Why is Agricultural Labour Productivity higher in some countries than others?

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Abstract

Agriculture productivity varies dramatically in different regions of the world. Using recent theories of economic growth and recently provided data sets, this study finds some empirical regularities between agricultural labour productivity growth, investment and education, as well as environmental factors, for 44 countries during the period 1980-1993. I find strong evidence that where agricultural investment and educated people rates are higher, agricultural labour productivity grows faster. Secondly, geographical factors as well as freer trade influence growth. Finally, I find evidence of conditional convergence, which means that cross-country agricultural productivity does not converge to the same level of steady-state but that productivity in each country converges to its own long-run equilibrium.

Key words: *growth, trade, labour productivity, convergence*

JEL Classifications: O47, Q18, R11.

Introduction**

Why has agricultural labour productivity in some countries grown more than in others? The remarkable growth in agricultural productivity is a reality, but unanimity disappears when we need a theory to explain the source of agricultural productivity growth, and also the differences across regions or countries, (Mundlack, 1997). Using World Bank's 1998 *World Development Indicator,* in 1996 over 1.3 billion of the World's economically active population were involved in the agricultural sector and 1.1 billion of these lived in countries that the World Bank labels as low income countries[1]. In these countries, the average agricultural gross domestic product (GDP) per worker in the period 1994-1996 amounted to $293 (1987 US prices). This means, for instance, that in the Netherlands, the agricultural GDP per worker in the same period was 140 times higher than the average agricultural GDP per worker in low income countries. In other words, a farmer in the Netherlands produced as much in less than three

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days as an average farmer in low income countries produced in one year[2]. Moreover, computing Gini's index to analyze the cross-sectional dispersion of agricultural labour productivity across 85 countries, I find that while for the year 1980 the index is equal to 0.65, in 1993 it increases to 0.70, highlighting increasing disparities in the agricultural GDP per worker. These facts provide the background to the questions which this paper attempts to answer. Which factors influence labour productivity growth? Has labour productivity, as predicted by new classical growth theory, converged in the last twenty years? And, if it hasn't, why?

Focusing our attention on the first question, in the last ten years a broad consensus has emerged between endogenous as well as neoclassical growth researchers that one of the key variables that explains growth is the increase in the quantity of human capital per person.

The acquisition of new machinery, the building of new infrastructure or, in other words, the accumulation of physical capital is, without doubt, one of the necessary conditions for sustained productivity growth in the agricultural sector. But this is only part of the story. The effective use of new technologies requires high levels of education or accumulation of human capital. Education interacts with new technologies in two different ways. First, higher levels of education are fundamental for the vast majority of innovations (see among others Hayami and Ruttan, 1985; Jamison and Lau, 1982). The effective use of new technologies often requires highly skilled individuals for, for example, the use of modern sophisticated machinery.

Second, health care may contribute to the growth of agricultural productivity through improvements in the farmers' productive capacity. Thus investment in human capital has to be seen not only as investment in higher skills but also as investment in better health.

A second piece of empirical evidence indicates that differences in the level of agricultural productivity, across countries or regions may be the result of different factors in the various economies. For example, Barro and Sala-I-Martin (1995) point that when regions have roughly similar preferences, technology levels and institutional and legal systems, they are more likely to see similar level of productivity in the long-run. But when regions or countries are heterogeneous relative to the previous factors, growth researchers usually reports different level of productivity across countries, once again in the long-run.

In the agricultural sector, besides differences in preferences, technologies and institutional systems, other factors can influence productivity heterogeneously across countries. These are given by geographical constraints such as soil quality and climate or the location of the country. Recent analysis (Gallup et al., 1999) has shown that these factors affect economic growth and especially the agricultural sector.

