Diversity Indices of Technical Capability of 14 African Countries
Working Paper No. 2005(1), ***Preliminary & Incomplete*** Draft 3 [January 31]

Voxi Heinrich Amavilah
REEPS
PO Box 38061
Phoenix, AZ 85069-8061

++

Abstract - I outline four, and calculate two, broad indices of the diversity of technical capability of 14 African countries based on nine common descriptors of technical capability. I find technical capability to be heterogenous, and conclude that performance policies that ignore technical diversity of capability are potentially misleading, ineffective, and perhaps even damaging.

Keywords: diversity indices, technical capability, diversity technical capability

JEL Code: O55, O49, C63, C65, P52

++

Is it so obvious that Nature is regular? I find myself tormented by its irregularities, by the occurrence of something unexpected .... The hope of progress lies in abandoning methods which require the law of universal causation (Arthur Balfour, 1914, quoted in TA Cook's *The Curves of Life*, 1979, p.430).

0. Introduction

ACCORDING TO Derry and Williams (1960) "technology comprises all that bewilderingly varied body of knowledge and devices by which man progressively masters his natural environment" (p. 1). To the extent it combines art, and applied and pure science, technology measures human creativity and innovation.[1] And as Hessenbruch (2000) points out "innovation is a collective experience - as opposed to the sudden insight of a genius - that takes the form of a progressive evolution" (p. 717ff). The very idea that innovations are evolutionary is implicit in the broad definition of technology, which partly explains why economists usually generalize technology as simply a *technical capability* (Abramovitz, 1979). In a familiar Cobb-Douglas framework, for example, a production activity can be carried out according to

$$Y = X^{\alpha}A \Leftrightarrow YX^{-\alpha} = A, \qquad (1)$$

where Y is a vector of the production activity such as GDP; X is a vector of resources like land, capital, labor, and entrepreneurship used to produce Y; α is the elasticity coefficient of X; and A is the technical capability broadly defined to include science and technology proper.

There is sufficient evidence that A is important to economic progress; in fact much of the growth literature is, in one way or another, about A and its rate of growth [$dA/dt \,/\, A$] (Solow, 1957, Lewis, 1965, Romer, 1990, Ruttan, 2001, Mokyr, 2003). What I find disturbing and which motivates this essay is a recent statement in the *African Development Report* (2004, p. 283) which claims that Africa's "large-scale enterprises, and smaller ones ... both show striking weaknesses in their technological capabilities" due in part to a feeble "technology infrastructure, which includes metrology, standards, testing and quality institutions, public research institutions and university research concerned with industry"(ib). To strengthen technological capabilities the *Report* calls for donor support; to sustain those capabilities long-term it recommends further human capital accumulation. In both cases the *Report* makes no specific mention of what kind of support it envisions, leaving the impression that its underlying assumption is that A is homogenous across African countries so that any solution that is good for the goose must be good for the gander. The disturbance: A does not have to be homogenous, because technical capability differ by country as it is a function of the country's population (N_i) and educational (Q_i) characteristics, cultural and communication (C_i) attributes, scientific and technological propensities (S_i), in addition to the level of economic activity (Y_i) as (1) shows, i.e.,

$$A_i = F(N_i, Q_i, S_i, C_i, Y_i) \ \forall i. \qquad (2)$$

[1] For the general theories of creativity and explanations see Rothenberg and Hausman (1976) and Pitt (1988), respectively.

Thus, for unique values of N_i, E_i, S_i, C_i, and Y_i, A_i is also unique. Therefore, dividing both sides of (2) by N_i gives per capita technical capability as

$$a_i = f(1, q_i, s_i, c_i, y_i), \quad (3)$$

where $a_i = A_i / N_i$ is per capita technical capability, $n_i = N_i / N_i = 1$ is a constant, $q_i = Q_i / N_i$ is per capita educational spending, $s_i = S_i / N_i$ is per capita expenditure on science and technology, $c_i = C_i / N_i$ is a vector matrix of per capita culturo-communication things, and $y_i = Y_i / N_i$ is per capita income.[2]

The objective of this essay is to calculate the capability (a_i) diversity of 14 African countries given common descriptors of technical capability. This is an important problem to address because growth policies that ignore the diversity of the technical capability of countries would lack prescriptive power. Lack of prescriptive power comes from the fact that once we admit the presence of diversity, as W.E. Deming teaches, we can ignore variability only at the risk of being *terribly wrong* (Deming, 1986, Walton, 1986). High diversity and variability both recommend specific approaches to problems facing individual countries. Section 1 outlines four broad diversity indices. In Section 2 I calculate two of the four indices outlined, and present the results in Section 3, followed by the conclusion in the last section.

1. Indices of Diversity

To determine whether *A* is homogenous or heterogenous I outline four broad non-parametric diversity indices many anchored in information theory (Shannon and Weaver, 1998, Ash, 1965, Khinchin, 1957) but widely used in ecological biology and natural resource biometrics (Zar, 1984, Putman and Wratten, 1984), and increasingly explored in economics as well (Stirling, 2001, Maignan, et. at., 2003). I describe technical capability as a qualitative variable that is a function of quantitative common descriptors discussed in Section 2. The description applies the Shannon-Weaver-Wiener's, Simpson's, Theil's, and modified Hill's formulas. However, calculation is limited to the first two. There is little loss of generality as all four indices can be shown to be related (Maignan, 2003).

