Generalized Knowledge Index: The Production, and Imputed Gross Future and Present Values of Doctoral Dissertations across Some African Countries

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Abstract *- The notion that lack of knowledge undermines the economic performance of African countries is deeply and widely held to be true. Yet evidence for the basis of that truth is few and far in-between. This paper first describes a production function approach to the creation of knowledge of African countries in terms of a relative and indirect measure of the quantity of dissertations. Second, the paper assesses the imputed gross future and present values of knowledge of the same group of countries. In the first instance it finds that relative income, population, and openness to the outside world are central to the production of knowledge of African countries. In the second instance, the imputed gross future and preset values of knowledge are positive, but of modest magnitude. The policy implications of the results recommend more investment in the production of knowledge of African countries, improved trade and therefore openness, and especially reduced opportunity cost of knowledge creation which now differs widely across countries, and averages 10.7%. For further research the results suggest that dissertations may be useful proxies for human capital in economic growth regressions.*

Keywords: Knowledge index, knowledge production function, imputed future and present values of doctoral dissertations, knowledge of African countries

JEL Code: O55, C5, I21, O39, O15

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0. Motivation

Recorded debate over the theory of knowledge (*epistemology*) reportedly goes back to the Greek philosophers (Carey, 1858, Capaldi, 1969, Russell, 1948, 1956, Berkeley, 1957). While epistemological arguments are still raging to-date, there is little dispute about the value of knowledge. At this point I defer to Loasky (1999), Cohn (1979), Samuelson (2004), and many others for expert discussions of these matters, but I add here that whereas the value of information can be absolutely zero, it is now well understood that the value of knowledge is zero only asymptotically. In the economic sphere Adam Smith, for instance, argues that the supply of the "necessaries and

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conveniences of life" depends on the "skill, dexterity, and judgment" of the labor that produces it (p.1 and Chapter 1 of Book I, Graham, 1937, Walter, 1969, de Sismondi, 1991). Alfred Marshall is even more emphatic than Smith in asserting that "knowledge is the most powerful engine of production; it enables us to subdue Nature and satisfy our wants" (quoted in Gurak, 2004, p.1). Put differently, knowledge determines labor productivity.

Hans-Diedrich Kreft (2004) sees the problem in quantifying human knowledge and proposes an innovative mathematical method for measuring knowledge as "human potential" based on Claude E. Shannon's well-known formula (Shannon and Weaver , 1998, Khinchin, 1957, Ash, 1965). The concluding implication of Kreft's proposal is that economic success is a function of the "stability" and "effectivity" of human potential. Despite this new effort, much of the current debate on knowledge centers around the economic problem of knowledge, i.e., around: (a) the kind of knowledge, and how is it to be produced, (b) how much is to be produced; and (c) for whom is it to be produced. These questions are wide-ranging to address in one paper. But for now the last question can conveniently be avoided by simply saying that once produced knowledge is either a public good or a private good with high positive externalities, so that it is largely for society's free taking in both cases. However, it is not easy to evade questions (a) and (b) and still talk sensibly about knowledge. And so I focus on how knowledge is produced, beginning with clarifying statements about where knowledge comes from.

Bertrand Russell (1948, 1956) and Thomas Sowell (1996) assert that knowledge derives from ideas, but that ideas and knowledge are not synonymous. Whereas ideas are *personal* and *private* to their individual sources, knowledge is *not.* It is then understandable for Russell to insist that "the community knows both more and less than the individual; it knows, in its collective capacity, all the contents of the encyclopedia and all the contributions to proceedings and learned bodies, but it does not know the warm and intimate things that make up the color and texture of an individual life"(p.3).[2] An obvious implication of Russell's insistence is that scientific knowledge is public knowledge to the extent that it is a result of a collective endeavor that grows and spreads by and through social media like language.

Sowell (1996) advances Russell further by recognizing that "specks of knowledge are scattered in a vast emptiness of ignorance, and everything depends on how solid individual specks of knowledge are, and on how powerfully linked and coordinated they are with one another. The vast spaces of ignorance do not prevent the specks of knowledge from forming a solid structure, though sufficient *misunderstandings* can disintegrate it in much the same way that radioactive atomic structures can disintegrate (...) or even explode" (p.4, original italics). On the basis of Sowell one can allege that ideas are clusters of information, so that knowledge is essentially authenticated ideas. The quantity and quality of knowledge both depend on the nature of the authentication process and the speed of authentication itself. Activities such as education, training, and learning-by-doing define the nature

[2]Russell is in full agreement with Schopenhauer who writes that "thoughts put on paper are nothing more than footprints in the sand; you see the way the man has gone, but to know what he saw on his walk, you want his eyes" (*Essays of Arthur Schopenhauer*, 1910).

of the authentication process, while the speed of authentication is a function of the surrounding environment (Boulding, 1946). The growth of human capital is then driven by the growth of knowledge over time (Schultz, 1981, Becker, 1993), which explains Sir W. A. Lewis's (1965) contention that "the proximate causes of economic growth are the effort to economize, the accumulation of knowledge, and the accumulation of capital." (p.164). Moreover, to Lewis the accumulation of knowledge over time has depended on two fundamental inventions: (a) writing and printing, both of which made knowledge intertemporal and intergenerational, and (b) the scientific method, which systematized the production, presentation, and diffusion of knowledge. The application of knowledge depends on attitudes towards innovations, incentives for the application of knowledge, complementary training, the capacity to absorb new knowledge, and the business and administrative organization for managing knowledge (cf. Rogers, 1983, Mokyr, 2002).[3] Quite obviously the growth of knowledge would have fared rather poorly without writing, printing, and, above all, the scientific method.

1. Knowledge of African Countries Versus African Knowledge

The Problem

Economic growth [and development] experts, like the World Bank (1989), claim that lack of knowledge undermines the performance of African countries, and recommend that investment in people is the key "toward human-centered development". In line with the World Bank, Wangwe and Rweyemamu (2001) point out that "capacity building for sustained economic development and transformation in Africa is now almost universally recognized as the 'missing link' in Africa's economic development" (p.2). Both the World Bank and Wangwe and Rweyemamu's arguments are reasonable in that knowledge increases productivity by affecting lifestyle decisions regarding sound management of productive resources including population, health, nutrition and fertility, thereby lowering production costs. Evidence shows that the state of the (higher) education sector in Africa is in trouble with disturbing implications for local skill building and accelerated so-called brain-drain, which apparently explains why private returns to higher education are as high as 30%, while social returns are only 13% (World Bank, 1989, cf. Soderbom, Wambugu, Teal, and Kahyarara, 2004).[4]

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[3]Knowledge of a particular society is not only a function of the number of local geniuses and the quantity of their work; it also depends on the surrounding community, and how that community receives, assimilates, and uses new knowledge.

[4]I personally believe that the brain-drain argument is an emotional "appeal to bandwagon" (Robert Gula, 2002). Knowledge building does not require physical presence; as agents of change, knowledge builders can effect change from *anywhere,* just like Nelson Mandela helped end Apartheid in South Africa from his prison cell on a remote island, or Andrei Sakhrov contributed to the understanding of the USSR from a concentration camp in Siberia. Moreover, intellectual nomadism and pilgrims have always been and will remain major characteristics of productive scholarship. The modern sabaticals (spel) are not that different from scholarly sojourns from Athens to Alexandria. Here is another shot at the point: to benefit from Shakespeare one neither do has to be William Shakespeare's contemporary, English, nor even reside in England.

Please do not get me wrong: I am aware that capacity and human resource building are not exactly the same thing as the generalized knowledge of African countries that interests me here. Even so, the question about whether or not African countries produce enough knowledge for their growth is no more misleading than asking if Microsoft produces enough software engineers for its growth. In the latter case the relevant question is: What are the conditions of the market for software engineers to which Microsoft must turn to meet it demand? Here Microsoft represents the demand side, and there is no requirement that it produce all its engineers from within (in-house) alone. If demand for engineers is there (known), then the policy task is to figure out the level of supply to meet that demand from *any* source. The same logic applies to markets of other forms of knowledge. But with respect to African countries debate often mixes up the quantity of knowledge supplied with the supply of knowledge. For example, to say that African countries lack knowledge, is in one way to imply that demand for knowledge there is greater than supply, that there is a shortage. With a shortage the price of knowledge is lower than the equilibrium price, and suppliers of knowledge have no incentives for additional production of knowledge. To restore incentives the price must rise towards its equilibrium level - an upward movement along a fixed supply curve. But we may have an identification problem on our hands because an increase in the demand for knowledge, holding constant its supply, would also lead to a higher equilibrium - a shift of the demand curve. It follows that one can conscript Africans into all kinds of knowledge-building endeavors assuming a constant demand, but in the end, with supply increasing, the price of knowledge falls and conscription becomes unsustainable.

Another implication of saying that African countries lack knowledge, suggests that there is a need for increasing the supply of the knowledge of African countries. For sure we can increase supply by increasing the number of educated Africans. However, knowledge is fundamentally "fungible", and it may be more profitable to focus on the other supply shifters: prices of resources and other inputs; expectations about future consumption and production prices of knowledge; and improved technology and therefore lower knowledge production costs and higher productivity. For this reason, rather than asking whether or not there are enough knowledgeable Africans to provide the knowledge necessary for Africa's growth, I first ask how knowledge of African countries is produced. Specifically, I estimate a production function of doctoral dissertations on 38 African countries, and only as a separate extension and in a separate project do I consider if that knowledge is sufficient for growth.[5]

[5]A wise and well-informed professor of mine once told me that the African Studies Program in the USA was designed to increase the supply of African knowledge by training technocrats interested in African countries for the sake of African countries. But neither governments nor firms (domestic or foreign) are interested in charities; their goal is self-interest and in this pursuit knowledge of African countries is a better bet than African knowledge. The seemingly trivial distinction between the narrow concept of African knowledge *á lá* Ghana's first President Kwame Nkhrumah and the broad notion of knowledge of Africa is worth observing. The former refers to knowledge of African countries produced by Africans for Africans' consumption; the latter suggests knowledge produced by *anyone* for *anyone's consumption*. The latter is *potentially dynamic* as it assumes learning from within and without; the former is *actually static*.

Justification

I chose to focus on doctoral dissertations for a number of reasons including the following two. First, the doctoral course of study is an authentication process. As such, one of its most important outputs, the dissertation, is authenticated knowledge. Dictionaries define a dissertation as a full and learned discourse. Most doctoral degree granting institutions describe a dissertation as an elaborate essay intended to illustrate a subject (thesis) as evidence of knowledge of an individual research. Acceptance of a dissertation as meeting the partial requirements for a doctoral degree is in itself authentication that the dissertation adds value to the existing fund of knowledge. In other words, as a research output a dissertation outlines existing knowledge, generates brand new knowledge, or reorganizes old knowledge in creative and useful ways (Hopkins, 1990). Second, I chose dissertations because they embody clear examples of Lewis's fundamental inventions: they are carried out in a scientific fashion, and their written and printed formats make them both intertemporal and intergenerational.

