IS AFRICAN AGRICULTURE CONVERGING? EVIDENCE FROM A PANEL OF CROP YIELDS

A. Lusigi, S. McDonald, J. Roberts and C. Thirtle[1]

1. INTRODUCTION

It is forty years since Willard Cochrane (1958) introduced the "technology treadmill", which suggested that farmers have to adopt new technologies to maintain profitability. Cochrane's concern was the agricultural sector of the United States, but the treadmill argument has global applicability, and has arguably influenced the international agricultural research effort. For world agriculture, the CGIAR system has the task of promoting technical change and, if it is succeeding in diffusing better technologies to the poorest countries, there should be some evidence of convergence. Thus, the less agriculturally successful countries within Africa should be closing the gap between them and the leaders, and the gaps between Africa and Asia, and the developed and developing countries should be decreasing.

The empirical macroeconomic growth literature has focused extensively on the convergence of GDP per worker (Mankiw *et al*., 1992; Barro & Sala-i-Martin 1995 and Sala-i-Martin 1996). The early research used cross-section econometrics to assess whether growth rates of GDP per worker were negatively correlated with initial levels of income. Typically this research found evidence for conditional convergence (Mankiw *et al*., 1992) and/or convergence clubs (Quah, 1997). Recently, these conclusions have been subject to a reappraisal based on the results from panel data econometrics (Islam, 1995 and Lee *et al*., 1997).

With respect to agricultural convergence the evidence is limited. Schimmelpfennig & Thirtle (1999) found evidence of total factor productivity (TFP) convergence in the EU. But they found evidence for two 'clubs': the USA and the EC countries with more advanced research systems (Netherlands, Denmark, France and Belgium) form a high productivity club, while Germany, Luxembourg, Greece, Italy, Eire and the UK converge to lower productivity levels. For the developing countries, Lusigi, Piesse &

[1] *Angela Lusigi, IFAD, Rome; Scott McDonald, University of Sheffield and University of Pretoria: Colin Thirtle, University of Reading and University Pretoria; Jennifer Roberts, University of Sheffield.*

Thirtle (1998) found conditional *beta* convergence of agricultural TFP for African regions, but not for the continent as a whole

In this paper a simple neoclassical (macroeconomic) growth model is adapted to explain yields in terms of initial conditions, investment and technical progress. The prediction of convergence in yields derived from this model is then tested using panels of aggregate and crop-level yield data for Africa.

2. CONVERGENCE

2.1 Concepts of convergence

The recent (empirical) growth literature has developed three main concepts of convergence. *Beta* convergence is said to occur if growth rates are inversely related to initial income levels. If explanatory variables other than the lagged or initial level of GDP are included in regressions estimating beta convergence, then a negative coefficient on the lagged income term indicates 'conditional' convergence (Barro & Sala-i-Martin, 1995:383-7). *Sigma* convergence is said to occur if the variance in the levels of GDP per capita across economies is reducing. This type of convergence is of interest when it is believed that countries converge to a common equilibrium level of per capita GDP (Barro & Sala-I-Martin, 1995)[1]. The third concept of convergence, developed by Lee *et al*., (1996), questions whether countries share common deterministic and/or stochastic trends, i.e., it is concerned with persistence and whether an economy is converging on its own steady-state equilibrium. Lee *et al*., (1997) have analysed this type of convergence, while related notions have been explored by Bernard & Durlauf (1996), Evans & Karras (1996), and Jones (1995).

This paper applies this third concept of convergence to African agriculture. It is arguable that this concept of convergence is particularly relevant for agriculture: the technology diffusion model presumes the existence of common trends across countries and this methods allows this to be tested while controlling for country specific conditions, e.g., variations in soil quality and climate.

