42	Iceland	1	Israel	0.82
Liberia	0.46			Sri Lanka	0.42	Honduras	0.75	Kuwait	0.42	Ireland	1	South Africa	0.82

The list of countries included in our initial sample is:

Code	Country	Code	Country
1	Albania*	47	Mali
2	Algeria	48	Mauritania
3	Angola	49	Mexico
4	Argentina	50	Morocco
5	Australia	51	Mozambique
6	Austria	52	Myanmar
7	Bangladesh	53	Nepal*
8	Benin*	54	Netherlands
9	Bolivia	55	Nicaragua
10	Brazil	56	Niger
11	Bulgaria	57	Nigeria
12	Burkina Faso	58	Pakistan
13	Burundi	59	Papua New Guinea*
14	Cambodia	60	Paraguay
15	Cameroon	61	Peru
16	Canada	62	Philippines
17	Chad	63	Poland
18	Chile	64	Portugal
19	China	65	Romania
20	Colombia	66	Rwanda
21	Cuba	67	Saudi Arabia*
22	Denmark	68	Senegal
23	Ecuador	69	Sierra Leone
24	El Salvador	70	Somalia*
25	Finland	71	South Africa
26	France	72	Spain
27	Germany	73	Sri Lanka
28	Ghana	74	Sudan
29	Greece	75	Thailand
30	Guatemala	76	Togo
31	Guinea	77	Tunisia
32	Haiti	78	Turkey
33	Honduras	79	Uganda
34	Hungary	80	United Kingdom
35	India	81	United States of America
36	Indonesia	82	Venezuela, Boliv Rep of
37	Iraq	83	Viet Nam
38	Ireland	84	Yemen*
39	Italy	85	Zambia
40	Japan	86	Zimbabwe
41	Kenya		
42	Laos*		
43	Liberia*		
44	Madagascar		
45	Malawi		
46	Malaysia		

* Indicates that output was not available for these countries.