I defend my choice of a production function by alleging that, while Africans may be entirely responsible for the production of African knowledge, if there is such a thing, and I have serious doubt about that one too, all concerned knowledge producers are equally responsible for the production of knowledge of African countries. The former serves mainly Africans, the latter *all* interested parties. In this assertion I appeal for support to Larry Samuelson's (2004) recent statement that "it is important to keep track not only of what people know, but what they know they know about what others know about what others know, and so on" (p.368). In other words, what determines the production of the knowledge of African countries? This paper is directed to this question, and it proceeds as follows: in Section 2 next below I outline a knowledge production function and the imputed gross future and present values of knowledge. The third section deals with data, data sources, and other measurement issues. Section 4 estimates the models developed in the preceding section. Section 5 presents the results and is followed by Section 6 which makes final remarks to motivate policy and further research.

2. The Production, and Imputed Present Value of the Knowledge of African Countries

2.1 The Production Function of Knowledge

I measure the quantity of knowledge of the ith African country as the *apparent* quantity of dissertations on that country (D_i) produced *by anyone anywhere in the world* during the 1960-February 2003 period. Drawing upon Evenson and Kislev (1975) I argue that D_i is determined by the ratios of local to world economic variables (X_i), and country-specific technological parameters (A_i) , i.e.,

$$D_i = f(X_i)\exp(A_i),\ i = 1,2,3,...,m, \qquad (1)$$

where the exp(Ai) form of technological parameters is by assumption. Given X_i and A_i the compact linear regression form of (1) becomes

$$D_i = X_i\Phi + \varrho_i, \ \forall \ E[\varrho_i\varrho_j]=0, Var[\varrho_i]=\sigma^2, \ i \neq j, \tag{2}$$

where Φ is a vector of all parameters including A_i, and ϱ_i is a normally-distributed random error term.

2.2 Imputed Gross Future and Present Values of Knowledge

Conventionally a value calculator standing (sitting) in the current year t = 0 (1960) looking to year T-t (2003), n≡44 years ahead, would estimate the future worth of knowledge of (dissertations on) the ith African country (Πi) as

$$\begin{aligned} \Pi_i &= R_i(1+r)^n = R_i(1+r_i)^{44} && (a) \\ \Pi_i &= R_i e^{rn} = R_i e^{r_i 44} && (b) \end{aligned} \tag{3}$$

where i=1, 2, 3, ..., m = 38 different African countries, ri is the ith country rate of interest compounded annually (continuously) over n years, and (3a) and (3b) are discrete and continuous cases, respectively. The present value of (3) is

$$\begin{aligned} R_i &= \Pi_i(1+r_i)^{-n} = \Pi_i(1+r_i)^{-44} && (a) \\ R_i &= \Pi_i e^{-rn} = \Pi_i e^{-r_i 44}, && (b) \end{aligned} \tag{4}$$

where $R_i = \overline{P_i} \times D_i$ and $\overline{P_i}$ is the sale price of a dissertation listed in Table 1. Since the variable of integration is a definite integral, it is a dummy variable in that the limit to the Riemann sum is a definite Riemann integral, i.e.,

$$\tilde{R}_i = \int_0^t \Pi_i(t) e^{r_i t} dt = \int_0^n \Pi_i(n) e^{r_i n} dn = \frac{1}{r_i^2} - \frac{1}{r_i^2} e^{-r_i n}(1 + r_i n), \ n>0, \tag{5}$$

is the cross-sectional present value of income stream flowing at some rate Π_i dollars per annum

given a continuous discount rate r_i.

Given (5) the stream (flow) of value of dissertations across *m* African countries over *n* number of years is

$$\tilde{R}_i^* = \int_i^m \int_0^n \Pi_i(n) e^{-r_i n} dn \; dm = \int_i^m [\frac{1}{r_i^2} - \frac{1}{r_i^2} e^{-r_i n}(1 + r_i n)] dm = \int_i^m \tilde{\Pi}_i dm \approx \sum \tilde{R}_i, \; n>0, m>0. \tag{6}$$

The mean of (1) is

$$A\tilde{R}_i^* = \frac{1}{m-i} \int_i^m \tilde{\Pi}_i dm \approx \frac{\tilde{R}_i^*}{37}, \tag{7}$$

which is average total imputed present value of knowledge across all *m* countries.

To find Π_i and/or R_i we need the discount rate r_i. From (3)

$$\ln \Pi_i = \ln R_i + r_i n \Rightarrow r_i = \frac{(\ln \Pi_i - ln R_i)}{n}, \tag{8}$$

which can still not be solved in two unknowns. For this reason I suggest that r_i can be calculated as the relative cost of a copy of a dissertation, because a copy of a dissertation is a share of the stock of knowledge, not unlike the share of a (common or preferred) stock of capital. Hence we can use the familiar Solomon-Gordon formula for the specific cost of capital to approximate r_i, see e.g. Kula (2004), such that,

$$r_i = [(\delta_i \equiv \bar{P}_i / R_i) + \gamma_i)], \tag{9}$$

where δ_i is the mean replacement cost of a lost or damaged copy of a dissertation, and γ_i is the country-specific deviation about δ_i. Alternatively γ_i is the equivalent of the growth (g) component of the Solomon-Gordon formula.

Now to estimate γ_i and δ_i let

$$R_i = R_0 e^{(\gamma_i + \delta_i)i},\ i = 1,2,3,\ldots,m = 38. \tag{10}$$

Taking the natural logs of both sides of (10) and solving

$$\gamma_i = \frac{\ln R_i - \ln R_0}{i} - \delta_i. \tag{11}$$

Plugging (11) into (9) gives cross-sectional r_i as

$$r_i = \delta_i + \frac{\ln R_i - \ln R_0}{i} - \delta_i = \frac{\ln R_i - \ln R_0}{i}. \tag{12a}$$

Notandum: *r* can be specific to each country as in $r_i = \gamma_i + (\ln R_i - \ln R_0)^{-i} - \gamma_i$, or *r* can be averaged across m African countries as in

$$\bar{r} = \frac{1}{m}\sum_{1}^{m} r_i \tag{12b}$$

4. Data, data sources, and other measurement issues

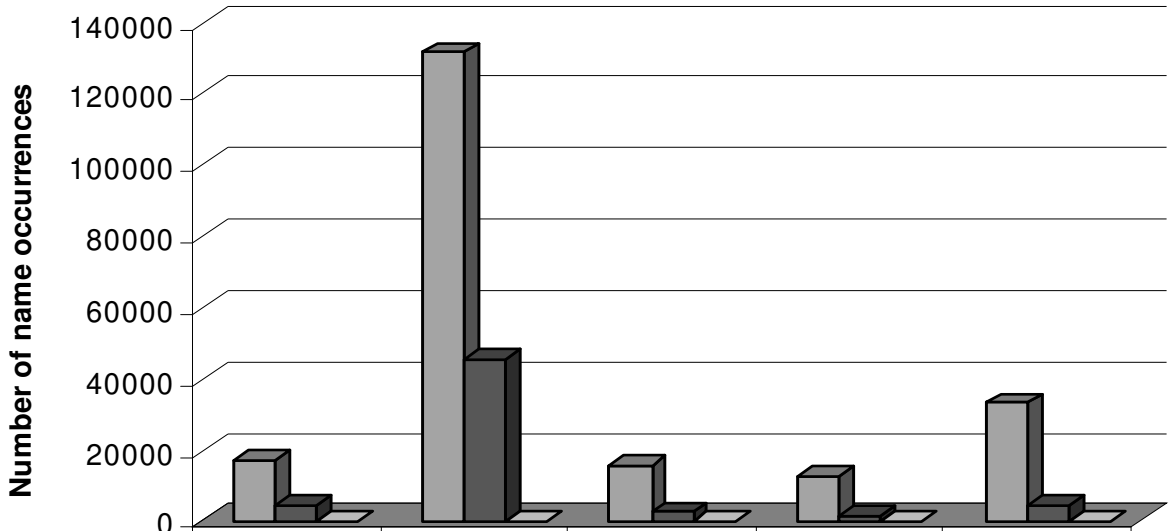
This section describes the data for the analysis, focusing on 38 African countries listed in Table 2 over a one period covering 44 years from 1960 to February 2003.

Dependent Variable (D_i)

The data used to construct the dependent variable (D_i) was generated by searching the Dissertation Abstract International (DAI) for the appearance of the name of the ith country, first "*anywhere*" in the database and then "*in-title*" of the dissertations. Figures 1-3 record the hits at the continent level for perspective. In Figure 1 the search returned the most hits for America (South + Central + North). Figure 2 shows that there has been a discernibly exponential increase in the appearance of "America" anywhere in the DAI database since the 1960s. Europe and Australia picked up from the 1970s onwards, and Asia since the 1980s. Africa started off higher than both Asia and Australia, but it is the only continent declining in appearance post-1980s.

Figure 3 plots the mention of the continent names in the dissertation titles. Except for America which rose in the first decade of the series and declined in the second, the other four continents were basically flat through the 1990s. Post-1990s America and Australia experienced tremendous growth.