2.2 Model

Assume the production function is a two input Cobb-Douglas with constant returns to scale and Harrod neutral technical change. Then at time *t* the function for any crop can be written as

$$Y(t) = [A(t)N(t)]^{1-\alpha} X(t)^{\alpha} \tag{1}$$

where

$N(t)$ is land, $X(t)$ is other inputs, which are used in fixed proportions, $Y(t)$ is output, $A(t)$ defines technology and α is the elasticity of output with respect to the capital-labour input with $0 < \alpha < 1$. Assuming that the supply of land is fixed, and that agriculture is operating at the extensive margin, then N is fixed, but the 'effective' supply of land can increase if there is technical progress. Assuming that technology grows at the exogenously fixed rate of g, i.e.,

$$A(t) = A(0)e^{gt} \tag{2}$$

and the stock of X depreciates at a constant rate, δ, such that

$$X(t) = I(t-1) + (1-\delta)X(t-1) \tag{3}$$

where

I is investment, and that investment is a constant proportion of output, s.

Then defining

$$y(t) = \frac{Y(t)}{N(t)} \tag{4}$$

where

$y(t)$ is yield (output per unit of land).

Solving for the steady-state yield (using definition (4) and by taking logs of (1)) gives

$$\begin{aligned} \ln y^*(t) &= \ln A(t) + \frac{\alpha}{1-\alpha}\ln s - \frac{\alpha}{1-\alpha}\ln(g+\delta) \\ &= \ln A(0) + gt + \frac{\alpha}{1-\alpha}\ln s - \frac{\alpha}{1-\alpha}\ln(g+\delta) \\ &= \ln y^*(0) + gt \end{aligned} \tag{5}$$

which is equivalent to the neoclassical growth model of Mankiw *et al.*, (1992).

A convergence process for yield can be written as

$$\Delta \ln y_t = g + \beta\left[\ln y_{t-1} - \ln y^*_{t-1}\right] \tag{6}$$

which on substituting using steady-state yield gives

$$\Delta \ln y_t \approx \beta \ln y_{t-1} - \beta g t - \beta\left[\ln y^*_0 - g\right] \tag{7}$$

which means that the change in the logarithm of yield is approximately a linear function of its past value, a constant and a deterministic linear time trend. If α and δ are the same across countries, but technical progress, investment rates and initial endowments are allowed to vary, adding a serially uncorrelated, independently distributed disturbance term gives

$$\ln y_{it} = g + (1+\beta_i)\ln y_{i,t-1} - \beta_i \ln y^*_{i,t-1} + \varepsilon_{it} \qquad \forall i = 1,2,....,N; t = 1,2,...T \tag{8}$$

where

$$\beta_i = -(1-\alpha)(g+\delta).$$

Substituting 5 into 8 produces

$$\mathrm{lny}_{\mathrm{it}} = {}_{\mathrm{i}} + {}_{\mathrm{i}}\mathrm{t} + {}_{\mathrm{i}}\mathrm{lny}_{\mathrm{i,t-1}} + {}_{it} \tag{9}$$

where

$$\mu_i = \lambda_i g_i + (1-\lambda_i)\left[\ln A_{i0} - \frac{\alpha}{1-\alpha}\ln(g_i+\delta) + \frac{\alpha}{1-\alpha}\ln s_i\right]$$
$$\lambda_i = 1 + \beta_i$$
$$\theta_i = (1-\lambda_i)g_i$$

which **allows all three parameters to vary across countries** with the intercept capturing the country specific constants. This is equivalent to the derivation developed by Lee *et al*., (1996).

2.3 Tests

For convergence $\lambda_i < 1$ which can be tested by a standard Dickey and Fuller (DF) test. If ε_t is not a white noise error process, the appropriate test is an Augmented Dickey Fuller (ADF) test of the form

$$\Delta \ln y_{it} = \mu_i + \theta_i t + (1-\lambda_i)\ln y_{i,t-1} + \sum_{j=1}^{p} p_{ij}\Delta \ln y_{i,t-1} + \varepsilon_{it} \forall i = 1,2,...N, t = 1,2,....T \quad (10)$$

If series are non-stationary (H_o: $1-\lambda_i=0$) it can be concluded that the series are unlikely to be converging over time. However it is well known that unit root tests have low power. Exploiting the panel structure of the data, the power of the unit root tests on the individual series can be increased by using the 't-bar test' (Im *et al.*, 1996). The test is based on the average value of the ADF statistics for individual countries. An important feature of the t-bar test is that it is more robust to misspecification of time trends in the individual group regressions than the standard ADF tests applied to individual series.[2]