It is well known that a country's location can affect agricultural labour productivity. Transferring advanced agricultural technologies developed in the temperate zone to the tropical zone may be difficult. For example, Hayamy (1997, pg. 83) points out that high-yielding rice varieties for temperate zones are susceptible to pests and insects found in tropical zones and so agricultural technology transfer from one environment to another is impossible without appropriate adaptive research. Abstracting from the aforementioned geographical constraints, theoretical and empirical literature, see for example Grossman and Helpman's (1991) and Edwards' (1992, 1998), shows that a higher degree of openness will allow smaller countries to absorb technology developed in the advanced nations at a faster rate and thus they will grow more rapidly. The same results appear in Roe and Mohtadi (2001). They provide an endogenous growth model where trade influence productivity growth in the agricultural sector. the results of Martin and Mitra (2001) suggest that a rapid convergence in agricultural sector productivity across countries may be ascribed to a relatively efficient transmission mechanism of knowledge in modern agriculture. Finally, in Gutierrez and Gutierrez (2002), strong evidence supporting the technological spillover of agricultural R&D from trade between temperate and tropical zones countries is shown.

In sum, besides the stock of physical capital, geographical constraints, differences in the capacity to absorb new technologies, differences in the quantity of human capital and trade openness are all factors that strongly influence agricultural productivity growth in a country.

In the following section, I first address the point connected to the geographical constraints and the diffusion of advanced technologies developed in temperate zones to tropical zones by analysing a model, largely derived from Barro and Sala-I-Martin (1995), where the equilibrium rate of growth in the poorer country (in our case the tropical country) depends on the cost of imitation, and on its initial stock of knowledge. If the costs of imitation are lower than the cost of innovation, the poorer country can grow faster than the advanced one and productivity can converge to the level of developed countries. But when strong adaptive research is needed to apply advanced technologies developed in temperate zones, tropical countries can experience a lower level and growth rate of agricultural productivity. Thus to find empirical support for the previous preposition, I specify an empirical equation that connects the rate of labour agricultural productivity growth in a country to its starting level and to a set of variables that I identify with geographical factors, human capital, degree of openness and, naturally, technical inputs.

In section three I estimate the previous equation for a sample of 44 countries. In synthesis, I find that agricultural labour productivity is closely linked to investment in technical input as well as in human capital. Secondly, geographical factors and trade exert a significant role in enhancing labour productivity in the agricultural sector. Finally, our empirical evidence refutes the hypothesis of absolute labour productivity convergence across countries but I find evidence of conditional convergence. Similar results have been reported in Gutierrez (1999) and Gutierrez (2000). Finally, section four concludes.

Theoretical Framework

In the previous section, I noted that the diffusion of advanced technologies developed in temperate zones to tropical zones can be difficult without adaptive research. In the following I address this issue using a simple leader-follower model.[3] The technology is spread from a country that I call the temperate country, to a follower country that I call the tropical country. In this model the level of technology is given by the number of intermediate products used in producing the agricultural final goods. The temperate country invests in research in order to invent intermediate goods that are used to produce the agricultural final goods. The tropical country does not invent intermediate goods, but attempt to adapt the product that are produced in the temperate country. Thus intermediate goods will be available in the tropical country only if funds are expended to adapt the goods to this environment. If N_1 intermediate goods are discovered in the temperate country, the final agricultural goods are produced by the following production function[4]

$$Y_1 = A_1 L_1^{1-\alpha} \sum_{j=1}^{N_1} \left(X_{1j} \right)^{\alpha}, \tag{1}$$

where $0 < \alpha < 1$, A_1 is the level of technology, L_1 is a given quantity of labour that I assumed constant, and finally X_{1j} is the quantity of intermediate input *j* used to produce the final good Y_1. Note that using (1) the marginal product of intermediate good *j* is independent of the quantity of intermediate product *i*, with $i \neq j$, used in the production process, i.e. the production function is additive separable. The marginal product of the *j*th intermediate input is given by

$$\partial Y_1 / \partial X_{1j} = A_1 \alpha L_1^{1-\alpha} X_{1j}^{\alpha-1}. \tag{2}$$

Assuming, without loss of generality, a unit cost of production for each X_{1j} and a unit price for the final good Y_1, and defining the price for each intermediate input as P_{1j}, I end with the factor prices and marginal products and the zero profit relationship [5]

$$P_{1j} = A_1 \alpha L_1^{1-\alpha} X_{1j}^{\alpha-1},$$

and X_{1j} can be written as

$$X_{1j} = \left(A_1 \alpha / P_{1j} \right)^{1/(1-\alpha)} L_1 \tag{3}$$

Equation (3) yields the demand function for intermediate input *j* in the country.