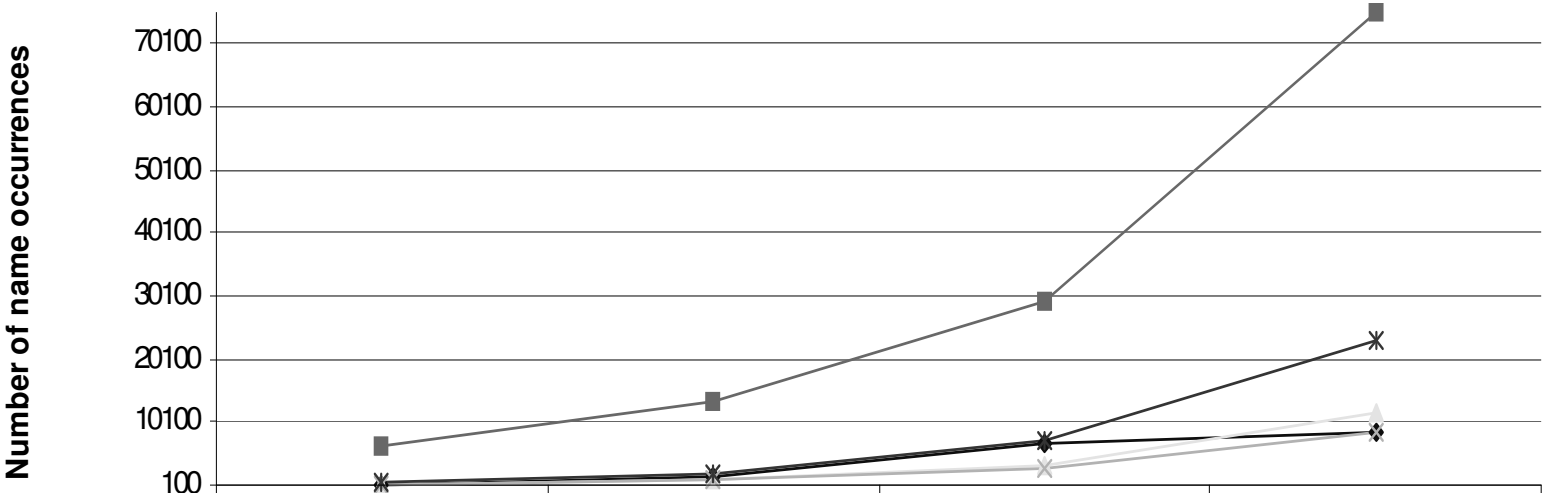
Figure 1 - Occurrences of Name of Continent "anywhere" in DAI, 1861-February 2003



	Africa	America	Asia	Australia	Europe
Anywhere	16843	131445	15536	12549	33062
In Title	4414	45454	2666	1525	4173
Di (%)	26.21	34.58	17.16	12.15	12.62

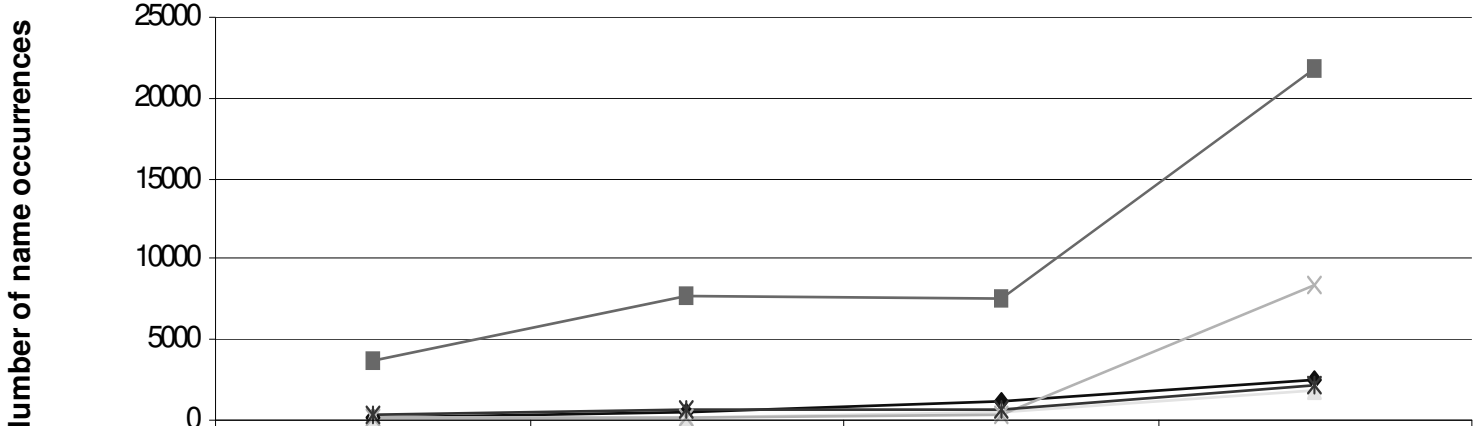
Continent

Figure 2 - Occurrences of Name of Continent by Decade "anywhere" in DAI, 1960-2003



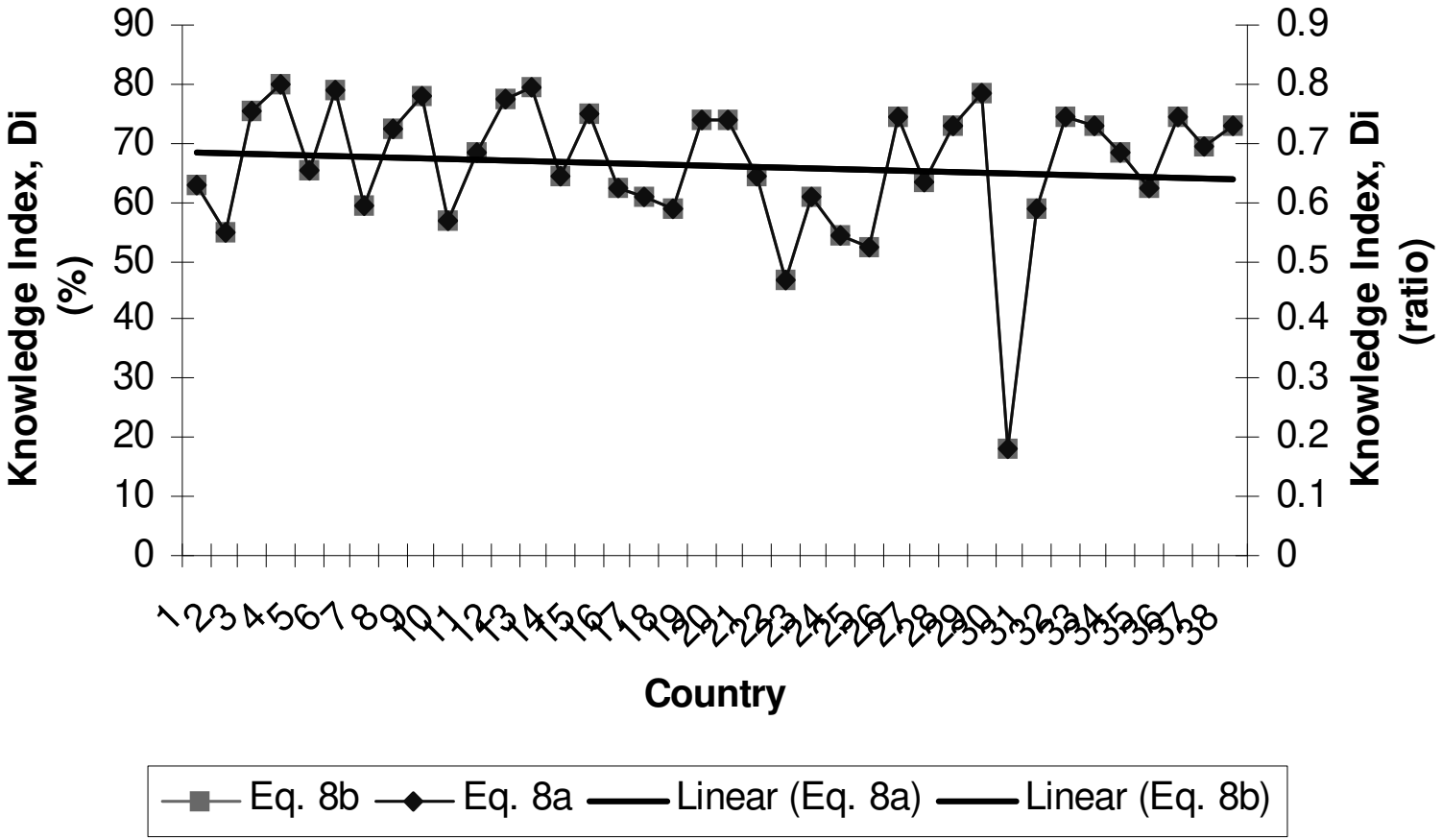
	1960-1969	1970-1979	1980-1989	1990-2003
Africa	173	1390	6598	8558
America	6451	13484	29042	74866
Asia	126	851	2981	11411
Australia	114	998	2852	8368
Europe	409	1831	7280	22797

Figure 3 - Occurrences of Name of Continent by Decade "in title" in DAI, 1960-2003



	1960-1969	1970-1979	1980-1989	1990-2003
Africa	171	530	1162	2434
America	3738	7701	7520	21852
Asia	94	235	477	1783
Australia	88	171	345	8363
Europe	346	640	612	2170

Figure 4 - Knowledge Index (Di) across African Countries, 1960-2003



Based on this perspective I define D_i as

$$D_i=\frac{\textit{occurrences of name of ith country} \in \textit{dissertation title} \in \textit{DAI database}}{\textit{occurrences of name of ith country anywhere} \in \textit{DAI database}} \quad (a)$$

$$\vee \qquad (13.1)$$

$$D_i=[\frac{\textit{occurrences of name of ith country} \in \textit{dissertation title} \in \textit{DAI database}}{\textit{occurrences of name of ith country anywhere} \in \textit{DAI database}}]100 \quad (b)$$

where "$\in$" is "in" as in "element of". Letting s_i be the occurrences of the name of the ith country in the DAI database, and S_i the occurrences of the name of the ith country anywhere in the DAI database, then (13.1) becomes

$$D_i=s_i/S_i \quad (a)$$

$$D_i=[s_i/S_i]100. \quad (b) \qquad (13.2)$$

Both "anywhere" and "in-title" hits are only numbers in the DAI database, and are most certainly fewer than the actual number of dissertations produced for each ith country over that time period. For example, Denstel (1966) counts 2,923 French doctoral dissertations on Africa for 1884-1961; Sims (1976) records 6,070 American and Canadian dissertations and master's theses for the 1886-1974 period; and Curto and Gervais (1994) list 3,112 master's and doctoral dissertations on Africa for Canada alone during the 1905-1993 years. These findings may be misleading because in the 1960s and prior most African, and some Asian and Latin American, countries did not exist as economic entities. Although D_i may not be the true population of dissertations on African countries, it is a representative indicator. The probability that every mention of the ith country anywhere in the database is a dissertation is very low (not zero); the probability that some mention of the ith country in the title of a dissertation is a dissertation on that country is high. Thus, the ratio is a modest indicator of the production of dissertations. The closer to unit the higher the precision of D_i as a predictor of dissertations (Bryce, Meadow, and Kraft, 1994, Okub0, 1997, Tague-Sutchliffe, 1995, Tijssen, Van Leeuwen, and Van Raan, 2000). Figure 4 depicts D_i across 38 African countries.

