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Voxi Heinrich Amavilah

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Voxi Heinrich Amavilah*
REEPS
PO Box 38061
Phoenix, AZ 85069 USA

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Extant literature indicates that technology, and by implication its underlying knowledge base, determines long-run economic performance. Absent from the literature with respect to developing countries are quantitative assessments of the nexus between technology as knowledge and economic performance. This paper imposes a simple production function on annual pooled observations on Botswana, Namibia, and South Africa over the 1976-2004 period to estimate the marginal impacts of technology as knowledge on economic performance. It finds that capital (k), openness to trade (τ), and even the share of government expenditure of GDP (G) among other factors, influence economic performance. However, the economic performance of countries like Botswana, Namibia, and South Africa depends largely on technology, technological change, and the basic knowledge that forms the foundation for both. For instance, measured as a homogenous "manna from heaven", technology is the strongest determinant of real per capita income of the three nations. The strength of technology as a determinant of performance depends on the knowledge underpinnings of technology measured as the number of publications (Q, q). Both Q and q are strongly correlated with the countries' performance. This suggests that the "social capability" and "technological congruence" of these countries are improving, and that developing countries like Botswana, Namibia, and South Africa gain from increased investment in knowledge-building activities including publishing. Obviously there is room for strengthening results, but this analysis has succeeded in producing a testable hypothesis.

Keywords: *knowledge, technology, economic performance*

JEL Code: *O55, O41, O47, O33, I29, D80, D83, C51, C23, C33*

*Amavilah is an independent economic researcher, a member of the Gerson Lehrman Group Councils (http://www.glgcouncils.com) and an adjunct instructor of economics at Glendale College, Glendale, Arizona, USA. He can be reached at vhsamavilah@gmail.com.

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Abstract

Extant literature indicates that technology, and by implication its underlying knowledge base, determines long-run economic performance. Absent from the literature with respect to developing countries are quantitative assessments of the nexus between technology as knowledge and economic performance. This paper imposes a simple production function on annual pooled observations on Botswana, Namibia, and South Africa over the 1976-2004 period to estimate the marginal impacts of technology as knowledge on economic performance. It finds that capital (k), openness to trade (τ), and even the share of government expenditure of GDP (G) among other factors, influence economic performance. However, the economic performance of countries like Botswana, Namibia, and South Africa depends largely on technology, technological change, and the basic knowledge that forms the foundation for both. For instance, measured as a homogenous "manna from heaven", technology is the strongest determinant of real per capita income of the three nations. The strength of technology as a determinant of performance depends on the knowledge underpinnings of technology measured as the number of publications (Q, q). Both Q and q are strongly correlated with the countries' performance. This suggests that the "social capability" and "technological congruence" of these countries are improving, and that developing countries like Botswana, Namibia, and South Africa gain from increased investment in knowledge-building activities including publishing. Obviously there is room for strengthening results, but this analysis has succeeded in producing a testable hypothesis.

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1. Introduction

The objective of this paper is to estimate the impact of technology, and the knowledge underlying it, on the economic performance of developing countries using limited annual publications data for the Southern African countries of Botswana, Namibia, and South Africa over the 1976-2004 years. The estimation is important for policy and research reasons. For policy the results informs predictions of long-run economic performance of developing countries like Botswana, Namibia, and South Africa. Regarding research even a small contribution to the understanding of the factors and forces that determine economic performance goes a long way towards opening up opportunities for further examinations of the processes of technical progress and economic development. Either way, the objective of this paper is valuable because recent research indicates that during the past nine years some African countries have performed well relative to their performance history, which raises the question of how that good performance can be accelerated, expanded, and sustained (Amavilah, 2006).

Over the years growth experts have drawn up long lists of the factors that ostensibly explain the performance of nations, see e.g., Collier and Gunning (1999), Temple (1999), Temple and Johnson (1998), Fafchamps (2004), Barro (1991, 1999), Easterly and Levine (1997), Benhabib and Spiegel (1994), Romer (1993), Artadi and Sala-i-Martin (2003), Sachs and Warner (1997), to list only a few.[1] In the case of African countries, however, factors undermining growth receive more emphasis than factors promoting growth. In a paper, well-received by the profession, W. Easterly and R. Levine (1997) state that "Africa's growth tragedy" is a function of "low schooling, political instability, underdeveloped financial systems, distorted foreign exchange markets, high government deficits, and insufficient infrastructure" (see both the abstract and conclusion of that paper). This statement sounds like a regression of the negatives, in that both the left-handside and right-handside variables are known to be negative and the results are predictable *a priori* - but that is not the point. The point is that an opportunity cost of this negative over-emphasis is the crowding-out of clarity about the factors that do promote Africa's good performance, which leaves us scared but less prepared about what to do. Thus, Kenneth Arrow in recent interview with Juan Dubra (2005) is correct that economists still neither understand well the causes of growth, nor know why growth rates differ across economies. This situation is not helpful to either policy or further research.