In order to motivate research in the leader country I assume that inventors will retain a monopoly profit on the invention. In this case the price P_{1j} will be set to a value that exceeds the marginal cost of production of the intermediate goods X_{1j}, i.e. producers will set the price to maximise the profit $\pi_{1j} = \left(P_{1j} - 1 \right) X_{1j}$ from sales of intermediate input *j*. Using (3) the expression to maximise is

$$\left(P_{1j} - 1 \right) \left(A_1 \alpha / P_{1j} \right)^{1/(1-\alpha)} L_1$$

and the solution for P_{1j} is

$$P_{1j} = P_1 = 1/\alpha > 1 \tag{4}$$

Substituting (4) in (3), the level of the intermediate product can now be written as

$$X_{1j} = \left(A_1\alpha^2\right)^{1/(1-\alpha)} L_1 \quad (5)$$

Using expression (5) and (1) I am ready to determine the level of output per worker in the temperate or leader country

$$y_1 = \frac{Y_1}{L_1} = \left(A_1\right)^{1/(1-\alpha)} \alpha^{2/(1-\alpha)} N_1 \quad (6)$$

A rise of the total factor productivity parameter A_1 or in the number of intermediate inputs N_1 increases the output per worker, or the average labour productivity, y_1. Profits are given by

$$\pi_{1j} = \frac{(1-\alpha)}{\alpha}\left(A_1\right)^{1/(1-\alpha)} \alpha^{2/(1-\alpha)} L_1 \quad (7)$$

In a competitive R&D environment, any producer will try to equate the present value of profit π_{1j}/r_1, where r_1 is a constant rate of return, to the exogenous cost η of inventing a new product so that :

$$r_1 = \frac{(1-\alpha)}{\alpha}\left(A_1\right)^{1/(1-\alpha)} \alpha^{2/(1-\alpha)} \left(L_1/\eta\right) \quad (8)$$

The final step requires the definition of the growth rate of output γ_1 in the temperate country. The simplest way is to use the well known Ramsey-household optimality condition. Assuming an utility function given by $u(C_1) = \left(C_1^{1-\theta} - 1\right)/(1-\theta)$, where $\theta > 0$ is the elasticity of marginal utility of consumption, maximisation of utility, subject to a budget constraint, leads that $\gamma_1 = \dot{C}_1/C_1 = 1/\theta(r_1 - \rho)$ where ρ is the consumer rate of time preference. It is simple now to show that both output Y_1 and consumption C_1 grow at the same rate. Looking at (6) we note that, given the hypothesis of a constant amount of labour L_1, total productivity A_1 and α, output Y_1 will growth at same rate as N_1, i.e. the number of intermediate inputs included in the production process. Thus in the model, the growth of N_1 reflects a form of technological progress. Assuming absence of trade, consumption is the residual when subtracting from output the amount of resources devoted in the period to R&D, that is equal to the cost of R&D, η, multiplied the growth of intermediate inputs in the period, $\dot{N}_1$, i.e. $\eta\dot{N}_1$ or $\eta\gamma_1 N_1$, and the cost of intermediate inputs, $N_1 X_1$, where $X_1 = \sum_j X_{1j}$. Thus economy's budget constraint can be written as $C_1 = Y_1 - \eta\gamma_1 N_1 - N_1 X_1$.