Explanatory Variables

Relative income (Y_i) determines the quantity of knowledge produced for each country. Theoretically, as a measure of income (Y_i) one would take the ratio of percentage of GDP of the ith country to that of the industrialized countries that is spent on education (preferably higher education) - see Tcha and Lee's example of Korea. For many African countries data on (both government and private expenditure) on education is sketchy and unreliable. Moreover, while spending on its own education

Table 1 - Average Price of Dissertation, 1950s - 2000s -todate , US$[6]

Years	Microfilm				Xerography				Average
	Demand	Standing	S&H	Average	Demand	Standing	S&H	Average	Total
1950s	2.75	4.00	1.40	2.72	3.00	6.00	-	4.50	3.61
1960s	11.81	9.00	2.26	7.69	21.52	18.00	3.75	14.42	11.06
1970s	13.00	9.50	2.28	8.26	24.50	19.75	3.75	16.00	12.13
1980s	19.42	-	4.02	11.72	33.00	-	5.69	19.35	15.54
1990s	29.38	-	5.33	17.36	46.00	-	6.74	26.37	21.87
2000s-todate	42.63	-	6.64	24.64	52.13	-	7.86	29.99	27.32
Average	**19.83**	**7.50**	**3.66**	**10.33**	**30.03**	**14.58**	**5.56**	**16.72**	**13.53**

[6]Microfilm and microform. Shipping and handling is average 4th class and airmail from the USA to anywhere in the world including within the USA. The average price of microfilm/microform and xerographic paper is average for demand copies, standing orders, and shipping and handling.

by the ith country is direct investment in its human capital accumulation, spending by industrialized countries on the education of the ith African country is not their human capital formation. Instead it is a consumption expenditure dependent on disposable income. For the lack of appropriate data I measure Y_i as the ratio of the percentage of GDP going to gross capital formation in the ith country to the percentage of GDP in industrialized countries that goes to final consumption. I construct both data series from IMF's *International Financial Statistics* (2000, 2001).

A second determinant of the quantity of knowledge produced is the relative size of population of the ith country. I calculate the average relative population size (N_i) as the ratio of the ith country median age population to the median age population of industrialized countries. The raw data comes from United Nations' *World Population Prospects* (1998).

Thirdly, the quantity of knowledge is a function of the country's openness to the outside world. The measure of openness (Z_i) is the average share of trade (exports + imports) of the ith country in average industrialized world trade (exports + imports). This data too comes from the *IMF's International Financial Statistics* (2000, 2001).

Finally, the fact that knowledge can be produced by anyone anywhere in the world, suggests that technological (level) parameters are likely influenced by geographical, social, cultural, political and historical affinities. For simplicity I assert that a dummy variable for a foreign official language of the ith country (Dum_i) is a reasonable proxy for A_i.[7] Countries adopt foreign languages as their official languages if they share special relationships with home countries of the languages they adopt as theirs. In the case of African countries, special affinities developed out of colonial experiences. Colonial relationships tend to reduce geographical and other kinds of distance between the ith country and the industrialized world at least in the sense that former colonizing countries tend to maintain active interest in their ex-colonies (Acemoglu. Johnson, and Robinson, 2001, Lange, 2004). I let the language dummy variable take the value of ***zero*** if the ith country was neither a French nor a British colony, ***one*** if the ith country was a British colony, and ***two*** if it was a French colony,i.e.,

$$\begin{aligned} Dum_i &= 2 \ \textit{if official language is French} \\ &= 1 \ \textit{if official language is English} \\ &= 0 \ \textit{if official language is neither French, nor English.} \end{aligned} \tag{14}$$

There is a general hypothesis that links linguistic fragmentation to the poor performance of African countries. The hypothesis is reasonable; its conclusion is partly incorrect because "verbal" knowledge is just as important as "ostensive" knowlegde, to lean on Russell's ideas (1948, p.ff). The little I know from reading George Steiner (1975) and Noam Chomsky (1965) persuaded me that the significance in determining economic performance attributed to language homogeneity is overrated in reality.

These dummy variable designations are arbitrary!

Other variables: R_i *and* $\overline{P}_i$

As explained above $R_i = \overline{P}_i \times D_i$. The price series was calculated from the basic price list occasionally included in DAI databases.

5. Model Specifications and Estimations, and Results

5.1 Model Specifications and Estimations

To recap, key variables in determining D_i include a measure of the ith country's income relative to industrialized world income (Y_i), the ratio of the ith country's population to world population (N_i), and openness to the *industrialized world* measured as the share of trade of the ith country in world trade (Z_i), where by "industrialized world" I refer to IMF's IFS definition. Technical factors (A_i) are represented by the Dum_i variable.

For current estimations I first treat D_i as the ratio of "in-title" to "anywhere" hits, i.e., (13.2).[8] Then given variables Dum_i, Y_i, N_i, and Z_i, I estimate (2) assuming the following functional forms:

$$
\begin{aligned}
D_i &= \phi_0 + \phi_1 Dum_i + \phi_2 Y_i + \phi_3 N_i + \phi_4 Z_i + e_i && (a)\\
\log D_i &= \phi_0 + \phi_1 Dum_i + \phi_2 Y_i + \phi_3 N_i + \phi_4 Z_i + e_i && (b)\\
D_i &= \phi_0 + \phi_1 Dum_i + \phi_2 y_i + \phi_3 n_i + \phi_4 z_i + e_i. && (c)\\
d_i &= \phi_0 + \phi_1 Dum_i + \phi_2 Y_i + \phi_3 N_i + \phi_4 Z_i + e_i && (d)
\end{aligned}
\qquad (15)
$$

Obviously $\phi_0 = \hat{\phi}_0$ if $Dum_i = 0$, $\phi_0 = \hat{\phi}_0 + \hat{\phi}_1$ if $Dum_i = 1$, and $\phi_o = \hat{\phi}_0 + 2\hat{\phi}_1$ if $Dum_i = 2$**.** There may well be important interactions between Dum_i and X_i, but I ignore them here, and instead observe that in (15a) and (15b) D_i is as defined in (13). In (15c) and (15d) $y_i = 1/Y_i, n_i = 1/N_i, z_i = 1/Z_i, d_i = 1/D_i$. Eq.(15d) asserts that D_i is reciprocal to Y_i, N_i, and Z_i, but not to ϕ_0 and Dum_i, while in (15c) $Di = \frac{1}{\Phi X_i} \Rightarrow \frac{1}{D_i} = \Phi X_i$.

[8] In a separate model which integrates this formulation into an aggregate production as a substitute for human capital in order to assess economic growth of African countries, I experiment with Di in (13) as a Fisher-like quantity index.

In general I expect N_i, Y_i and Z_i to be positively related to D_i. However, the smaller these variables are, the more D_i (d_i) is likely to be produced externally than internally. This is particularly the case for the reciprocal forms of (15) since $Y_i = \frac{Y_{\text{hom}\,e}}{Y_{world}} \Rightarrow y_i = \frac{1}{Y_{\text{hom}\,e}/Y_{world}} = \frac{Y_{world}}{Y_{\text{hom}\,e}}$, then a positive coefficient of y_i suggests that $D(Y_{world}) > D(Y_{\text{hom}\,e})$, and so on. Even so, the expectations are for

$$
\begin{aligned}
E[D_i \vee \log D_i | X_i, Dum_i = 0] &= \phi_0 + \phi_i^* X_i \\
E[D_i \vee \log D_i | X_i, Dum_i = 1] &= \phi_0 + \phi_1 + \phi_i^* X_i \\
E[D_i \vee \log D_i | X_i, Dum_2 = 0] &= \phi_0 + 2\phi_1 + \phi_i^* X_i,
\end{aligned}
\tag{16}
$$

where ϕ^*_i is the vector of the coefficients of the remaining X_i, excluding Dum_i.

Knowledge Production - Results

I estimated (15) using three single-equation estimators: OLS, 2SLS, and the least absolute error (LAE), for which *Shazam: The Econometric Software* (1990) provides an easy estimation procedure. The robust estimator is capable of dealing with outliers like a few evident from, but not limited to, Figure 4. Tables 2 - 5 present estimation results and I comment on those briefly next below.

When D_i is Linear

Assuming a linear functional form of D_i the short-run impact of relative income on the relative generalized knowledge index ranges from 0.275 to 0.469. This suggests that the relative rate of return on investment in a dissertation for this group of African countries is anywhere between 27% and 47%. One implication of this result is that as the ith country invests more in its knowledge building internally, the contribution of the external world either remains unchanged or declines, and the index of knowledge increases. External contribution varies partly because foreigners are more likely to finance and carry out dissertation research in crisis situations, and/or for small-population countries where the dissertation impact is most likely high. Consequently, the relative size of the ith country in terms of population also has a positive but lower impact on knowledge produced compared to that of relative income. This makes sense: a larger population is both a potential source of knowledge and a consumer of scarce resources. For this group of countries openness has a negative effect on knowledge building. The suggestion here is either that the share of trade of African countries is small relative to that of industrialized countries, or that this group of countries is somehow closed to knowledge building.

The estimates outlined above are consistent for all three estimators, and technically efficient and unique for the OLS and 2SLS methods. Using LAE results, for example, the mean of the knowledge index for countries whose official languages are neither English nor French is 0.623. The mean

Table 2- $D_i=\phi_0+\phi_1 Dum_i+\phi_2 Y_i+\phi_3 N_i+\phi_4 Z_i+e_i$

(*Parentheses are t-ratios at 5% significance level*; $R^2_{D\hat{D}}$ *is R-square* ∦ *observed* ∧ *predicted*; Ω *is objective function*; *LAE mean is empirical quantile mean*)

Variable	**OLS**	**2SLS**	**Robust (LAE)**
Constant	0.584 (9.889)	0.584 (10.613)	0.623(15.171)
Dum_i	0.035(1.599)	0.035(1.716)	-0.019(-1.292)
Y_i	0.275(1.285)	0.275(1.379)	0.469(2.869)
N_i	0.033(1.543)	0.033(1.656)	0.002(0.136)
Z_i	-0.879(-3.869)	-0.879(-4.152)	-1.165(-6.899)
Adj.R^2	0.3254	0.3983	N/A
SEE	0.09655	0.08997	0.0005
LLF	37.5922	37.5922	N/A
DW(ρ)	2.434(-0.248)	2.434(-0.248)	2.302(-0.175)
$R^2_{D\hat{D}}$	0.3983	0.3983	0.3228
Normal t	1.3241	1.3241	1.1726
Chi-Square(df)	6.4311(3)	9.2295(3)	12.0604
Mean Di	0.66237	0.66237	0.65094
Omega	N/A	N/A	1.3656
No. Observations	38	38	38

Table $3 - \log D_i = \phi_0 + \phi_1 Dum_i + \phi_2 Y_i + \phi_3 N_i + \phi_4 Z_i + e_i$