The null hypothesis is that there is a unit root in the series. If a series is non-stationary it implies that the series does not converge to any series specific steady-state value. However, non-stationarity is a necessary but not sufficient for non-convergence: hence the presence of unit roots across multiple series only implies an absence of convergence. Equation 9 is an example of a dynamic heterogenous panel, and hence the mean group estimator, which estimates separate time series regressions for each country, is an appropriate method to test for a common rate of technical progress (Lee *et al.*, 1997; Pesaran and Smith, 1995). Estimating (9) as a **random coefficient model wherein parameter heterogeneity across countries is viewed as stochastic variation** approximates this method. The resulting coefficient estimates can either be weighted or unweighted (Greene, 1991).

2.4 Data

The only data are crop yields for all the African countries (53 covered by FAO), for the period from 1960 to 1995. They are from the FAO Agrostat database (1990), updated from FAO's files at their website. The data used were unadjusted except in so far as omitting apparently anomalous series, e.g., series where the yields were recorded as identical over a number of years, and series with limited or discontinuous observations. The largest samples are for an aggregate of all cereals, which covers 51 countries, coarse grains, which are reported for 47 countries and roots and tubers, which are available for 48 countries. Yields for 25 individual crops and aggregates such as vegetables and fibre crops are also used, with sample sizes varying form 8 countries for oats to 46 for maize, which is the most important grain crop. The crops covered and sample sizes are listed in Table 1 (*N* identifies the number of countries in each crop sample).

Table 1: T-Bar tests on the yields data (No * indicates rejection of null of non-stationarity)

	N	*P* = 0	*P* = 1	*P* = 2	*P* = 3	*P* = 4
All Cereals	51	-14.61	-6.88	-2.31	-2.76	-2.31
Barley	11	-7.94	-3.56	-1.74*	-2.44	-0.06*
Beans	25	-7.83	-4.12	-1.78*		
Cassava	29	-6.02	-2.90	-2.65	-1.19*	-1.28*
Coarse Grains	47	-14.89	-7.95	-3.72	-3.36	-2.11
Cocoa	15	-5.61	-2.60	-1.28*	0.76*	-0.60*
Coffee	23	-9.48	-2.63	-0.95*	-0.71*	0.32*
Fibre Crops	24	-7.61	-1.89*	-0.57*	0.89*	1.80*
Groundnuts	32	-10.07	-4.55	-1.55*	-1.30*	-0.33*
Maize	46	-12.41	-6.63	-3.11	-2.64	-2.70
Millet	30	-12.54	-5.35	-2.51	-2.02	-1.85*
Oats	8	-6.29	-5.05	-1.52*		
Oil Crops	45	-8.14	-3.24	-1.70*	-1.41*	-0.70*
Paddy Rice	36	-8.16	-3.80	-2.83	-2.02	-2.02
Potatoes	17	-4.44	-2.44	-2.52	-1.14*	-1.20*
Pulses	40	-10.02	-4.78	-1.70*	-1.80*	-1.80*
Roots & Tubers	48	-5.01	-2.37	-1.62*	-0.29*	-1.40*
Sesame	13	-5.75	-2.62	-2.22	-2.30	-0.92*
Sorghum	36	-13.53	-5.79	-2.39	-2.23	-2.20
Soya Beans	13	-5.39	-2.71	-0.42*	-2.74	-1.45*
Sweet Potatoes	22	-7.34	-5.06	-2.27	-2.05	-1.02*
Taro	11	-2.89	-0.14*	0.14*	-0.11*	0.08*
Tea	16	-5.76	-3.18	-0.78*	-0.21*	0.32*
Tree Nuts	19	-2.37	-3.64	-1.6+E9		
Vegetables	41	-4.79	-1.42*	0.08*	0.20*	0.73*
Wheat	22	-10.93	-6.20	-3.67	-2.89	-1.48*
Yams	19	-3.89	-3.45	-0.93*		-0.37*

2.5 Results

The ADF tests were conducted using intercepts and/or intercepts and time trends and the lags were varied between 0 and 4. The results, not reported, are not clear and vary with the number of lags[3]. The number of rejections of the null hypothesis decline as the number of lags increases, and there are slightly fewer rejections when a time trend is included. Since, more emphasis should be placed on the ADF results where P is greater, since a small P is more likely to be associated with misspecification errors while a larger P only implies increased inefficiency, the results with a trend and 4 lags may be most reliable.