Substituting for Y_1 and γ_1 in the economy's budget constraint it is simple to show that, given a constant amounts for L_1 and A_1, C_1 will grow at the same rate as N_1, so that consumption grows at the same rate γ_1 as Y_1 and N_1. Thus using (8) and substituting for r_1 in the optimality condition we end with the following expression for output growth rate

$$\gamma_1 = (1/\theta)\left[\frac{(1-\alpha)}{\alpha}(A_1)^{1/(1-\alpha)}\alpha^{2/(1-\alpha)}(L_1/\eta)-\rho\right] \quad (9)$$

The production function in the tropical country is similar to equation (1)

$$Y_2 = A_2 L_2^{1-\alpha}\sum_{j=1}^{N_2}(X_{2j})^{\alpha} \quad (10)$$

where now the tropical country produce the final good Y_2 using the quantity of labour L_2 and N_2 intermediate inputs X_{2j}. Given the hypothesis of tropical country as follower of the discoveries made by innovators in the temperate country the model assumes that $N_2 < N_1$, i.e. in each period the follower country has access to a limited number of discoveries made in country 1.

Once the tropical country adapts the discovery to its environment, it acquires a monopoly power over the production and sale of the good. Thus the model follows exactly the same line introduced for the leader country. The price of the intermediate goods are $P_2 = 1/\alpha$, thus the tropical country produces the following quantity of the *j*th intermediate good

$$X_{2j} = \left(A_2\alpha^2\right)^{1/(1-\alpha)} L_2 \quad (11)$$

and the labour productivity is given by

$$y_2 = \frac{Y_2}{L_2} = (A_2)^{1/(1-\alpha)}\alpha^{2/(1-\alpha)}N_2 \quad (12)$$

Assuming a constant rate of return the optimal condition requires that the present value of profits from sales of *j*th in tropical will equal the cost of imitation ν. As for the leader country output growth will be given by

$$\gamma_2 = (1/\theta)\left[\frac{(1-\alpha)}{\alpha}(A_2)^{1/(1-\alpha)}\alpha^{2/(1-\alpha)}(L_2/\nu)-\rho\right] \quad (13)$$

I am now ready to compare the output growth in the two countries looking at expressions (9) and (13). Assuming for a moment that $A_1 = A_2$ and $L_1 = L_2$, the tropical country will grow at a faster rate then the temperate country, i.e. $\gamma_1 < \gamma_2$, only if the cost of imitation is lower then the cost of inventing new intermediate goods, i.e. $\nu < \eta$. Note that the relationship is clearly reversed when the cost of imitation is higher than the cost of invention. Leaving aside differences in the total productivity A_i, $i = 1,2$, and in the quantity of labour used, L_i, $i = 1,2$, labour productivity in the tropical country will converge to labour productivity in the temperate country only if $\nu < \eta$.[6] Naturally this means that the tropical country will acquire all the intermediate inputs used in the temperate country. In this case output per worker, or labour productivity in the tropical country will equal labour productivity in the temperate country, i.e. $y_2 = y_1$.

Until now I have assumed equal total factor productivity in the two countries, i.e. $A_1 = A_2$. When differences in level of education, for example, cause differences in the total factor productivity we have that the tropical country will converge to a lower level of labour productivity, $y_2 < y_1$. Thus the follower country can grow at the same rate as the leader country when all intermediate inputs used in the leader country are acquired. Even so, differences in labour productivity will eventually remain.

Concluding, costs of adaptation and imitation influence labour productivity growth in follower country. When the costs of imitation are cheaper than the costs of invention, follower countries could experience convergence to the higher labour productivity level in temperate advanced countries. Otherwise, differences in the level of agricultural productivity can still persist in the long-run. The international transfer of agricultural technology is more difficult than that of industrial technology, (Hayami, 1997; Hayami and Ruttan, 1985; and Sachs, 2001). Modern agricultural technology has mainly been improved in developed countries located in temperate zones. Thus without appropriate adaptive research which helps to assimilate and exploit externally available information, but implies sometimes consistent costs of imitation, countries located in tropical zones may not benefit from technological spillovers and then show a lower level of productivity compared to countries located in temperate zones.

Secondly, looking at equations (9) and (13) other factors can influence productivity growth and convergence in the agricultural sector. Differences in education, health and trade policy can affect total factor productivity and gaps between temperate and tropical can still persist.