(*Parentheses are t-ratios at 5% significance level*; $R^2_{D\hat{D}}$ *is R-square* ≬ *observed* ∧ *predicted*; Ω *is objective function*; *LAE mean is empirical quantile mean*)

Variable	**OLS**	**2SLS**	**Robust (LAE)**
Constant	4.058(35.692)	4.058(38.301)	4.133(73.322)
Dum_i	0.034(0.808)	0.034(0.867)	-0.010(-0.654)
Y_i	0.624(1.517)	0.624(1.628)	0.699(3.006)
N_i	0.073(1.789)	0.073(1.921)	0.004(0.163)
Z_i	-2.279(-5.210)	-2.279(-5.591)	-1.809(-7.382)
Adj.R^2	0.4480		N/A
SEE	0.18589	0.17323	0.10437
LLF	12.6999	12.6999	N/A
DW(ρ)	2.384(-0.244)	2.385(-0.244)	2.343(-0.189)
$R^2_{D\hat{D}}$	0.5077	0.5077	0.4538
Normal t	1.1726	1.1726	1.8477
Chi-Square(df)	7.8451(3)	8.2222(3)	23.8142(3)
Mean Di	4.1697	N/A	4.1832
Omega	N/A	N/A	2.3619
No. Observations	38	38	38

Table $4-D_i=\phi_0+\phi_1 Dum_i+\phi^* X_i^*+e_i,\ X_i^*=1/X_i$

(*Parentheses are t-ratios at 5% significance level*; $R^2_{D\hat{D}}$ *is R-square* ≬ *observed* ⋀ *predicted*; Ω *is objective function*; *LAE mean is empirical quantile mean*)

Variable	**OLS**	**2SLS**	**Robust (LAE)**
Constant	0.556(10.220)	0.556(10.967)	0.637(15.186)
Dum_i	0.057(2.274)	0.057(2.439)	0.011(1.865)
y_i	0.009(1.101)	0.009(1.181)	0.012(1.567)
n_i	0.005(1.082)	0.005(1.165)	0.004(0.920)
z_i	-0.0002(-1.148)	-0.0002(-1.232)	0.0004(-2.166)
Adj.R^2	0.0615	0.1629	N/A
SEE	0.11388	0.10613	0.10338
LLF	31.3191	31.3191	N/A
DW(ρ)	2.246(-0.134)	2.2463(-0.134)	1.655(0.166)
$R^2_{D\hat{D}}$	0.1629	0.1629	0.0162
Normal t	1.0682	1.0682	-1.2608
Chi-Square(df)	13.795(3)	13.2791(3)	
Mean Di	0.66237	0.66237	0.69317
Omega	N/A	N/A	1.5251
No. Observations	38	38	38

Table 5 – $d_i=\phi_0+\phi_1 Dum_i+\phi_2 y_i+\phi_3 n_i+\phi_4 z_i+e_i$
($d_1=1/D_i$, $y_i=1/Y_i$, $n_i=1/N_i$, $z_i=1/Z_i$; *Parentheses are t-ratios at 5% significance level*; $R^2_{D\hat{D}}$ *is R-square ≬ observed ∧ predicted*; Ω *is objective function*; *LAE mean is empirical quantile mean*)

Constant	**OLS**	**2SLS**	**Robust (LAE)**
Constant	1.768(6.299)	1.768(6.759)	1.584(13.732)
Dum_i	0.016(0.158)	0.016(0.169)	-0.013(-1.538)
Y_i	-1.752(-1.725)	-1.752(-1.851)	-0.658(-1.283)
N_i	-0.197(-1.939)	-0.197(-2.113)	-0.090(-0.401)
Z_i	6.942(6.428)	6.942(6.759)	2.236(4.163)
Adj.R^2	0.5492	0.5979	N/A
SEE	0.45903	0.42777	0.22708
LLF	-21.6508	-21.6508	N/A
DW(ρ)	2.186(-0.168)	2.186(-0.168)	2.087(-0.048)
$R^2_{D\hat{D}}$	0.5979	0.5979	0.5517
Normal t	0.9868	0.9868	1.0682
Chi-Square(df)	20.573(3)	18.252(3)	26.892(3)
Mean Di	1.6126	1.6126	1.56146
Omega	N/A	N/A	4.4445
No. Observations	38	38	38

Figure 5a - Knowledge Index Conditional on Openness to Trade across African Countries

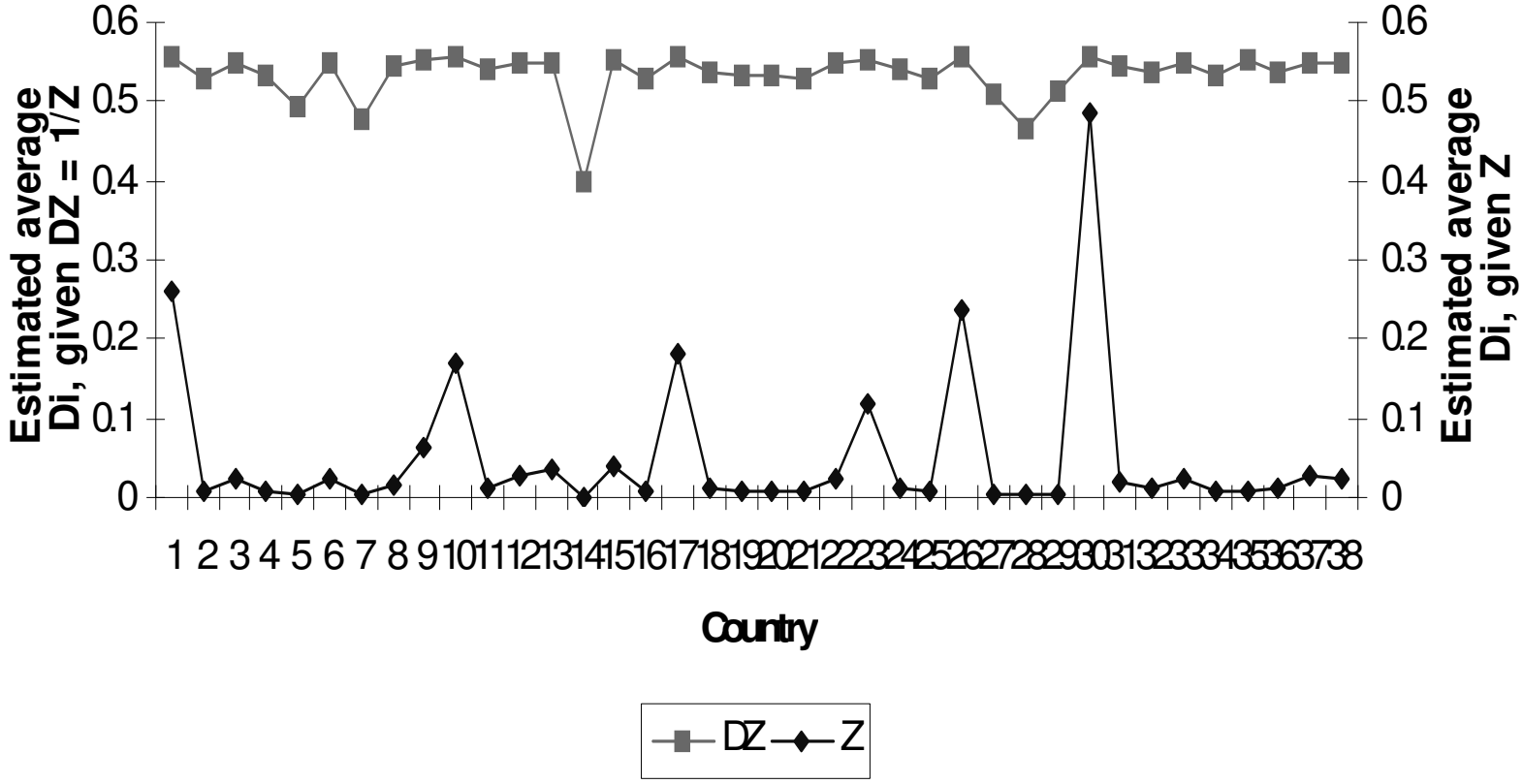


Figure 5b - Knowledge Index Conditional on Trade Openness across African Countries