1.1 Shannon-Weaver-Wiener Index

The Shannon-Weaver-Wiener's formula measures diversity as:

---

[2] Viewed as (2) and (3) technical capability here combines Abramovitz's "social capability" and "technological congruence" as outlined in Los and Verspagen (2001), and Temple and Johnson (1998). Also note that if $n_i = 1$ (3) suggests that even if countries had the same population size, their technical capabilities would still differ because the descriptors of technical capability are different.

$$H' = -\sum_{i}^{k} p_i \log p_i, \tag{4}$$

where H' is interpretted here as the general diversity index of technical capability, *k* is the number of descriptive categories within one country or across 14 countries, and p_i is the proportion of observations in the ith category. Zar (1984) shows that if we let *G* be the sample size, and g_i be the number of observations in the ith category, then $p_i = g_i / G,$ such that (4) is equivalent to

$$H' = [G \log G - \sum_{i}^{k} g_i \log\ g_i] G^{-1}. \tag{5}$$

Given that $H' = f(G, k),$

$$E_{H'} = [G \log G - \sum_{i}^{k} g_i \log g_i][G \log k]^{-1} = H' H'^{-1}_{\max},\ [H'_{\max} = \log k], \tag{6}$$

indicates the relative ***e****venness* (homogeneity) of technical capability, and the measure of ***u****nevenness* (heterogeneity) of technical capability is

$$U_{H'} = 1 - E_{H'}. \tag{8}$$

Eqs. (5)-(7) assume random sampling. For non-random samples H' can be Brillouin-modified as Zar (1984) demonstrates (see, pp. 34-36).

1.2 Simpson Index

The Simpson's index (D) measures the likelihood that if for instance we picked at least two African countries from a [random] sample they would have the same technical capability, implying that technical capability is evenly distributed across these countries. In other words,

$$D = \sum_{i}^{k} p_i^2 \ for\ 0 \le D \le 1, \tag{8}$$

which structurally is the famous Herfindahl-Hirschman Index (HHI). Then the Simpson's E_D

Table 1 - Raw Descriptors of Technical Capability, 14 African Countries

Country	Population (N_i) 000,000 1994	Educational Expenditure (Q_i), Millions, Selected Years	Number of Libraries (L_i)	Number of Books by UDC Title produced (B_i)	Number of Museums and Related Institutions (M_i)	Number of Radio Broadcast Receivers (R_i), Thousands, 1994	Number of TV Broadcast Receivers (TV_i) Thousands, 1994	Net Trade in Books and Related Materials (T_i), Millions, Selected Years	Public Spending on R & D (S_i), Millions, Selected Years	Real GDP (Y_i), Millions, 1994 at 1995 US$
Benin	5.25	58.82	17.0	647.0	21.0	480.0	29.0	0.0	0.70	1921.00
Burundi	6.20	41.12	234.0	0.0	3.0	400.0	9.0	0.0	0.30	1079.00
Congo (B)	2.52	0.20	5.0	0.0	1.0	290.0	18.0	-0.1	0.00	2015.00
Egypt	61.64	1271.90	429.0	3108.0	65.0	18950.0	6700.0	-2.1	1.00	57478.00
Gabon	1.28	156.90	1.0	0.0	1.0	189.0	49.0	-7.9	0.00	4635.00
Guinea	6.50	61.90	0.0	0.0	1.0	280.0	50.0	0.0	0.00	3536.00
Libya	5.23	166.90	0.0	0.0	1.0	1180.0	525.0	-10.8	0.20	25603.00
Madagascar	14.30	60.90	0.0	143.0	160.0	2740.0	280.0	-1.5	0.50	3107.00
Mauritius	1.10	93.10	1.0	96.0	5.0	405.0	245.0	-5.5	0.40	3671.00
Nigeria	108.47	362.50	88.0	1562.0	77.0	21300.0	4150.0	0.0	0.10	27423.00
Rwanda	7.75	90.30	0.0	0.0	1.0	158.0	1.0	0.0	0.50	3495.00
Senegal	8.10	253.50	7.0	0.0	1.0	945.0	297.0	-6.9	0.00	4256.00
South Africa	40.56	5643.40	1200.0	4751.0	1.0	12750.0	4100.0	0.0	1.00	146547.00
Tunisia	8.73	891.70	250.0	1165.0	1.0	1740.0	710.0	-2.7	0.30	17579.00
Total	277.63	9153.14	2232.0	11472.0	339.0	61807.0	17163.0	-37.5	5.00	302345.00

associated with D in (13) is

$$E_D = D[D_{\max}]^{-1}. \tag{9}$$

Based on (10) Simpson measure of heterogeneity (U_D) becomes $0 \le U_D = 1 - E_D \le 1$. Simpson's heterogeneity can also be measured as a reciprocal of D, i.e., $1 \le U'_D \equiv 1/D \le D_{\max}$, where U'_D is the reciprocal of D, and D_{max} is maximum D given complete evenness.[3] The implication: $E_D = 0$ means complete unevenness and $E_D = 1$ means complete evenness or "equitability", so that the higher U_D and U'_D, the lower diversity.[4]

1.3 Theil's Index

Theil's index (τ) is the third diversity index of technical capability. It is the statement that

$$\tau = \sum_i^k p_i[\log p_i - \log(1/k)] \in (0, \infty). \tag{10}$$

As the expression indicates, τ is just H adjusted for *k* so that $\tau = 0$ represents perfect homogeneity; $\tau = \infty$ suggests perfect heterogeneity.

1.4 Modified Hill's Ratio

The modified Hill's ratio, commonly known as E5 in the literature, measures evenness and is unaffected by the sample richness. It is

$$E5 = \frac{\frac{1}{D} - 1}{\exp(H') - 1} = \frac{\frac{1-D}{D}}{\exp(H') - 1} = \frac{1-D}{D} \times \exp(H') - 1 = \Phi \exp(H') - 1, \tag{11}$$

for Simpson's D and Shannon's H', and the rest should be obvious.

2. Data and Calculations of Indices of Diversity

Focus is on the following countries: Benin, Burundi, Republic of Congo, Egypt, Gabon, Guinea,

---

[3] Note here that although I follow the literature in formulating them, these indices are richer in content as they cut across categories as well as countries .

[4] The choice of these two indices described above is arbitrary; Andrew Stirling (2001, see. E.g., pages 47 and 52) and Maignan et. al. (2003) give alternative versions.