We focus on Botswana, Namibia, and South Africa because these three countries offer an excellent study example, not because they are located in the same geographical region of the world, but because they represent developing countries in their differences and similarities, again making them a realistic case for other countries at different levels of development. In terms of the differences South Africa is the most technologically advanced of the trio in some respects. However, its nascent democratic institutions and long Apartheid history have disadvantaged the country in many other important areas. Consequently, South Africa is only an upper-middle-income country. Botswana, on the other hand, has been one of the fastest growing economies in the world for nearly four decades (Acemoglu, Johnson, and Robinson. 2001a, 2001b, 2002). Rapid performance puts Botswana in the same income category as South Africa. Although Namibia is a lower-middle income country, its modern sectors rival South Africa's.[2]

With respect to commonalities, all three economies are resource-based economies, with mining (diamonds for Botswana and Namibia, and gold for South Africa) piggybacking each economy

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[1]See a sample list of papers on economic growth and technological change of African countries at http://ideas.repec.org/g/afrogro.html .

[2]Income groups: according to the World Bank's Atlas method in 2005, low-middle-income economies are those with an annual gross national income per capita of $875 or less; lower-middle-income ranges from $876 - $3,465; upper-middle-income lies between $3,466 and $10, 725; and high income is $10,726 and above.

for many years. While South Africa's industrial base is larger than those of Botswana and Namibia combined, a significant number of people in all three countries depend on domestic agriculture (mainly subsistence farming) for a livelihood. Also the three economies are similarly export-oriented. Their macroeconomic environments and financial sectors are competitive as well as closely linked. All three nations are members of the Southern African Customs Union within the Rand monetary orbit and the socio-political economy of the Southern African Development Community of the proposed African Union (Masanjala and Papageorgiou, 2006, Aziakpono, undated, Lange, 2004). The three countries' going rates of interest and currency exchange are interconnected. Thus, it is not unreasonable to assume that the level of knowledge in these countries is approximately the same (World Bank, 2001, Marope, 2005, Nicolson and Tjezeke, undated). Moreover, it is also reasonable to say that the prospects for economic integration in this part of Africa is greatest among these countries. In fact, not long ago the Namibian and South African economies were essentially one economy.

In Section 2 below we *scan* (not review) the relevant literature for the theoretical basis of the empirical relations to be used. Section 3 specifies those empirical relations as a simple econometric model with technology as knowledge as one of its arguments. The fourth section describes measurement issues. Section 5 presents the results, and the final section draws a conclusion.

2. Knowledge, technology, production, and economic performance

Economists have always appreciated the role technology plays in the production process, economic performance, and human welfare (Sampat, 2005, 2006, Rosenberg, 1982, Nelson, 2002, Mokyr, 2005). However, early economic literature on most aspects of technology depended on the assumption of exogeneity (Solow, 1956, 1957, Swan, 1956, 2002). The assumption served two broad purposes: On one hand it was a good "measure of our ignorance" - i.e., our limited knowledge (Abramovitz, 1979, 1986); on the other hand, it was consistent with the classical linear regression model.