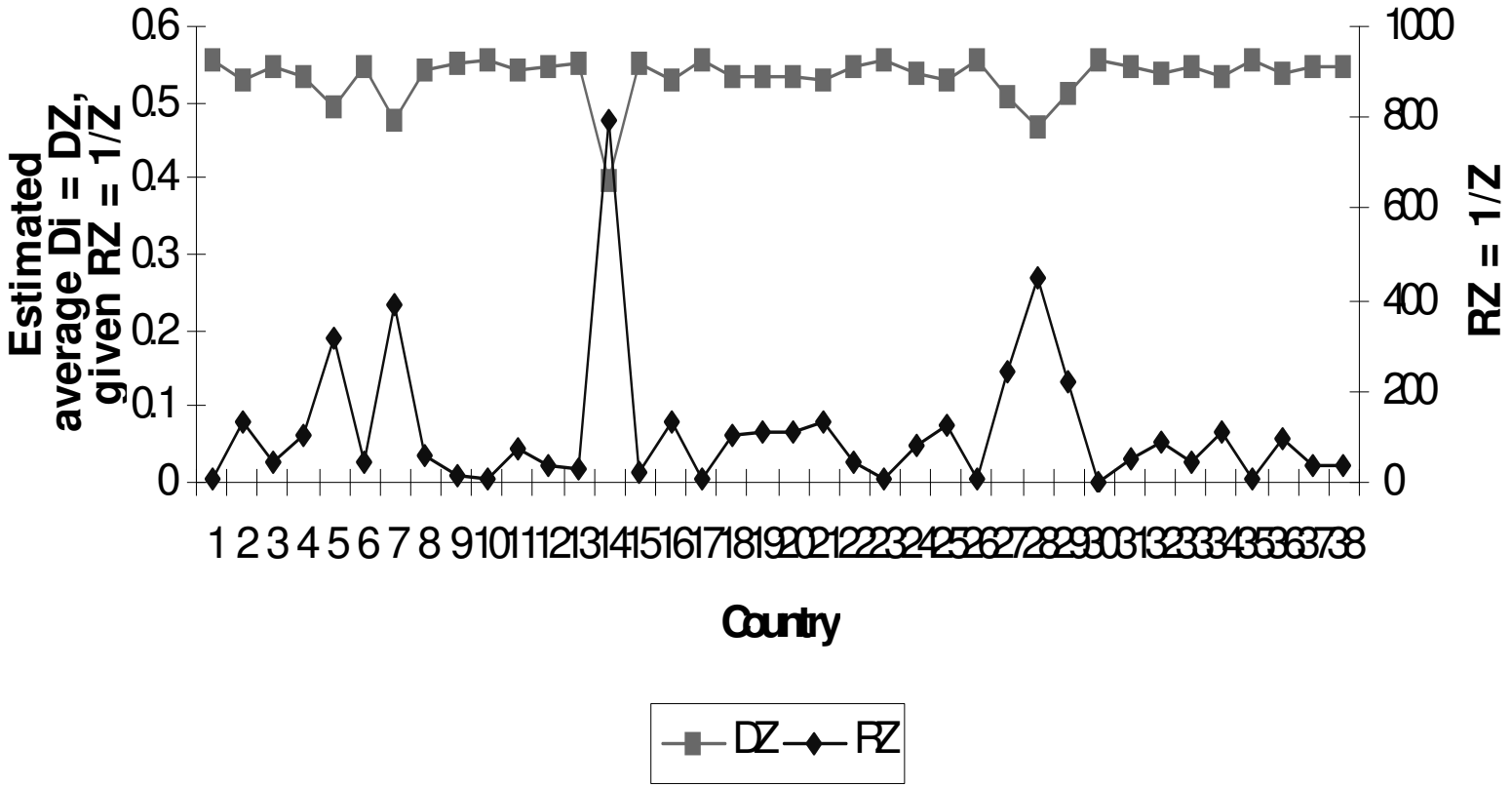


Figure 6a - Knowledge Index Conditional on Income across African Countries

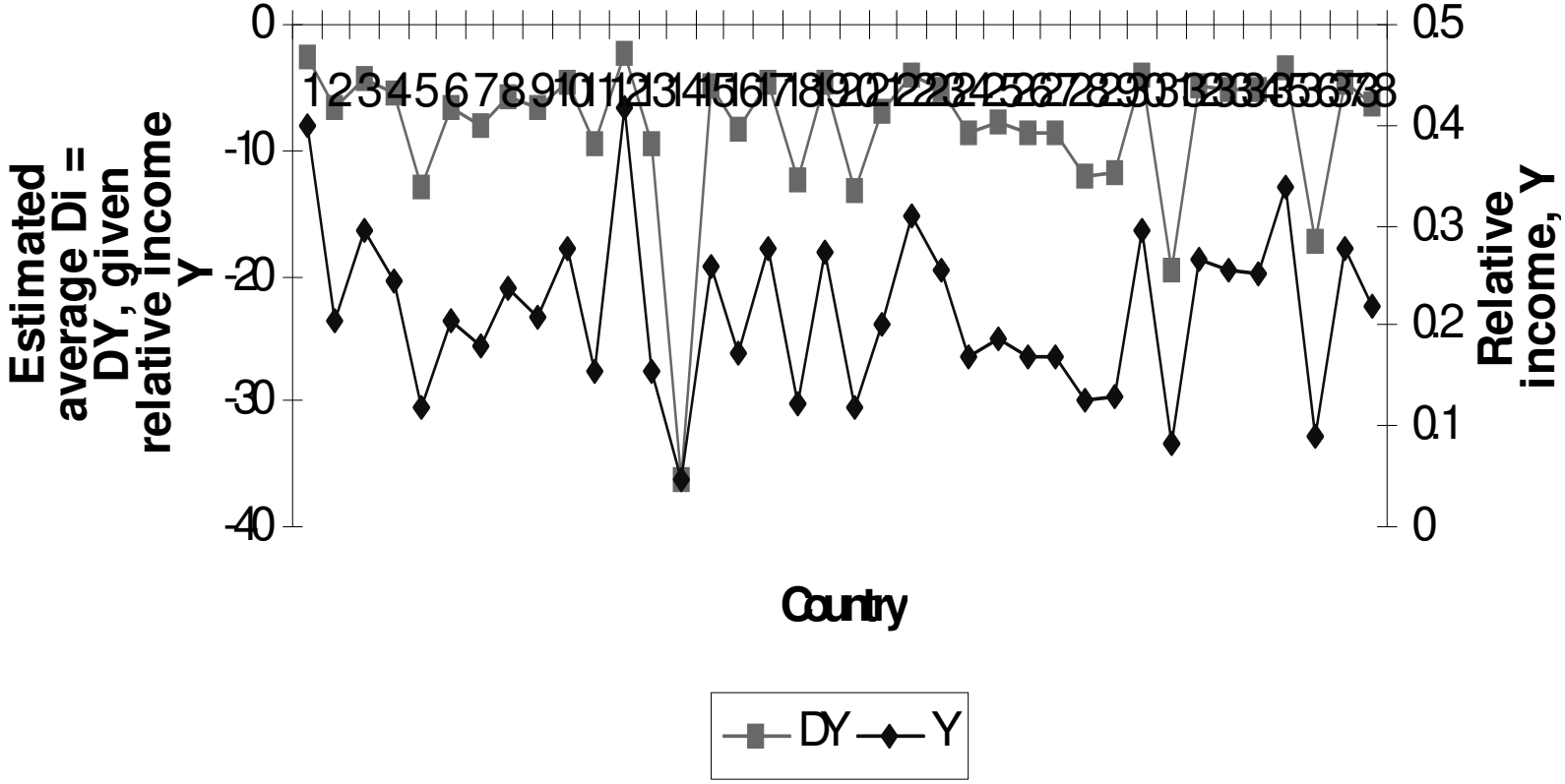


Figure 6b - Knowledge Index Conditional on Income across African Countries

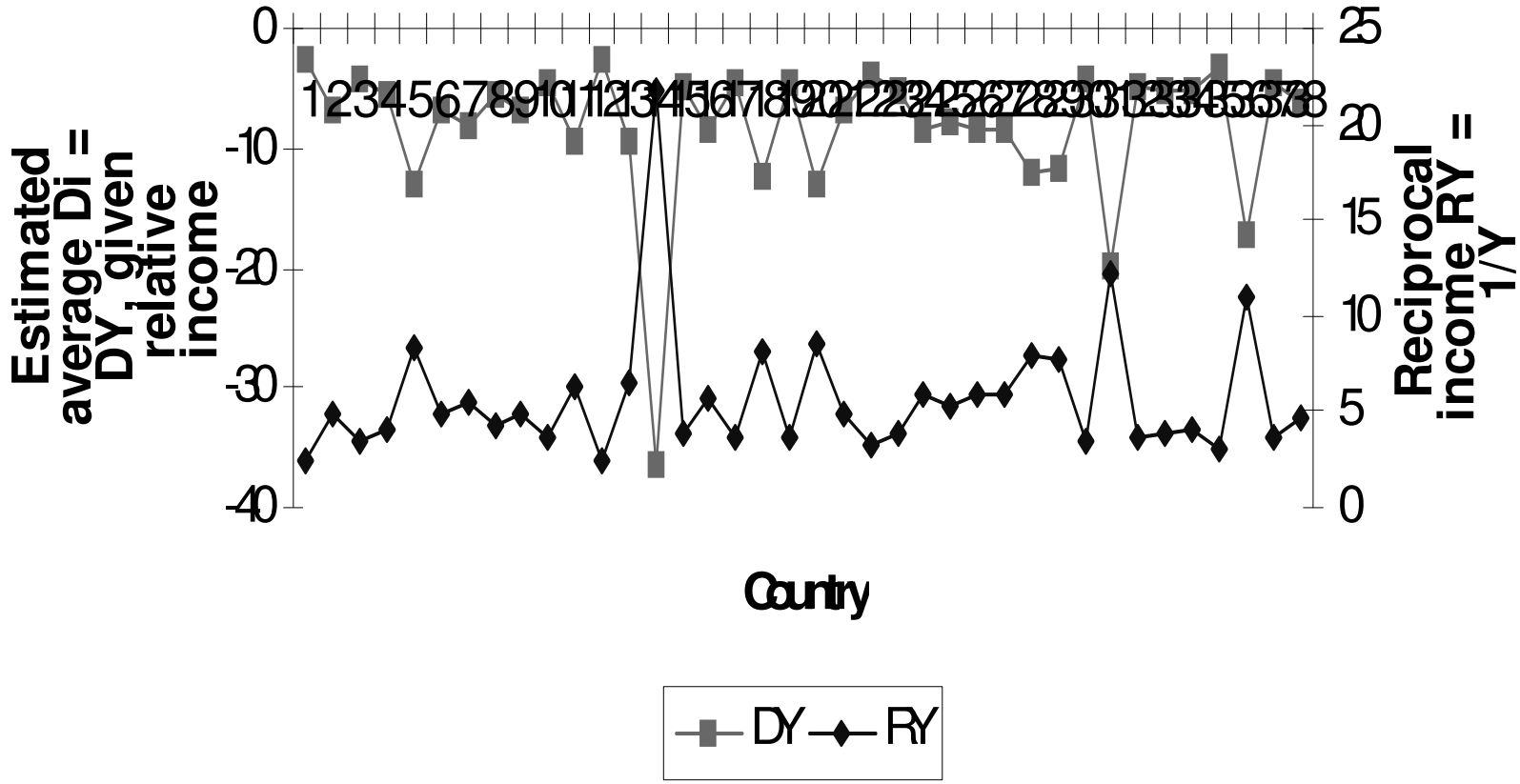


Figure 7a - Knowledge Index Conditional on Population across African Countries

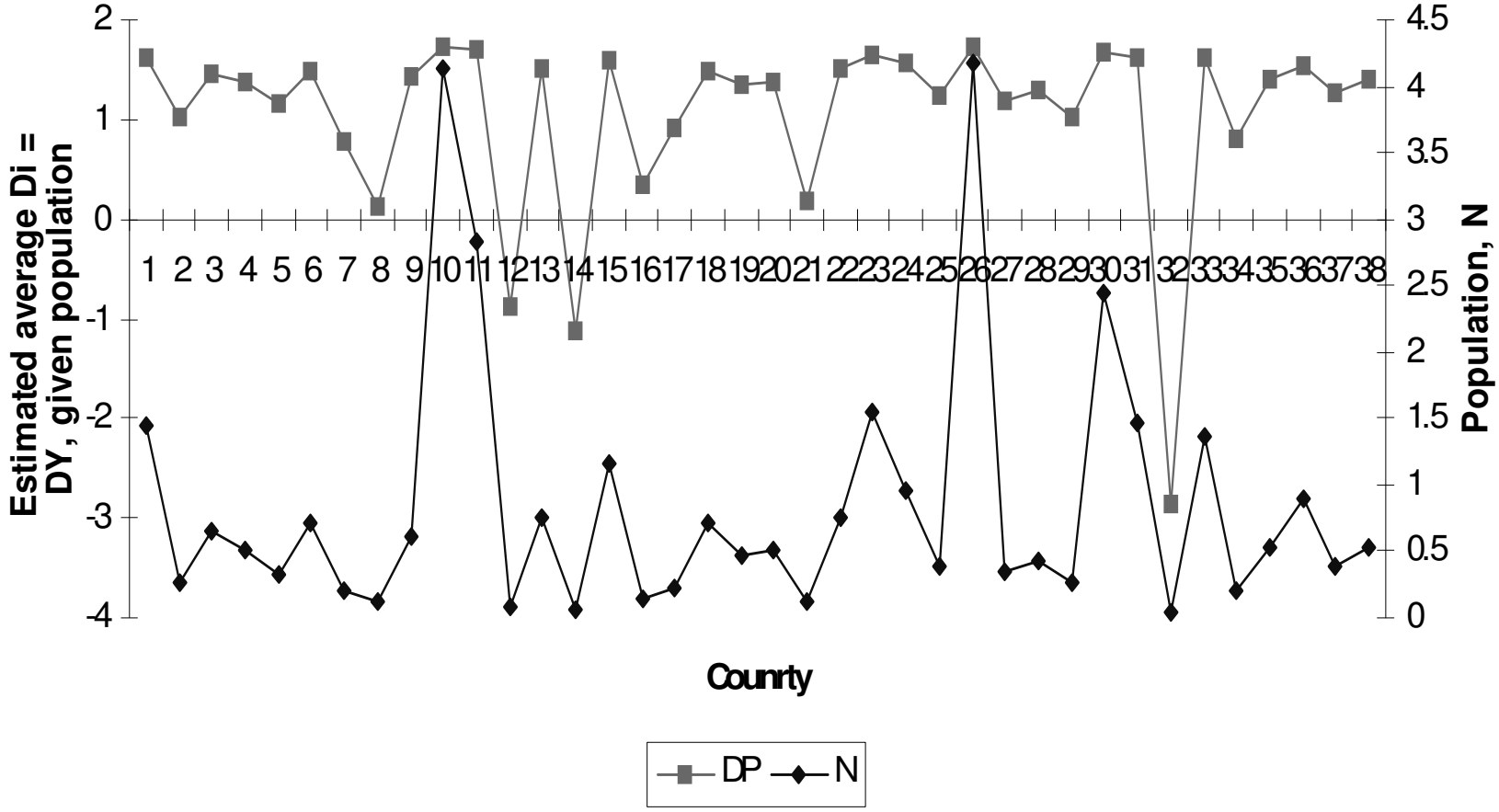
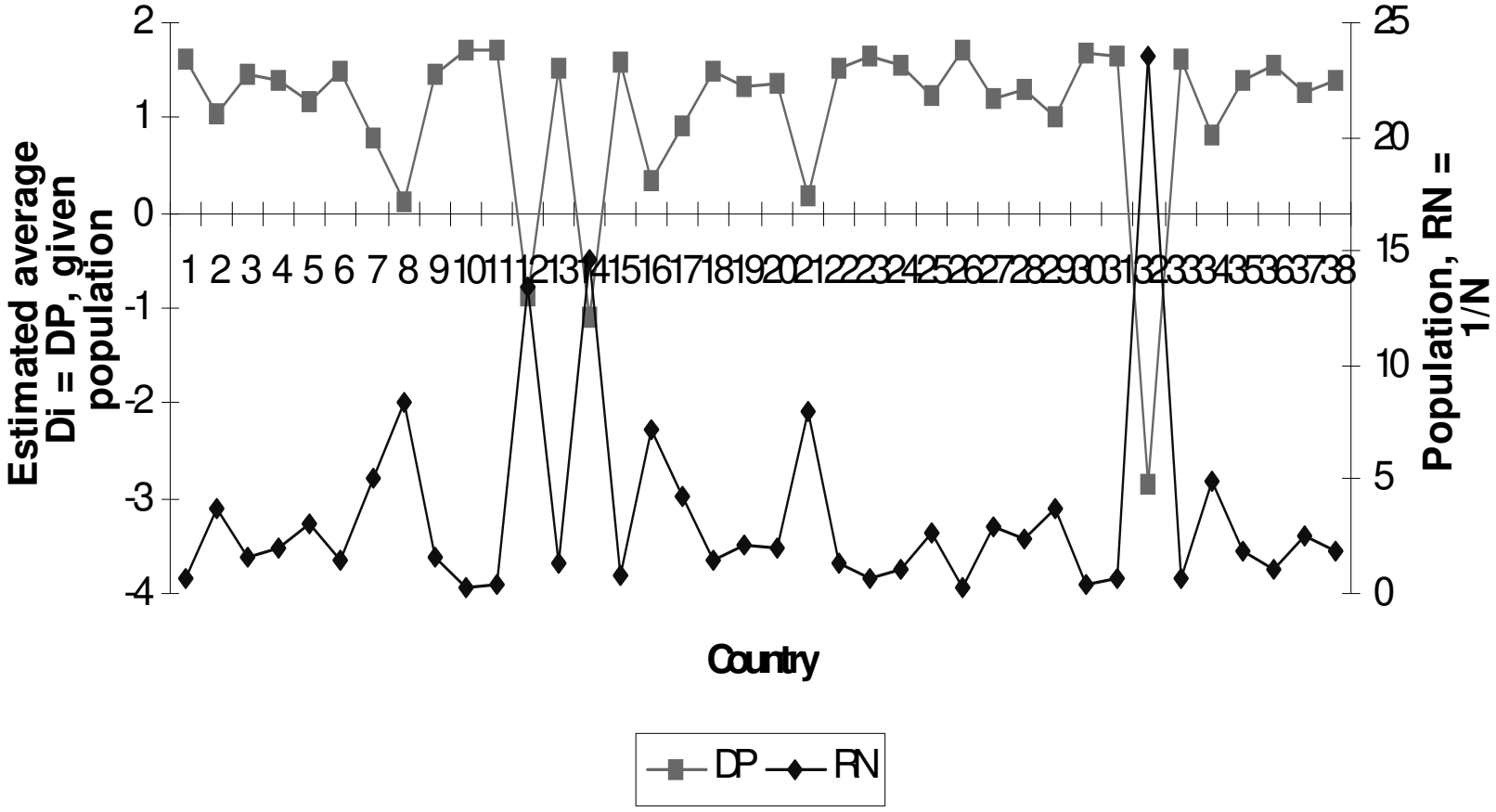


Figure 7b- Knowledge Index Conditional on Income across African Countries



indices of knowledge for Francophone and Anglophone African countries are $0.504 + \Phi X_i$ and $0.575 + \Phi X_i$, respectively. What this means is that technological differences have significant influence on knowledge building.

The goodness-of-fit of roughly 30% is reasonable for cross-sectional regressions. At around 86.4% $(1 - \frac{SEE}{MeanD_i})100$, the predictive power of the regressions is also good.

When D_i Log-linear

In the log-linear form the key results are consistent with those of the linear form. *Ceteris paribus*, the slopes of the dependent variable with respect to Y_i and N_i range from 0.60 to 0.70 and 0.0004 to 0.07, respectively, according to all three estimators. However, by the LAE method country-specific dummies affect knowledge building negatively, with 40% of variations in the dependent variable well-explained by the included regressors.

When D_i is Reciprocal