Table 2 - Relative Descriptors of Technical Capability, 14 African Countries

	$q_i = Q_i / N_i$	$l_i = L_i / N_i$	$b_i = B_i / N_i$	$m_i = M_i / N_i$	$r_i = R_i / N_i$	$tv_i = TV_i / N_i$	$t_i = T_i / N_i$	$s_i = S_i / N_i$	$y_i = Y_i / N_i$
Country	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
Benin	11.20	0.0000032	0.0001232	0.0000040	0.0914	0.0055	0.0000	0.133	365.91
Burundi	6.63	0.0000377	0.0000000	0.0000010	0.0645	0.0015	0.0000	0.048	174.03
Congo	0.08	0.0000019	0.0000000	0.0000040	0.0001	0.0071	-0.0397	0.000	799.60
Egypt	20.63	0.0000069	0.0000504	0.0000010	0.3074	0.1087	-0.0341	0.016	932.48
Gabon	122.58	0.0000008	0.0000000	0.0000010	0.1477	0.0383	-6.1719	0.000	3621.09
Guinea	9.52	0.0000000	0.0000000	0.0000010	0.0431	0.0077	0.0000	0.000	544.00
Libya	31.91	0.0000000	0.0000000	0.0000002	0.2256	0.1004	-2.0650	0.031	4900.00
Madagascar	4.29	0.0000000	0.0000001	0.0000112	0.0002	0.0196	-0.1049	0.035	217.27
Mauritius	84.64	0.0000091	0.0000873	0.0000046	0.3682	0.2227	-5.0000	0.364	3337.27
Nigeria	3.34	0.0000008	0.0000140	0.0000010	0.1964	0.0383	0.0000	0.001	252.82
Rwanda	11.65	0.0000000	0.0000000	0.0000001	0.0204	0.0001	0.0000	0.065	300.00
Senegal	31.30	0.0000009	0.0000000	0.0000001	0.1167	0.0367	-0.8519	0.000	525.43
South Africa	139.14	0.0000296	0.0001171	0.0000000	0.3143	0.1011	0.0000	0.025	3613.09
Tunisia	102.14	0.0000286	0.0001355	0.0000001	0.1993	0.8130	-0.3093	0.034	2013.63
Total	579.05	0.0001200	0.0005000	0.0000300	2.0953	1.5007	-14.5768	0.752	21596.62

Table 3a - Proportional Descriptors of Shannon-Weaver's Diversity Indices of Technical Capability, 14 African Countries

Country	$p_{i,q}$	$p_{i,l}$	$p_{i,b}$	$p_{i,m}$	$p_{i,r}$	$p_{i,tv}$	$p_{i,t}$	$p_{i,s}$	$p_{i,y}$	**H'**	**$E_{H'}$**	**$U_{H'}$**
Benin	0.0193467	0.0266667	0.000031623	0.1333334	0.0448475	0.0036606	0.0000000	0.1768618	0.0169440	0.158	0.166	0.834
Burundi	0.0114499	0.3141765	0.000000000	0.0333332	0.0307831	0.0000000	0.0000000	0.0638294	0.0080560	0.154	0.161	0.839
Congo	0.0000000	0.0158335	0.000000000	0.1333334	0.0000000	0.0047328	0.0027202	0.0000000	0.0037024	0.127	0.133	0.837
Egypt	0.0356272	0.0575004	0.000054772	0.0333332	0.1467092	0.0072433	0.0023452	0.0212767	0.0431775	0.160	0.105	0.895
Gabon	0.2116915	0.0066633	0.000000000	0.0333332	0.0704904	0.0255205	0.4234057	0.0000000	0.1676690	0.026	0.027	0.972
Guinea	0.0164378	0.0000000	0.000000000	0.0333332	0.0205693	0.0051283	0.0000000	0.0000000	0.0251872	0.100	0.105	0.895
Libya	0.0574778	0.0000000	0.000000000	0.0066633	0.1076694	0.0669021	0.1416633	0.0412237	0.2268874	0.122	0.128	0.872
Madagascar	0.0007403	0.0000000	0.000000000	0.3733334	0.0000000	0.0130613	0.0071972	0.0465424	0.0100598	0.156	0.164	0.836
Mauritius	0.1461705	0.0758333	0.000000000	0.1533329	0.1757267	0.1483974	0.3430107	0.4818069	0.1545273	<0.378>	0.396	0.604
Nigeria	0.0057619	0.0066633	0.000000000	0.0333332	0.0937331	0.0255205	0.0000000	0.0013416	0.0117046	0.133	0.139	0.861
Rwanda	0.0201196	0.0000000	0.000000000	0.0003332	0.0097365	0.0000000	0.0000000	0.0864361	0.0138888	0.115	0.121	0.879
Senegal	0.0540537	0.0075033	0.000000000	0.0003332	0.0055697	0.0244560	0.0584422	0.0000000	0.0243289	0.132	0.138	0.862
South Africa	0.2402902	0.2466667	0.000100000	0.0000000	0.1500023	0.0673683	0.0000000	0.0332445	0.1672960	0.039	0.041	0.959
Tunisia	0.5578019	0.2383334	0.000141421	0.0003332	0.0951178	0.541617	0.0212179	0.0452128	0.0932384	<0.322>	0.337	0.663
H'	0.191294	0.0018027	0.0011489	0.0138146	0.0207689	0.0278546	0.0000010	0.0009648	0.0142321	**0.016**	**0.110**	**0.843**
$E_{H'}$	0.166905	0.0015723	0.0010024	0.0120533	0.0181209	0.0243032	0.0000010	0.0008418	0.0124176		**0.026**	
$U_{H'}$	0.833095	0.9984277	0.9989976	0.9879467	0.9818791	0.9756968	0.9999999	0.9991582	0.9875825			**0.974**

Table 3b - Proportional Descriptors of Simpson's Diversity Indices of Technical Capability, 14 African Countries