To analyze the effect of previous factors on agricultural labour productivity growth, I now introduce an estimable growth equation. In the literature on cross-country growth regressions, see for a survey Temple (1999), authors often focus on the analysis on the neoclassical production function $y = Ak^{\alpha}$, where y and k are respectively the output and capital per unit of effective labour and $\alpha < 1$. Expressed in this form, the production function shows diminishing marginal productivity of capital. I can introduce now the steady-state level of the output per effective unit of worker, denoted y^*. If the capital stock converges gradually to its steady-state, output per worker will also converge. I can write the growth equation in the following form:

$$\gamma_i = \left(dy_{i(t+T)} / dy_{it}\right) / T = c + \lambda\left(\ln y_i^* - \ln y_{it}\right) \qquad i = 1,\ldots,N \qquad (14)$$

where on the left side we have the average growth rate of output per effective worker in country *i* measured over the interval between the period *t* and *T*. The growth rate depends on a constant *c*, and on the gap between the steady-state level of output per worker and the level of output per worker in the initial period *t*.

Now we can assume that the steady-state output per effective worker may be approximated by the following log-linear relationship $\ln y_i^* = \boldsymbol{\delta}'\mathbf{X}_i$ where $\mathbf{X}_i$ is a vector of variables which influence the steady-state of output per worker, such as for example the previously analysed variables given by the investment ratio, the level of human capital, the environmental and geographical constraints and the degree of openness. Finally, $\boldsymbol{\delta}$ is a vector of coefficients. Introducing the previous expression on equation (14) we end up with the following *conditional growth rate equation*:

$$\gamma_i = c + \lambda \boldsymbol{\delta}' \mathbf{X}_i - \lambda \ln y_{it} \qquad i = 1,\ldots,N \tag{15}$$

Equation (15) has become extremely popular in the last ten years and Barro and Sala-I-Martin (1995) show that, in cross-section studies, it is consistent with the diffusion technology model presented in the previous pages (see Barro and Sala-I-Martin (1995) chap. 8 pag 274-276).

The average growth rate in (15) is the function of the $\mathbf{X}_i$ variables and the initial output per worker. The latter term is of great importance because from the λ parameter we can learn whether there is a tendency toward convergence of output per worker, as neoclassical models assert or divergence, as postulated by the endogenous growth researchers. An estimated value of $\lambda>0$ in the equation (15) is taken as evidence for a type of convergence labelled *conditional convergence*. In this case a country that is further away from its output per worker steady-state will grow faster, but its own steady-state will be in general different from that registered in others countries. This form of convergence is definitely weaker than *absolute convergence*, where all countries converge to the steady-state of the same level of output per worker.

Empirical Results

The empirical analysis is based on a sample of 44 countries for which we collected data on agricultural GDP per worker and life expectancy from World Bank, investment ratios[8] from Larson and al. (1999), human capital from Barro and Lee (1996) and finally fertilizer and trade variables from FAO. The availability of data determined which countries[9] were included in the study.

Table 1. Agricultural GDP growth determinants

	GDP per worker 1980 (1987 US$)	*Annual Average*	*Invest-ment*	*Secondary*	*Life*
Countries		*Growth Rates*	*Ratios*	*Education*	*Expectancy*
		1980-1993	*1980*	*1980*	*1980*
Highest GDP per worker	23.131	3.6%	35%	2.6	76
Average GDP per worker	6.316	3.1%	18%	1.6	66
Lowest GDP per worker	162	-1.1%	6%	0.1	44

Source: World Bank, Barro and Lee (1996), Larson and al. (1999)

As previously mentioned, agricultural productivity in a country depends on its own growth determinants and, as we have seen, particularly on the investment ratio and on the level of human capital. In Table 1, we analyze how the growth determinants for a given country compare with those of other countries. Firstly, it emerges that during the period 1980-1993 the country where agricultural GDP per worker was highest in the initial period, the Netherlands, grew faster than the average growth rate of the sample countries and, above all, faster than the country with the lowest GDP per worker, Malawi, where labour productivity decreased at an annual average rate of 1.1%. This means that, during the period, the sample refuses the hypothesis of absolute convergence between countries. Secondly, looking at the growth determinants, the Table highlights that where investment ratio, average years of secondary schooling and life expectancy are higher, we note a higher GDP per worker growth rate. The same pattern is shown in the cross-countries average.