These suggest that the probability of convergence appears to be low, e.g., for all cereals, the null hypothesis of a non-stationary process with a deterministic trend, is rejected in only two cases while for soya beans and sesame, non-stationarity can be rejected in only 15 percent of countries. However, the power of the ADF test is known to be low.

The t-bar tests in Table 1 produce a similarly confused picture. Most series are stationary with 0 and 1 lags, but rejections of the null hypothesis decline as the number of lags increase. Thus the t-bar tests imply that the necessary conditions for convergence apply for a number of the most important African crops, i.e., all cereals, coarse grains, maize, paddy rice and sorghum. On balance the evidence from the unit root tests is inconclusive. Since, non-stationarity is a necessary but not sufficient for non-convergence, and additional tests were conducted using random coefficient models with trend stationary and unit root processes to approximate equation (9).

Table 2 reports the results for the trend-stationary process. The coefficients of μ, the intercept term, θ, the time trend term and λ, the unit root coefficient on the lagged term in (9) are all reported. The key point is that the minimum and maximum values show relatively large variations in all the parameter estimates across countries. Thus, although the random coefficients model allows for both country specific and time specific variations in these parameters, considerable differences still persist. As a result, the chi-squared test for the joint restriction of homogenous coefficients across the countries in the sample is rejected in every case for the trend stationary process, meaning that they do not share common deterministic trends. So, this test clearly rejects the convergence hypothesis for the full sample of African countries.

3. POLICY IMPLICATIONS

Despite the growing literature on the internationalisation of R&D, discussed in Schimmelpfennig & Thirtle (1999), which may eventually lead to technological proximity, which is a prerequisite for convergence, there is no evidence that this tendency has yet appeared in African yields. We suspect that this negative result indicates that for a continent as diverse as Africa, R&D and technology generation needs to be at the regional level. Thus, Lusigi, Piesse & Thirtle (1998) found the same lack of convergence for TFP indices for African agriculture. However, when their sample was divided into regions (north, west, central, eastern and southern) there was reasonably strong evidence of convergence. Thus, agricultural technology appears to still be somewhat localised and the CGIAR system may need to concentrate more on regional organisations, such as SADAC.

Table 2: Random coefficients model: Trend stationary process

	μ_i				θ_I				λ_i				χ^2
	unweighted	**min**	**max**	**weighted**	**Unweighted**	**Min**	**max**	**weighted**	**unweighted**	**Min**	**max**	**weighted**	
All Cereals	4.609	1.472	9.988	0.097	0.004	-0.0004	0.011	0.00005	0.485	-0.1059	0.827	0.990	903.58
	0.386				0.001				0.044				
Barley	4.826	1.50	10.21	0.22	0.003	-0.0002	0.01	0.0001	0.459	-0.128	0.864	0.976	240.94
	0.978				0.002				0.112				
Beans	4.172	0.749	7.398	0.066	0.004	-0.00004	0.174	-0.00003	0.521	0.080	0.911	0.993	373.41
	0.584				0.002				0.066				
Cassava	4.007	1.583	14.92	0.185	0.002	-0.00006	0.010	-0.00004	0.638	-0.323	0.846	0.984	386.42
	0.621				0.002				0.055				
Coarse Grains	4.772	1.477	9.862	0.195	0.003	-0.009	0.011	0.0001	0.464	-0.094	0.843	0.980	857.55
	0.398				0.001				0.045				
Cocoa	3.464	1.579	6.969	0.165	-0.004	-0.010	0.013	-0.0004	0.576	0.157	0.8192	0.980	204.90
	0.642				0.004				0.074				
Coffee	3.285	0.495	6.774	0.489	-0.001	-0.008	0.019	0.001	0.610	0.204	-0.928	0.939	253.00
	0.488				0.003				0.057				
Fibre Crops	3.979	-0.134	7.732	1.040	0.001	-0.006	0.007	0.0002	0.514	0.049	1.014	0.873	333.03
	0.603				0.001				0.073				
Groundnuts	4.266	1.776	6.710	0.816	0.0002	-0.0009	0.0008	0.0001	0.523	0.271	0.787	0.910	396.61
	0.408				0.002				0.045				
Maize	4.479	1.701	8.503	0.272	0.004	-0.006	0.010	-0.0003	0.509	0.082	0.806	0.971	695.84
	0.373				0.001				0.039				
Millet	4.877	1.593	7.624	0.863	0.001	-0.0009	0.021	.00004	0.434	-0.054	0.830	0.903	491.35
	0.488				0.002				0.058				
Oats	5.511	2.512	7.538	0.402	-0.001	-0.028	0.012	-0.0005	0.364	0.123	0.705	0.955	141.30
	0.964				0.008				0.113				
Oil Crops	2.874	0.399	5.820	0.209	-0.00005	-0.00003	0.008	0.0001	0.614	0.286	0.946	0.971	520.64
	0.290				0.001				0.038				
Paddy Rice	3.637	1.731	6.580	0.267	0.004	-0.004	0.011	0.0001	0.613	0.311	0.816	0.974	434.81
	0.348				0.001				0.037				