Country	$(p_{i,q})^2$	$(p_{i,l})^2$	$(p_{i,b})^2$	$(p_{i,m})^2$	$(p_{i,r})^2$	$(p_{i,tv})^2$	$(p_{i,t})^2$	$(p_{i,s})^2$	$(p_{i,y})^2$	D	E_D	U_D
Benin	0.00037	0.00071	0.00000	0.01778	0.00201	0.00001	0.00000	0.03128	0.0002871	0.052447	0.005827	0.994173
Burundi	0.00013	0.09870	0.00000	0.00111	0.00094	0.00000	0.00000	0.00407	0.0000649	0.1050149	0.011668	0.988332
Congo	0.00000	0.00025	0.00000	0.01778	0.00000	0.00002	0.00001	0.00000	0.0013708	0.019431	0.002159	0.997841
Egypt	0.00127	0.00331	0.00000	0.00111	0.02153	0.00525	0.00001	0.00045	0.0018643	0.034794	0.003866	0.996134
Gabon	0.04481	0.00004	0.00000	0.00111	0.00497	0.00065	0.17927	0.00000	0.0281129	0.2589629	0.028774	0.971226
Guinea	0.00027	0.00000	0.00000	0.00111	0.00042	0.00003	0.00000	0.00000	0.0006344	0.00246	0.000273	0.999727
Libya	0.00304	0.00000	0.00000	0.00004	0.01159	0.00448	0.02007	0.00169	0.0514779	0.092388	0.010265	0.989735
Madagascar	0.00006	0.00000	0.00000	0.13938	0.00000	0.00017	0.00005	0.00217	0.0001012	0.1419312	0.015770	0.984229
Mauritius	0.02137	0.00575	0.00000	0.02351	0.03088	0.02202	0.11766	0.23214	0.0238787	0.4772087	0.53023	0.946977
Nigeria	0.00003	0.00004	0.00000	0.00111	0.00879	0.00065	0.00000	0.00000	0.0001370	0.010757	0.001195	0.998805
Rwanda	0.00040	0.00000	0.00000	0.00001	0.00009	0.00000	0.00000	0.00747	0.0001929	0.00816	0.000907	0.999093
Senegal	0.00292	0.00006	0.00000	0.00001	0.00310	0.00059	0.00342	0.00000	0.0005919	0.010692	0.001188	0.998812
South Africa	0.05774	0.06084	0.00000	0.00000	0.02251	0.00454	0.00000	0.00111	0.0279880	0.174728	0.19414	0.980586
Tunisia	0.31114	0.05680	0.00000	0.00001	0.00905	0.29335	0.00045	0.00204	0.0086934	0.6815334	0.075726	0.924274
D	0.443558	0.226518	0.00000	0.20408	0.115878	0.331765	0.320928	0.282433	0.145395	0.147929	0.016433	**0.982984**
E_D	0.031683	0.016179	0.00000	0.014577	0.08277	0.023698	0.022923	0.020174	0.010385		0.025	
U_D	0.968317	0.983821	0.00000	0.985423	0.991723	0.976302	0.977077	0.979826	0.989615			**0.98356**

Libya, Madagascar, Mauritius, Nigeria, Rwanda, Senegal, South Africa, and Tunisia. I draw most of the data, except GDP data, form UNESCO's *1996 Statistical Yearbook*. GDP data for 12 countries comes from *African Development Indicators* (2004); and for Libya and Rwanda it comes from *Sub-Saharan Africa: From Crisis to Sustainable Growth* (1989) and are both for 1987. Table 1 presents raw data on population (N_i), education (Q_i), culture and communication (C_i), net foreign trade in books and book related materials (T_i), science and technology (S_i), and general economic activity (Y_i).

Population is the median number of people in millions. Education refers to total educational expenditure (i.e. the sum of current and capital expenditures on education) in million of local currency converted to US $ using market exchange rate data which comes from the IMF's *International Financial Statistics Yearbook* (1998). In addition, a country's culture and communication (C_i) is reflected in its institutions: libraries (L_i), museums and similar entities (M_i), radio (R_i) and TV_i broadcast receivers. Another important dimension of C_i is the production of books (B_i) by the number of titles according to the universal decimal classification (UDC). Also associated with C_i is trade (T_i) defined as the ratio of the books and related materials exported (x) LESS imported (m) to the SUM of books and related materials exported and imported (x + m), i.e., $T = {}^{x-m}\!/_{x+m}$, which turned out to be either zero (balanced trade) or negative (trade deficit) in all 14 cases. The final column of Table 1 shows the economic activity measured as real GDP in 1994 at 1995 US$ prices.

UNESCO also gives statistics for selected science and technology (S_i) indicators: persons engaged in **R**esearch & **D**evelopment, and the number of scientists, engineers, and technicians in R and experimental D. Because these data are rather difficult to summarize, as a common-denominator I use expenditures on R & D as a percent of GNP to represent S_i.

Table 2 presents per capita data implied by (3). While n_i, q_i, s_i, and y_i are straightforward, measurement of c_i is not as simple, although technically one can represent it as

$$c_i = \frac{1}{6N_i}[libraries + books + museums + radios + TVs + trade] \Leftrightarrow C_i = c_i \times 6N_i, \qquad (12)$$

where libraries refers to the number of libaries, books to the number of books by UDC titles, museums to museums and other attractions, radios to the number of radio receivers, TVs to the number of TV receivers, and trade to trade as previously defined. However, the "culturo-communication thing" (C_i) in (12) is operationally nonsensical as it lacks a common denominator. Since adding apples to oranges is meaningless, Table 2 keeps the components of C_i separate. Table 3 recalculates Table 2 in terms of proportions (p_i). These p_i are then used to find the indices of diversity.