I tried two slightly different versions of a reciprocal relationship between the knowledge index and the independent variables. First Di is assumed to be reciprocal with respect to Y_i, N_i, and Z_i, but not in relation to the Dum_i and the intercept, i.e., $D_i = \phi_o + \phi_1 Dum_i + \Phi^* X_i^*, X_i^* = 1/X_i$. Second, D_i is "fully" reciprocal, i.e., $D_i = 1/\Phi X_i \Rightarrow 1/D_i = \Phi X_i$. In the first instance relative income, population, and dummy variables strongly determine, while openness is inversely related to, knowledge building in this group of countries. The results are consistent with those discussed above. An added perspective is that as $X_i \to \infty, \Phi X_i \to 0 \wedge D_i \to \phi_0$ as its limiting asymptote, implying that neither X_i nor D_i can increase indefinitely because the slope

$$dD_i/dX_i^* = -\phi X_i^* > 0 \ \text{if} \ \phi < 0, \ \wedge \ dD_i/dX_i^* = -\phi X_i^* < 0 \ \text{if} \ \phi > 0. \qquad (17)$$

Again (17) means that there is threshold of Y_i (y_i), N_i (n_i) and Z_i (z_i) below and above which knowledge production does not go, see Figure 5 - 7.

Across the three tables OLS and 2SLS estimates are nearly identical. The LAE estimates are also similar. The difference between the latter and the former two is explained by the objective of minimizing absolute errors due to the presence of outliers. The LAE adjustment mechanism generates two relevant statistics: "objective function" (Ω), and the "empirical quantile function" at the mean values of independent variables. Both statistics are reported in the tables. Note that Ω is a solution to the following minimization problem

Table 2 - Knowledge Index and other Basic Data across African Countries, 1960-February 2003