These values seem to confirm those of a large empirical literature that show a positive relationship between investment, human capital and income per capita growth (Barro and Sala-I-Martin, 1995).

In Table 2, we present the estimated coefficients for five cross-section regressions. We use, starting from regression (1) which I label *basic* growth regression, a bottom-up strategy introducing new variables in order to appreciate their effects on the previous estimates. In the *basic* regression, I regress the average annual growth rate of agricultural labour productivity on a constant and on the logarithm of the agricultural GDP per worker in 1980. The results show a positive and significant relationship between the productivity growth rate and the 1980 GDP per worker level. Thus as previously noted, the estimate refutes the absolute convergence hypothesis that agricultural labour productivity in different countries converges to a common steady-state level. This result is common to many recent works. For example, Caraveli and Darzentas (2001) reject the hypothesis of absolute convergence between rural and non rural/central EU regions.

To take account of cross-countries differences in the growth determinants, I introduce the logarithm of the ratio of agricultural fixed investment to agricultural GDP in the initial period in the regression. The estimated coefficient is positive and significant at the 5% level for a two sided test. Although the coefficient shows a positive relationship between investment and labour productivity growth, reserve causality may still hold. Countries where GDP per worker is higher may expect a higher savings rate which increases agricultural investment. This pitfall may be avoided by using of the investment ratio in the starting period of analysis. We also run a regression where the investment variable was given by fixed investment plus livestock and orchards investments (Larson and al., 1999). In this case, the estimated coefficient is still positive but not statistically significant.

In the third regression, I introduce the logarithm of the ratio of fertilizer to agricultural land area. The fertiliser/land variable is used as proxy for the use of a large set of modern technical inputs not included in the fixed investment variable. As underlined by Hayami and Ruttan (1985), these factors are needed to spur modern agricultural development.

The effect of fertilizers on agricultural labour productivity is positive and significant. Note that in the regression the investment ratio coefficient does not change from the previous regression. Finally the estimated coefficient of the log GDP per worker is now negative, but not significant.

Table 2. Cross-section regressions

		Regressions			
Variables					
	(1)	(2)	(3)	(4)	(5)
Constant	**-0.0312**	**0.0368**	**0.0300**	**0.025**	**0.126**
	(-1.550)	(1.011)	(0.894)	(0.643)	(2.319)
	[-2.376]	[1.129]	[0.989]	[0.851]	[2.880]
Log GDP per worker, 1980	**0.0064**	**0.0007**	**-0.0008**	**-0.0124**	**-0.0130**
	(2.574)	(0.198)	(-0.233)	(-2.700)	(-3.075)
	[4.119]	[0.228]	[-0.264]	[-2.901]	[-3.305]
Log investment ratio[1], 1980		**0.0109**	**0.0103**	**0.0127**	**0.0091**
		(2.199)	(2.271)	(3.062)	(2.185)
		[2.530]	[2.547]	[3.313]	[2.616]
Log fertilizer [2], 1980			**0.006**	**0.004**	**0.003**
			(2.891)	(2.348)	(1.437)
			[3.256]	[2.822]	[2.225]
Life expectancy, 1980				**0.001**	**0.001**
				(1.924)	(1.581)
				[2.133]	[1.837]
Log secondary education [3], 1980				**0.008**	**0.008**
				(2.063)	(1.778)
				[2.323]	[2.293]
Log openness[4]					**0.008**
					(2.131)
					[2.588]
Sachs-Warner openness dummy,1980					**0.012**
					(1.546)
					[1.814]
Dummy for tropical countries					**-0.019**
					(-2.486)
					[-2.740]
Implied ß convergence	**-0.006**	**-0.001**	**0.001**	**0.013**	**0.014**
	(-2.671)	(-0.199)	(0.236)	(3.356)	(3.862)
	[-4.273]	[-0.299]	[0.268]	[3.606]	[4.152]
Number of osservations	44	44	44	44	44
R2	0.14	0.23	0.36	0.51	0.65
F-test	6.63	6.03	7.53	7.77	7.34
LM normality test [5]	1.89	1.52	2.53	2.20	0.73
Breush-Pagan test [6]	62.79	54.13	55.57	52.42	27.93

Source: Author's calculations using World Bank, FAO, Larson & al.(1999), Barro and Lee(1996) data sets.