Figure 1a - Diversity Indices of Technical Capability, 14 African Countries

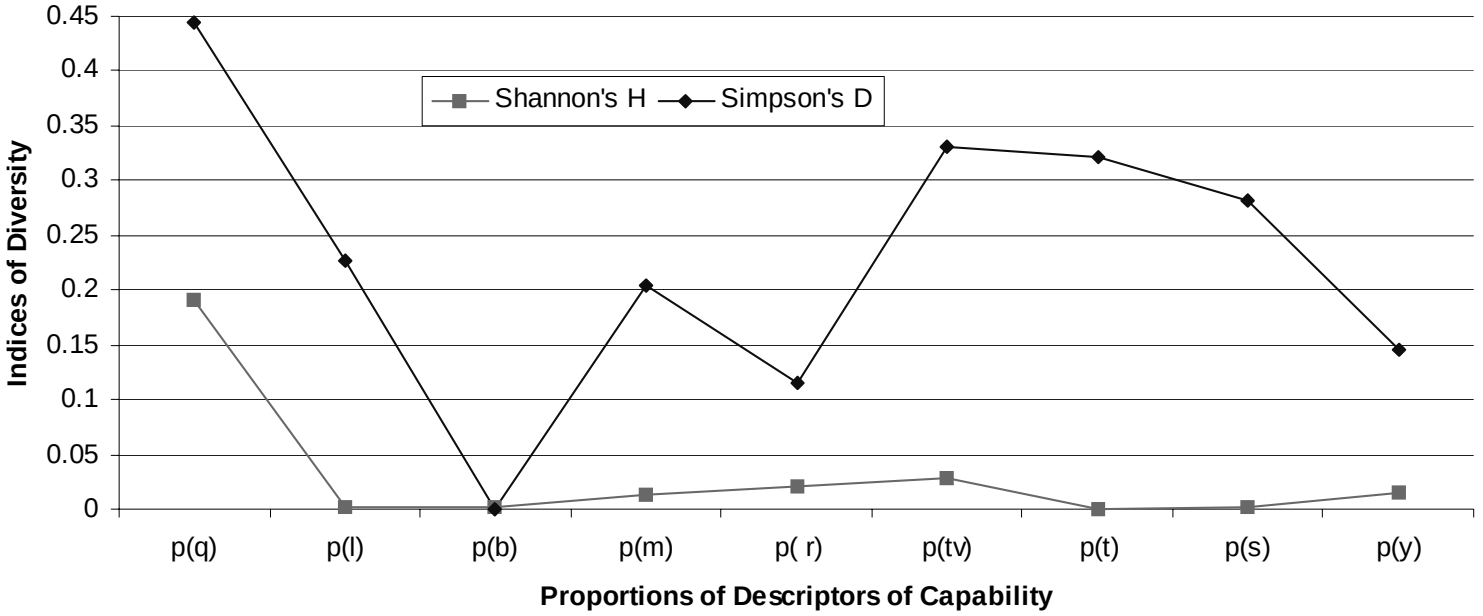


Figure 1b - Within-Country Diversity Indices of Technical Capability, 14 African Countries

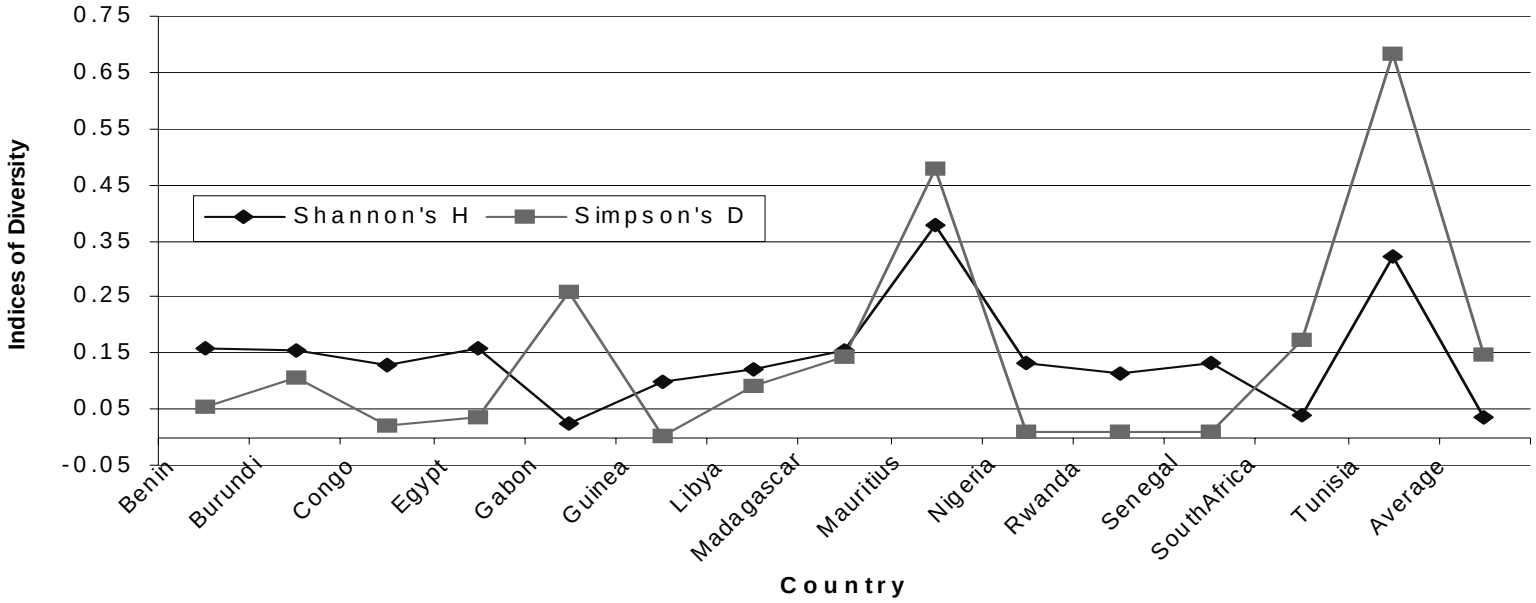


Figure 2a - Cross-Country Measures of Evenness of Technical Capability, 14 African Countries