Country	D_i	R_i	$\overline{P}$	δ_i	γ_i	r_i	Rank by D_i
Burkina Faso	**80.00**	**851.0806**	**13.53**	**0.0125**	**0.2786**	**0.2911**	**1**
Ghana	**79.22**	**744.15**	**13.53**	**0.0126**	**0.0761**	**0.0887**	**2**
Cameroon	**78.94**	**1018.594**	**13.53**	**0.0127**	**0.1788**	**0.1915**	**3**
Sierra Leone	**78.37**	**1082.4**	**13.53**	**0.0128**	**0.0266**	**0.0393**	**4**
Cote d'Ivoire	**77.90**	**881.0233**	**13.53**	**0.0128**	**0.1132**	**0.1259**	**5**
Gabon	**77.47**	**1067.985**	**13.53**	**0.0129**	**0.0811**	**0.0939**	**6**
Botswana	**75.28**	**804.4865**	**13.53**	**0.0133**	**0.3519**	**0.3653**	**7**
Kenya	**74.69**	**981.0073**	**13.53**	**0.0134**	**0.0591**	**0.0725**	**8**
Uganda	**74.41**	**1054.037**	**13.53**	**0.0135**	**0.0167**	**0.0301**	**9**
Nigeria	**74.40**	**767.8868**	**13.53**	**0.0134**	**0.0282**	**0.0417**	**10**
Swaziland	**74.38**	**927.7149**	**13.53**	**0.0135**	**0.0204**	**0.0338**	**11**
Malawi	**73.97**	**1048.099**	**13.53**	**0.0135**	**0.0432**	**0.0567**	**12**
Mali	**73.79**	**1071.842**	**13.53**	**0.0136**	**0.0402**	**0.0537**	**13**
Zimbabwe	**72.98**	**869.7857**	**13.53**	**0.0137**	**0.0143**	**0.0279**	**14**
Tanzania	**72.89**	**1010.611**	**13.53**	**0.0137**	**0.0184**	**0.0322**	**15**
Senegal	**72.84**	**846.1759**	**13.53**	**0.0137**	**0.0241**	**0.0379**	**16**
Congos (combined)	**72.51**	**821.131**	**13.53**	**0.0138**	**0.0118**	**0.1319**	**17**
Zambia	**69.51**	**795.8824**	**13.53**	**0.0144**	**0.0129**	**0.0273**	**18**
Ethiopia	**68.57**	**1000.79**	**13.53**	**0.0146**	**0.0762**	**0.0907**	**19**
Togo	**68.14**	**998.4488**	**13.53**	**0.0147**	**0.0145**	**0.0292**	**20**
Burundi	**65.12**	**871.9333**	**13.53**	**0.0154**	**0.0174**	**0.1896**	**21**
Mauritania	**64.44**	**631.4**	**13.53**	**0.0155**	**0.0292**	**0.0447**	**22**
Guinea Bissau	**64.29**	**820.5588**	**13.53**	**0.0156**	**0.0513**	**0.0668**	**23**
Rwanda	**63.37**	**738**	**13.53**	**0.0158**	**0.0184**	**0.0342**	**24**
Algeria	**62.90**	**706.0047**	**13.53**	**0.0159**	**0.0899**	**0.9156**	**25**
Liberia	**62.54**	**1006.66**	**13.53**	**0.0159**	**0.0409**	**0.0569**	**26**

Country	D_i	R_i	$\overline{P}$	δ_i	γ_i	r_i	Rank by D_i
Tunisia	**62.23**	**857.3465**	**13.53**	**0.0161**	**0.0098**	**0.0259**	**27**
Libya	**60.69**	**985.5537**	**13.53**	**0.0164**	**0.0355**	**0.0519**	**28**
Morocco	**60.65**	**1060.345**	**13.53**	**0.0165**	**0.0219**	**0.0384**	**29**
Central African Rep.	**59.46**	**245.152**	**13.53**	**0.0168**	**0.0107**	**0.1236**	**30**
Sudan	**58.97**	**797.8773**	**13.53**	**0.0169**	**0.0107**	**0.0277**	**31**
Madagascar	**58.82**	**1006.294**	**13.53**	**0.0170**	**0.0306**	**0.0476**	**32**
Egypt	**56.75**	**986.2477**	**13.53**	**0.0176**	**0.0649**	**0.0826**	**33**
Benin	**55.00**	**921.9558**	**13.53**	**0.0182**	**0.0382**	**0.4003**	**34**
Mozambique	**54.55**	**841.9748**	**13.53**	**0.0183**	**0.0148**	**0.0331**	**35**
Niger	**52.18**	**1006.822**	**13.53**	**0.0192**	**0.0112**	**0.0304**	**36**
Mauritius	**46.67**	**940.4648**	**13.53**	**0.0214**	**0.0945**	**0.0309**	**37**
South Africa	**18.12**	**987.4379**	**13.53**	**0.0552**	**-0.046**	**0.0088**	**38**
Sum	**2517.01**	**34055.16**	**-**	**-**	**-**	**-**	**38**
Average	**66.24**	**896.19**	**13.53**	**0.0161**	**0.0909**	**0.1071**	**-**

Table 3 – Gross Future and Present Values of Knowledge across African Countries, 1960-February 2003

Country	Π_i	R_i	Rank by Π_i
Burkina Faso	**120551.90**	**1082.40**	**1**
Ghana	**119376.00**	**1071.84**	**2**
Cameroon	**118946.50**	**1067.99**	**3**
Sierra Leone	**118095.50**	**1060.35**	**4**
Cote d'Ivoire	**117393.00**	**1054.04**	**5**
Gabon	**116731.60**	**1048.10**	**6**
Botswana	**113445.50**	**1018.59**	**7**
Kenya	**112556.50**	**1010.61**	**8**
Uganda	**112134.50**	**1006.82**	**9**
Nigeria	**112116.40**	**1006.66**	**10**
Swaziland	**112075.60**	**1006.29**	**11**
Malawi	**111462.70**	**1000.79**	**12**
Mali	**111201.90**	**998.45**	**13**
Zimbabwe	**109975.50**	**987.44**	**14**
Tanzania	**109843.00**	**986.25**	**15**
Senegal	**109765.70**	**985.55**	**16**
Congo (Combined)	**109259.30**	**981.01**	**17**
Zambia	**104743.90**	**940.46**	**18**
Ethiopia	**103323.90**	**927.71**	**19**
Togo	**102682.50**	**921.96**	**20**
Burundi	**98123.65**	**881.02**	**21**
Mauritania	**97111.26**	**871.93**	**22**
Guinea Bissau	**96872.07**	**869.79**	**23**
Rwanda	**95486.66**	**857.35**	**24**
Algeria	**94788.80**	**851.08**	**25**
Liberia	**94242.54**	**846.18**	**26**

Country	Π_i	R_i	Rank by Π_i
Tunisia	**93774.64**	**841.97**	**27**
Libya	**91453.17**	**821.13**	**28**
Morocco	**91389.44**	**820.56**	**29**
Cent. African Rep.	**89599.39**	**804.49**	**30**
Sudan	**88863.30**	**797.88**	**31**
Madagascar	**88641.11**	**795.88**	**32**
Egypt	**85523.12**	**767.89**	**33**
Benin	**82879.44**	**744.15**	**34**
Mozambique	**82194.48**	**738.00**	**35**
Niger	**78631.02**	**706.00**	**36**
Mauritius	**70321.95**	**631.40**	**37**
South Africa, Rep.	**27303.72**	**245.15**	**38**
Sum	**3,792,881.00**	**34055.16**	**38**
Average	**99,812.66**	**896.19**	**-**

$$\Omega = Min\ \phi[\sum \theta|e_i| + \sum (1-\theta)|e_i|],\ e_i = |D_i - \Phi X_i|\ \ for\ \theta = 0.5. \qquad (18)$$

The value of the empirical quantile function compares favorably to the OLS and 2SLS mean D_i. Across all Tables notice that the log-likelihood function (LLF) suggests that the sets of technical coefficients are unique. However, the Chi-square and Normal t statistics indicate that residuals may be non-normally distributed, counseling cautious interpretation of results.

Imputed Gross Future and Present Values - Results

I started the calculations of this section with (10) by first regressing R_i on a country-specific dummy variable-i. The result of this regression show that R_i is negatively related to the country-specific dummy, but in a statistically insignificant way. That is not really the point; the point is that taking the constant term of the regression ((lnR0)/i = 6.8347) as (12a) asserts, and given δ_i, I compute (11) for γ_i such that $r_i = \delta_i + \gamma_i$ solves (9). Table 2 lists basic statistics in descending order of D_i as stated in (13). From this table the cross-country social discount rate r_i ranges from the lowest (0.9%) for South Africa to the highest (92%) for Algeria. While there is no obvious correlation between D_i and r_i, there is one between R_i and r_i. The lower the opportunity cost of producing D_i, the higher R_i. For r_i = 0.9% and D_i =18.12, R_i is about $999.00 in South Africa. In contrast, given r_i = 12% and D_i = 59.5, R_i = $245.50 for the Central African Republic. Again the opportunity cost of a dissertation is lower for South Africa than for the Central African Republic, meaning South Africa has comparative advantage in the production of knowledge. Across this group of countries the average opportunity cost ($\bar{r}$) of a dissertation is 10.7%, average D_i is 66, and average R_i is $897.00.

Table 3 lists imputed gross future and present values of knowledge across African countries. For this group of countries standing in 1960 the average future value in 2003 is $99,813.00; the corresponding average present value is $896.00. The sum of future worth of knowledge across countries over this period is $3.8 million, and the sum of the present value is $34,055. Burkina Faso ranks first and South Africa last. The ranking appears uncorrelated with the language dummy variable. However, five of the six top-ranked countries are French-speakers, the next five are all English-speakers, and the remainder a good mix of all three language options.

6. Concluding remarks

This study turned out a lot more complicated than I anticipated, and it is still incomplete. For that reason the concluding remarks I am making here are all tentative. However, I am making this results available because like Keynes (1953) so wisely said, “it is astonishing what foolish things one can temporarily believe if one thinks too long alone, particularly in economics ...” (p.vii). And there we go.

African countries made reasonable progress in knowledge building measured in terms of dissertations. Although the rate of such progress slowed since the 1980s the average index of knowledge building is

still high at 66. Three relative factors are responsible for knowledge creation: (a) income as a proxy for investment in knowledge building, (b) population, and (c) openness. Relative returns to investment in knowledge building is about 37% - which is high. The difficult question is: who should gets this return - local or foreign determinants of knowledge? I cannot answer this question. But if it turned out that the production of the knowledge of African countries is financed mainly from external sources, then the so-called brain-drain is not a drain at all; it is a *just* return to forgone consumption by residents of industrialized countries.

Technical factors and population also affect knowledge creation, but in statistically insignificant ways. Over this one period of 44 years openness measured by trade flows between African countries and the industrialized world has influenced knowledge production adversely, either because trade has been small or closed for this group of countries.

One obvious policy implication is continued investment in knowledge building; there are positive returns to be had although I am not clear what would be a just and fair distribution of those returns. The second and third policy implications are to improve openness and to reduce the opportunity cost of knowledge production. I have serious doubt that these can be achieved only, or even mainly, by increasing the quantity of educated Africans.

One implication for research of this study is to integrate this index into economic growth theory and compare results associated with it to those associated with conventional measures of human capital, i.e.,.

$$Q_{it}=B_i L_{it}^{\alpha_i} K_{it}^{\beta_i}[H_{it}\equiv D_{it}]^{\gamma_i}\exp(\lambda_i t), \qquad (19)$$

where for the ith country in period t Q_{it} is gross domestic product, L_{it} is physical labor, and K_{it} is capital stock, $H_{it} \equiv$ Dit is human capital, and B_i, α, β,, γ, and λ are parameters to be estimated. Before trying out (19) further work needs done to deal with apparent econometric and data issues. The data used to construct Y_i needs careful revision because as is Y and K will be highly correlated. The assumption of linear regressions may be inappropriate; tests seem to support non-normal distribution of error. In addition, D_i as estimated now is highly correlated with K. But those problems can be confronted at the appropriate time.

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