Table 2 (cont): Random coefficients model: Trend stationary process

	μ_i				θ_i				λ_i				χ^2
	unweighted	**min**	**max**	**weighted**	**unweighted**	**min**	**max**	**weighted**	**unweighted**	**Min**	**max**	**weighted**	
Potatoes	3.775	2.756	4.949	0.091	0.002	-0.007	0.008	0.0003	0.659	0.491	0.774	0.993	190.61
	0.492				0.002				0.046				
Pulses	3.786	0.874	7.385	0.216	0.002	-0.001	0.015	-0.003	0.559	0.242	0.897	0.976	560.80
	0.383				0.001				0.435				
Roots & Tubers	3.200	1.180	8.334	1.718	0.002	-0.00007	0.011	-0.0001	0.709	0.436	0.900	0.995	460.23
	0.344				0.0008				0.030				
Sesame	3.624	4.502	7.215	0.269	0.003	-0.0002	0.015	0.0003	0.547	0.050	0.839	0.968	180.61
	0.656				0.004				0.085				
Sorghum	4.894	1.770	7.693	0.199	-0.0002	-0.009	0.010	-0.0001	0.445	0.140	0.780	0.979	626.02
	0.377				0.002				0.043				
Soya Beans	4.707	1.431	6.202	0.171	0.008	-0.0008	0.014	-0.0003	0.460	0.179	0.863	0.983	164.84
	0.779				0.003				0.091				
Sweet Potatoes	4.314	1.543	8.780	0.115	0.002	-0.0009	0.014	-0.0007	0.602	0.152	0.841	0.991	340.73
	0.520				0.002				0.050				
Taro	3.181	1.336	5.090	0.067	-0.0007	-0.001	0.003	-0.0002	0.708	0.567	0.846	0.994	107.10
	0.592				0.001				0.050				
Tea	4.085	2.340	5.764	0.530	0.005	-0.0005	0.013	0.00000	0.547	0.380	0.738	0.945	39.45
	1.255				0.004				0.136				
Tree Nuts	3.692	0.879	6.502	0.058	-0.0003	-0.00002	0.010	-0.0008	0.581	0.322	0.888	0.997	191.93
	0.741				0.003				0.076				
Vegetables	3.170	1.309	5.841	0.028	0.002	-0.0009	0.005	0.0001	0.714	0.516	0.903	0.998	426.81
	0.329				0.0004				0.030				
Wheat	5.124	2.867	9.294	0.402	0.008	-0.010	0.027	0.0004	0.433	-0.031	0.704	0.959	401.13
	0.517				0.002				0.061				
Yams	3.537	2.147	4.800	0.094	0.0003	0.0009	0.004	0.00001	0.678	0.531	0.804	0.992	194.67
	0.478				0.0010				0.044				

4. CONCLUDING COMMENTS

The analysis reported in this paper suggests that crops yields in Africa do not share common deterministic and/or stochastic trends, i.e., they are not converging to their own steady-state equilibria. Furthermore, the results of the unit root tests, which are conducted on the individual series, crop and country specific, are not suggestive of convergence clubs. However, the evidence, while not unambiguous, lends very little support for the hypothesis of convergence in output per unit of land. A particular need in this respect is to separate out the effects of g_i and λ_i on θ_i (see equation 9).