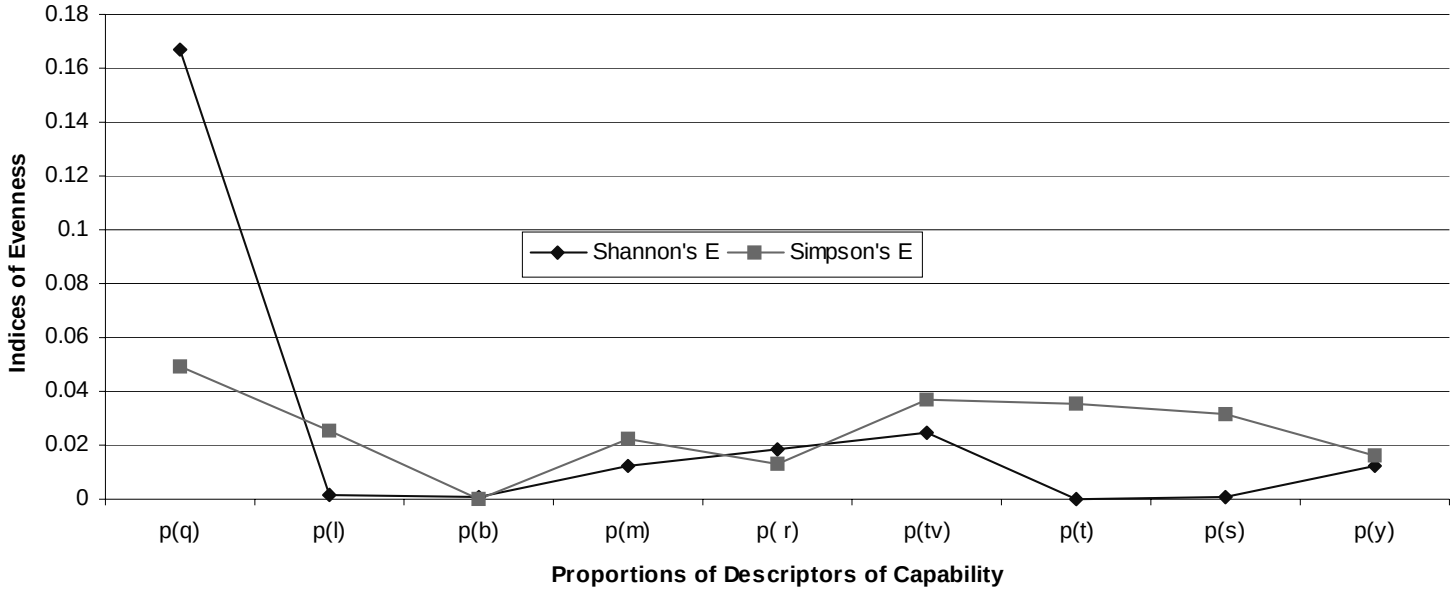


Figure 2b - Within-Country Measures of Evenness of Technical Capability, 14 African Countries

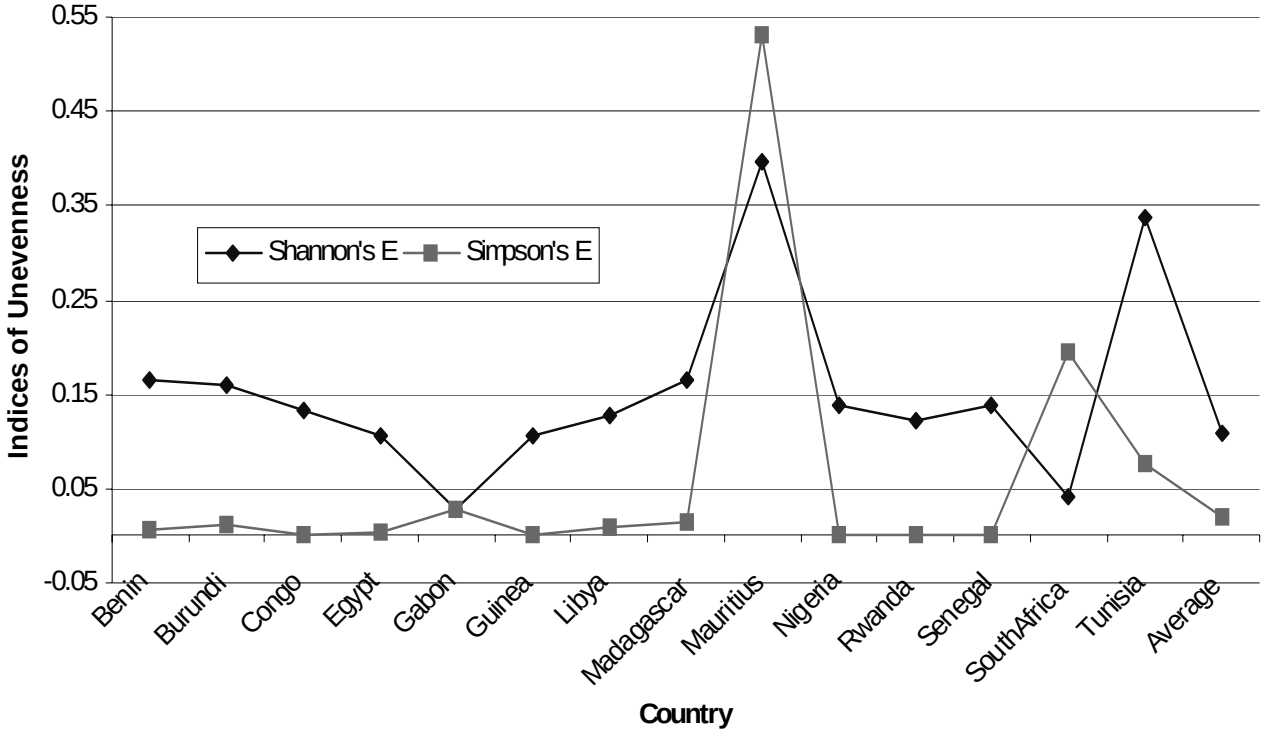


Figure 3a - Cross-Country Measures of Unevenness of Technical Capability, 14 African Countries