The dependent variable is the average annual growth rate of labour productivity for 1980-1993. In round brackets t-statistics. In square brackets White(1980) heteroskedastic-consistent t-statistics.

1] Log ratio of agricultural fixed investment to agricultural GDP.

2] Log ratio of fertilizer to total agricultural area.

3] Log average years of secondary schooling in the total population.

4] Log average 1979-80 agricultural (exports+imports)/ total GDP.

5] LM test on the null hypothesis that the errors are normally distributed.

6] Breush-Pagan test on the null hypothesis that errors are homoskedastic.

In the regression (4), I introduce, as proxies of the human capital level in the countries, the logarithm of years of secondary school of the total population, (Barro and Lee, 1996), and the life expectancy. Both coefficients are positive and significant at the usual 5% confidence level. The regression does not change the estimated coefficients related to the investment ratios and fertilizers variables but what it seems relevant to emphasise is that the coefficient of the log GDP per worker is now negative and strongly significant. When we introduce the human capital variable, the regression shows conditional convergence. That is countries converge to different labour productivity steady-states, and the steady-state is mainly conditioned by the level of physical as well as human capital.

Finally, in the last regression we address the issues connected to the empirical relationship between openness, a country's location and agricultural labour productivity growth. In regression (5), I introduce a dummy variable, which is 1 if more than fifty percent of the land area in a country is inside the tropics, and two openness indicators. The first is given by the log of the ratio of agricultural exports plus imports to the total GDP. This openness indicator is ready-available but has many limitations, as a country can distort agricultural trade heavily, and still have a high value for the ratio. The second indicator is Sachs and Warner's (1995) openness dummy variable, based on five trade-related indicators, including tariff and non tariff barriers, black market premia and the role of the state in the economy. As for the investment ratio variable and for the agricultural trade ratio, we use the 1980 values for Sachs and Warner's dummy in order to avoid reversed causality.

The tropical dummy coefficient is negative and significant. This means that, all other things being equal, tropical labour productivity has grown on average more slowly than in temperate countries. Thus geographical factors greatly limit agricultural labour productivity growth. Naturally, further research is needed, but I assume that many of the differences in the level of productivity between countries located in different climate zones, can be accounted for by the high adaptive costs that countries located in tropical zones must sustain to apply modern agricultural technologies developed in temperate countries. [10,11] If this is true, a policy that stimulate investments in R&D directed to enhances the tropical countries ability to assimilate and exploit existing technologies developed in temperate countries, can positively influence their productivity and contribute to the reduction of the productivity gap between the two zones.

Finally, both openness indicators have a positive effect. Thus the results confirm those found in the large empirical literature that freer trade can increase productivity.

I can now measure the relative importance of the variables included in the regression and look at the effect of a one-standard-deviation increase in a single variable on the agricultural labour productivity growth. When I raise the ratio of real agricultural fixed investment to real agricultural GDP by one-standard-deviation, the agricultural labour productivity growth rate is estimated to rise by 0.9% points per year whereas the effect of the secondary school and life expectancy variables is respectively of 0.7% and 0.9% per year. Thus secondary school education plays a significant role in the growth regression, but a less important one than life expectancy. This result is common in the empirical literature on growth regressions and has been justified with the arguments that life expectancy is a proxy for features other than good health, such as better work habits or higher level of skills, (Barro and Lee, 1994). Finally, a one-standard-deviation shock on the fertilizers variable and on the ratio of exports plus import to total GDP variable raises the labour productivity growth rate by 0.4% and 0.6% per year respectively.