This analysis therefore suggests that despite the efforts of the CGIAR, and other bodies, to improve agricultural technology in Africa there is an absence of convergence in African agriculture. As such the current evidence indicates a need to consider carefully the extent to which technology diffusion model that has guided international agricultural research is operating as expected.

NOTES:

1. *Beta convergence is a necessary but not sufficient condition for the existence of sigma convergence (Quah, 1993). If the dispersion of income decreases the poorer economy must have grown faster, but if a poorer economy's growth rate is such that it becomes richer than the initially better off economy, the dispersion in GDP levels may not fall.*

2. *Im et al., (1995) show that under the null hypothesis, the t-bar test has standard normal distribution and provide values for the mean and variance of the distribution of ADF statistics.*

3. *There are arguments for using further tests to determine the number of lags and whether the processes have deterministic trends.*

REFERENCES

BARRO, R.J. & SALA-I-MARTIN, X., (1992). Convergence. *Journal of Political Economy*, 100:223-251.

BARRO, R.J. & SALA-I-MARTIN, X., (1995). *Economic growth*. New York: McGraw-Hill.

BERNARD, A.B. & DURLAUF, S.N. (1996). Interpreting tests of the convergence hypothesis. *Journal of Econometrics*, 71:161-173.

COCHRANE, W.W. (1979). *The development of American agriculture: A historical analysis*. University of Minnesota Press, Minneapolis.

EVANS, P. & KARRAS, G. (1996). Do economies converge? Evidence from a panel of U.S. States. *Review of Economics and Statistics*, 78:384-388.

IM, K., PESARAN, M.H. & SHIN, Y. (1995). *Testing for unit-roots in heterogeneous panels*. University of Cambridge, DEA Working Paper 9541.

IM, K., PESARAN, M.H. AND SHIN, Y. (1996). *Testing for unit-roots in heterogeneous panels.* University of Cambridge, DEA Working Paper 9541 (Revised).

ISLAM, N. (1995). Growth empirics: A panel data approach. *Quarterly Journal of Economics*, 110:1127-1170.

GREENE, W.H. (1991). *Econometric analysis*. London: Maxwell Macmillan.

JONES, C.I. (1995). Time series tests of endogenous growth models. *Quarterly Journal of Economics*, 110:495-525.

LEE, K., PESARAN, M.H. AND SMITH, R. (1996). *Growth and convergence: A multi-country empirical stochastic Solow model*. University of Leicester, Department of Economics, Discussion Paper 96/14.

LEE, K., PESARAN, M.H. & SMITH, R., (1997). Growth and convergence in a multi-country empirical stochastic Solow model. *Journal of Applied Econometrics*, 12: 357-392.

LUSIGI, A., PIESSE, J. & THIRTLE, C. (1998). Convergence of per capita incomes and agricultural productivity in Africa. *Journal of International Development*, 10(1):105-15.

MANKIW, N.G., ROMER, D. & WEIL, D.N. (1992). A contribution to the empirics of economic growth. *Quarterly Journal of Economics*, 107:407-437.

PESARAN, M.H. & SMITH, R. (1995). Estimating long-run relationships from dynamic heterogeneous panels. *Journal of Econometrics*, 68:79-113.

QUAH, D.T. (1993). Galton's fallacy and tests of the convergence hypothesis. *Scandinavian Journal of Economics*, 95:427-443.

QUAH, D.T. (1997). *Empirics for growth and distribution: stratification, polarization and convergence clubs.* Centre for Economic Policy Research, Discussion Paper No.1586, London, March.

SALA-I-MARTIN, X. (1996). The classical approach to convergence analysis. *Economic Journal*, 106:1019-1036.

SHIMMELPFENNIG, D.S. & THIRTLE, C. (1999). Research spillovers between the European community and the United States. *Contemporary Economic Policy*, 19:457-68.