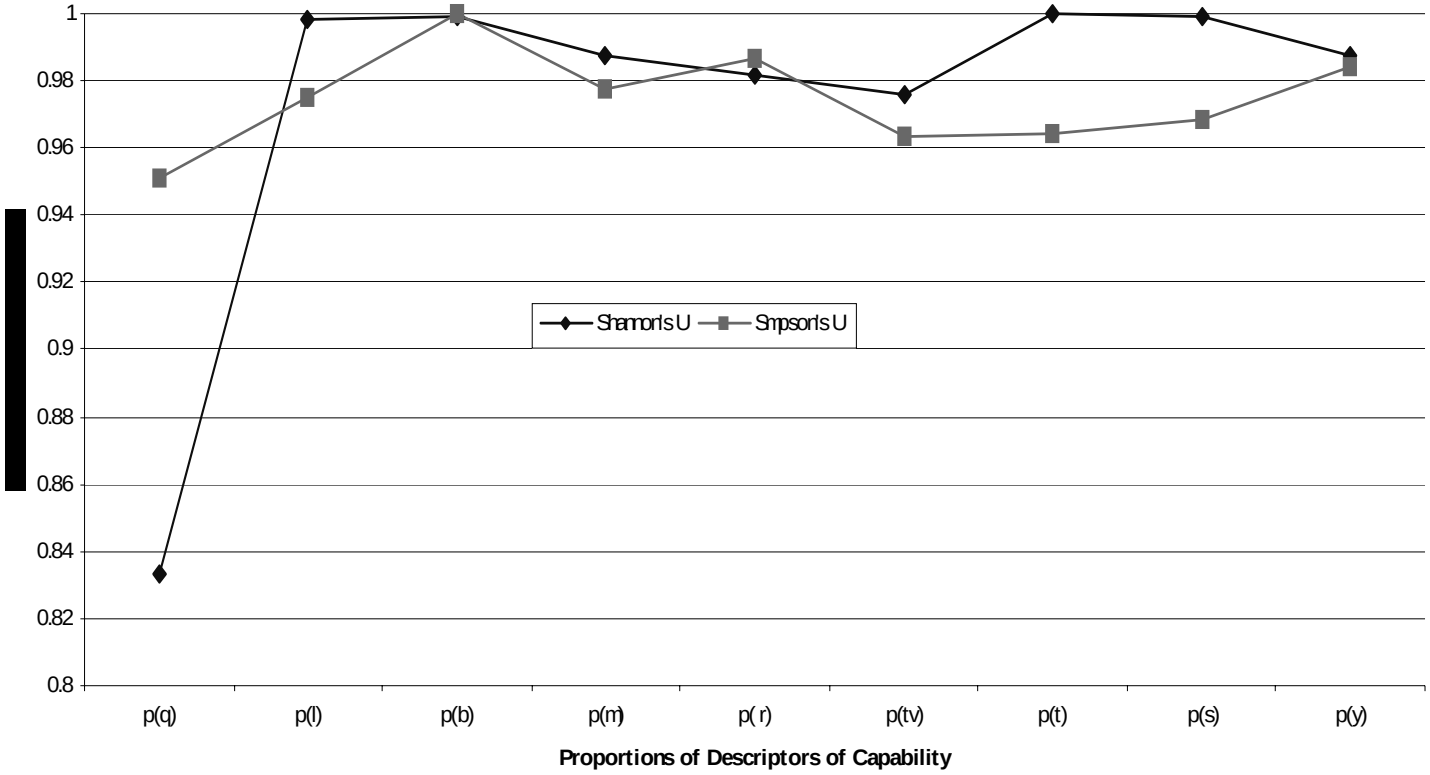
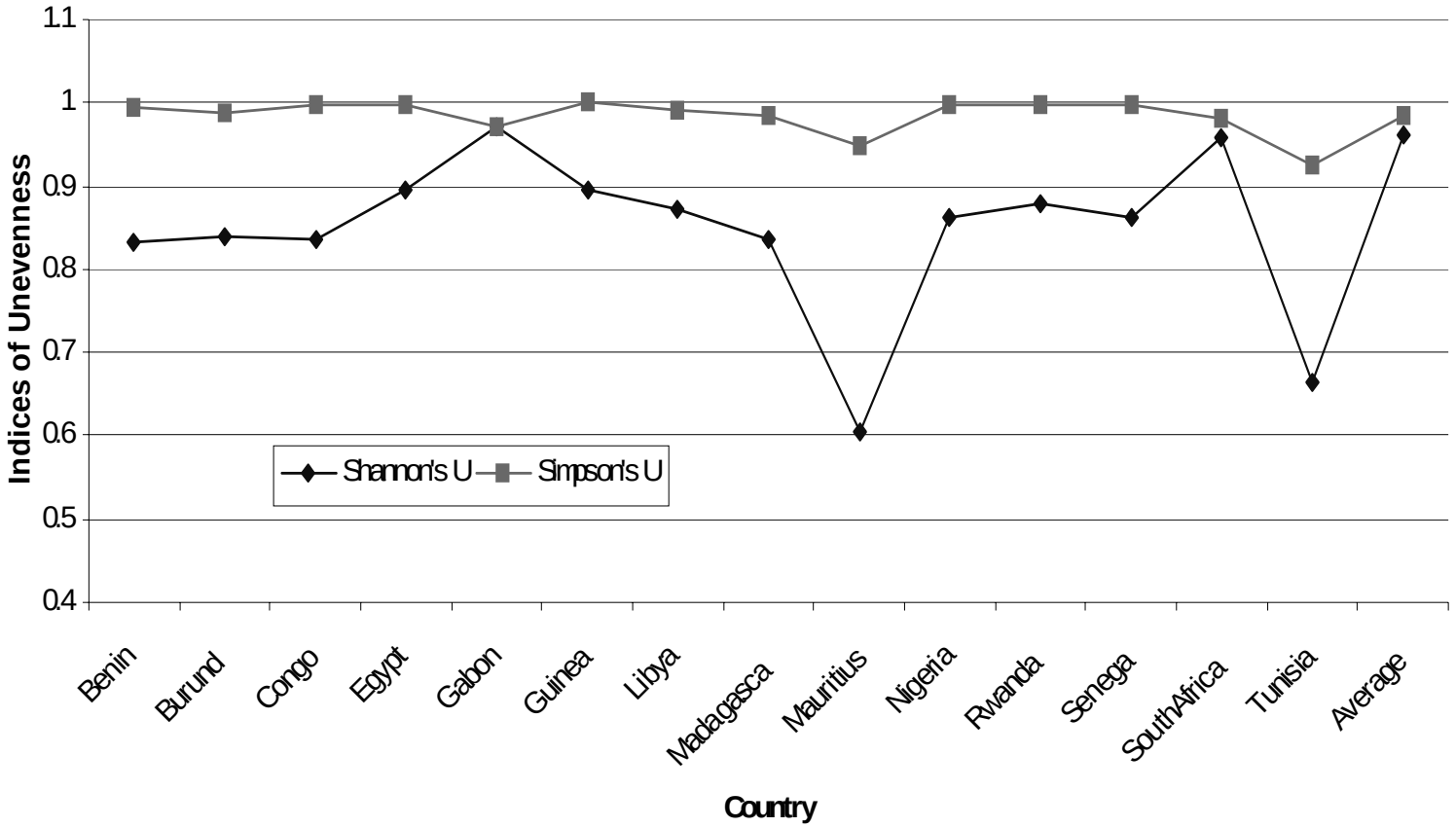