We now return to the problem of convergence. As we have seen, the coefficient on the log of initial GDP per worker can be used to estimate the convergence rate, i.e. the rate at which a country converges to its own steady-state of labour productivity. Using the values of regressions (4) or (5), I note that the convergence rate is 0.014 which means that each year there is reduction equivalent to 1.4 percentage point in a country's own agricultural GDP per worker gap[12]. Thus the convergence of agricultural labour productivity is lower than for the whole economy, where the convergence rate is usually estimated to be 2% per year.

Conclusions

Differences in agricultural labour productivity growth rates across countries are large and, as we have shown, related to a set of quantifiable explanatory variables. Our empirical analysis suggests that countries where agricultural labour productivity is higher have a higher rate of investment in physical and human capital. Thus agricultural sector performance in the long run is determined by government policies to promote the development of institutions which encourage farmers to invest, increase their labour skills and introduce new methods of production. Freer trade may foster agricultural labour productivity and the implementation of liberalizing trade reforms may reduce productivity differentials. Finally, geographical factors influence labour productivity. We have shown that, during the period 1980-1993, and all else being equal, agricultural labour productivity in the tropical countries grew less on average than in temperate countries. This may be the result of a large set of different factors but, I think, many of these may be connected, in accordance with the model presented in the second section, to frictions in transferring modern technologies mainly developed in temperate zone to tropical zone. Investments in R&D directed to enhances the tropical countries ability to assimilate and exploit existing technologies developed in temperate countries, can positively influence their productivity and contribute to the reduction of the productivity gap between the two zones. Recent studies by Gutierrez and Gutierrez (2002) provide empirical evidence that the average rate of return for investment in agricultural R&D is substantially higher in tropical countries than in temperate countries. Thus further reflection is needed on how to increase appropriate research and technology transfer from one environment to another. Finally, regressions show the tendency for conditional convergence. In other words the analysis predicts higher growth of agricultural labour productivity in response to lower starting GDP per worker only if other explanatory variables are held constant. The estimated coefficient implies that convergence occurs at the rate of 1.4% per year.

Notes

1 orld Bank defines a low income country as a country with a GDP per capita less than US $785.

2 It is well known that using the US dollar official exchange rate we tend to underestimate the level of economic welfare in low income countries relative to high income economies. Nonetheless even if using purchasing power parities reduces the gap, it will usually remain extremely wide.

3 The model is broadly based on Barro and Sala-I-Martin (1995; 1997).

4 Either (1982) for the first time applies the following production function.

5 Naturally the equality between wage and labour productivity holds.

6 Note that we have assumed a constant quantity of labour in both countries so that output per worker growth parallels output growth.

7 For a theoretical derivation of the equation (15) the reference is Barro and Sala-i-Martin (1995).

8 The data set on investment in the agricultural sector has been kindly provided by Donald Larson. The investment ratio variable that has been calculated has the ratio of real fixed investment to real agricultural GDP.

9 The 44 countries are:

Argentina, Australia, Austria, Canada, Chile, Colombia, Costa Rica, Cyprus, Denmark, Dominican Republic, Egypt, El Salvador, Finland, France, Greece, Honduras, India, Indonesia, Iran, Italy, Jamaica, Japan, Kenya, Korea Rep., Malawi, Mauritius, Netherlands, New Zealand, Norway, Pakistan, Peru, Philippines, South Africa, Sri Lanka, Sweden, Syria, Trinidad and Tobago, Tunisia, Turkey, United Kingdom, Uruguay, United States, Venezuela, Zimbabwe.

10 A referee rightly pointed that soil fertility and climate can influence labour productivity and usefully could be used to discriminate between labour productivity in temperate and tropical zones. In regression (5), I introduce a soil fertility index using data published by FAO Digital Soil Map of the World (1995) and a rainfall/temperature index. Both variables, albeit positively related with agricultural labour productivity, were found non

significant, both when tropical dummy was included or excluded, and thus not inserted in the final regression.

12 I do not report for sake of brevity, estimates of tropical dummy for regression (1)-(4). The effect of the tropical dummy on agricultural productivity growth is always negative and statistically significant.

13 The convergence rate β can be rapidly calculated using the relationship $\beta=(1+\lambda T)/T$, where T=13. See Gutierrez (1999) for the analytical derivation.

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