Figure 3b - Within-Country Measures of Unevenness of Technical Capability, 14 African Countries



3. Results

Table 3 and Figures 1-3 present basic results. At the bottom of the tables are cross-country indices, while to the right of the tables are within-country indices. The bold lower right hand corner presents averages. The indices are important for evaluating information about (un)commonness. In the present case the evaluation is useful for determining the structure of technical capability of 14 African countries. The results show tremendous within- and cross-country diversity. For example, in Figures 1a and 1b the Shannon's H and Simpson's D are lower than one (unity), implying diversity. Figure 2 indicates that Shannon's E and Simpson's E as measures of the degree of "equitability" (evenness) are similarly low. Figure 3 shows that there is great within- and cross-country heterogeneity of technical capability even in this small group of African countries. Generally $U_D > U_H$, but both are larger than 0.60.

4. Conclusion

Technical capability is important to economic performance, and there is no disputing that African countries (like other countries) would benefit from improved technical capability. Yet policies that paint countries with one broad brush are potentially misleading, ineffective, and maybe even damaging. The example of this small group of African countries reveals tremendous heterogeneity of technical capability and challenges policy syllogisms that economically weak performers all need the same prescription for their problems. Strengthening technological capabilities requires recognizing the diversity of the technical capabilities of different countries.

References

Abramovitz, M (1979) Rapid growth potential and its realization: The experience of capitalist economies in the postwar period. In E. Malinvaud (ed), *Economic Growth and Resources*. New York: St. Martin's Press.

African Development Bank (2004) *African Development Report*. New York: African Development Report 2004. Oxford University Press.

African Development Bank (2004) *African Development Indicators 2004.* New York: Oxford University Press.

Ash, BA (1965) *Information Theory*. New York: Dover Publications, Inc.

Deming, WE (1986) *Out of the Crisis*. Cambridge (MA): MIT Press.

Derry, TK and TI Williams (1960) *A Short History of Technology.* New York: Oxford University Press.

Hessenbruch, A (2000) *Reader's Guide to the History of Science*. Chicago: Fitzroy Dearborn Publishers. pp.716-720.

IMF (2005) *International Financial Statistics Yearbook 2004.* Washington, D.C.: IMF.

Jonard, N and M. Yildizoglu (1999) Sources of Technological Diversity. University of Pasteur. France.

Khinchin, AI (1957) *Mathematical Foundations of Information Theory*. New York: Dover Publications, Inc.

Lewis, WA (1965) *The Theory of Economic Growth*. New York: Harper Torchbooks.
Los B. and B Verspagen (2001) The Evolution of Productivity Gaps and Specialization Patterns <http://www.ub.rug.nl/eldoc/ccso/200301/200301.pdf>

Maignan, C, G. Ottaviano, D. Pinelli, and F. Rullani (2003) Bi-ecological Diversity vs. Socio-economic Diversity: A Comparison of Existing Measures, No. 13.2003. Fondazione Eni Enrico Mattei. <http://www.feem.it/web/activi/_wp.html>.

Mokyr, J (2003) Long-term Economic growth and the History of Technology. <http://www.faculty.econ.northwestern.edu/faculty/mokyr/durluf.pdf>.

Pitt, J (1988) *Theories of Explanation*. New York: Oxford University Press.

Putman, RJ and SD Wratten (1984) *Principles of Ecology*. Berkeley/Los Angeles: University of California Press, Chapter 12.

Romer, PM (1990) Endogenous technological change. *Journal of Political Economy* 98(5): S71-102.

Rothenberg, A and CR Hausman (1976) *The Creativity Question*. Durham (NC): Duke University Press.

Ruttan, Vernon (2001) *Technology, Growth, and Development*. New York: Oxford University Press.

Shannon, CE and W Warren (1998) *The Mathematical Theory of Communication*. Urbana.Chicago: University of Chicago Press.

Solow, RM (1957) Technical change and the aggregate production function. Review of *Economics and Statistics* 39: 312-320.

Stirling, A (2003) On the Economics and Analysis of Diversity SPRU Paper No. 28. <http://www.sussex.ac.uk/Units/spru/publications/imprint/sewps/sewp28/sewp28.pdf>

Temple, J and PA Johnson (1998) Social capability and economic growth. *Quarterly Journal of Economics*, 113(3): 965-90.

UNESCO (1996) *Annual Statistical Yearbook*. Paris: UNESCO.

Walton, M (1986) *The Deming Management Method*. New York: Dodd, Mead, and Company.

World Bank (1989) *Sub-Saharan Africa: From Crisis to Sustainable Growth: A Long-Term Perspective Study*. Washington, D.C.: World Bank.

Zar, JH (1984) *Biostatistical Analysis,* Second Edition. Cliffs (NJ): Prentice Hall. Pp. 32-36.