2.1. Knowledge and technology

A key driver of technology is human knowledge and pretensions about knowledge (von Hayek, 1937, Boulding, 1966, Loasky, 1999, Paul Romer, 1989, 1990, and Warsh,2006, Brooks, 1994). However, although each economy is knowledgeable in its own way, not all knowledge is productive. In addition, knowledge may exist people may know how use it productively; this is what von Hayek (1974) calls "the pretence of knowldge". Further still, in some economies productive knowledge is unevenly distributed, and/or its rates of growth and spread limited, across the population. This points out that there are institutional factors that influence knowledge accumulation, and hence its impact on technology. In fact, long before the endogenous model became a standard tool for accounting performance, Francis Bacon, Adam Smith, Alfred Marshall and so on acknowledged the economic value of knowledge in production. For example, common knowledge attributes the saying that "knowledge is power" to Bacon. Adam Smith (1976, p.1) argues that the supply of the "necessaries and conveniences of life" depends on the "skill, dexterity, and judgment" of the labor that produces it. For Alfred Marshall "knowledge is the most powerful engine of production; it enables us to subdue Nature and satisfy our wants" (quoted in Gurak, 2004, p.1). More recently Bertrand Russel (1948), Thomas Sowell (1996) and many others have stressed the importance of knowledge in different human endeavors, but W. Arthur Lewis (1965) is particularly informative for our purpose.

Lewis ranks knowledge high on his list of "the proximate causes of economic growth," third only after "the will to economize" and "economic institutions" (p. 164). The ranking suggests that a production activity is principally a function of human effort. A key driver of human effort is the desire for some reward, and the material wealth and comfort, which the reward provides. However, the desire for material wealth in some societies may be limited by such things as "asceticism", social status, and cultural and physical considerations. The limitations suggest either the lack or weakness of surrounding economic institutions. And where economic institutions are absent, weak, or hostile towards private property rights, the rights to reward work effort, and to foster specialization and voluntary exchange of comparative advantages are similarly hampered. Consequently economic freedom is also curtailed, resulting in other institutions such as religion being either too weak, too powerful, or downright immutable.[3] According to Mueller (1983) and Choi (1983), Mancur Olson has named such a phenomenon "institutional scelerosis", and it happens because economic institutions determine and are determined by knowledge are dysfunctional (North, 1990, Mokyr, 2005). In each society the growth of knowledge depends on philosophical attitudes, class structure, inventions and research. The application of knowledge also depends on attitudes to innovations. That norms are important to optimizing behavior is a subject of George Akerlof's (2007) "The missing motivation in macroeconomics".

Meadow (1992) defines knowledge as an informative data set known to be true because those who believe it to be true are justified in believing it is true. In order to justify beliefs as true, societies use education to condition beliefs into useful knowledge to serve their cultures - not all initial conditions are exogenous. Alfred North Whitehead (1929) echoes that notion of knowledge in stating that " culture is [an] activity of thought, and [a] receptiveness to beauty and humane feeling. ... [An education] ... aim[s] at producing men [women] who possess both culture and expert knowledge in some special direction. Their expert knowledge will give them the ground to start from, and their culture will lead them as deep as philosophy and as high as art. [Education should produce useful ideas because].... [e]ducation with inert idea is not only useless: it is, above all things, harmful, *Corupti optimi, pessima*. ... Every intellectual revolution which ever stirred humanity to greatness has been a passionate protest against inert ideas" (pp. 1-2, [] added). Economists would readily take the idea of specialization in the production of knowledge as seriously as they would take specialization in other production activities. However, others like Ludwig von Bertalanffy (1968, p. 50) would caution against the dangers of "too narrow specialization," and for the value of "integrative" knowledge.[4]

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[3]Lewis's definition of "economic organization" is that of Frank Knight (1921).

[4] My own views on specialism in general have been shaped by George Stigler's classic *The Intellectual and the Marketplace* (1984), which I read many times as an undergraduate

For Bertrand Russell (1948, 1953), in contrast to Whitehead, vague and inexact definitions of knowledge are “inevitable” (p. 154), mainly because “knowledge is a sub-class of true beliefs: every case of knowledge is a case of true beliefs, but not vice versa.” Some true beliefs are supported by evidence; they are deductively or inductively logical. Other true beliefs need no proof of evidence; they are perceptive and non-logical. Russell also considers if it would be sufficient to define knowledge as a self-evident and coherent “whole body of beliefs that promote success” (p. 156). He rejects that definition because “the question ‘What do we mean by *knowledge’* is not one to which there is a definite and unambiguous answer anymore than to the question ‘What do we mean by baldness’” (p. 158).

Whereas Russell is vague, Thomas Sowell (1996) is emphatically clear that knowledge and ideas are not the same: “*Ideas are everywhere, but knowledge is rare*” (p. 3, italics added). What Sowell means is that not all ideas qualify as knowledge. The few ideas that meet the generality test for knowledge must be produced. The cost of producing knowledge limits the quantity of knowledge available, and one way of cutting the cost of knowledge production is to specialize on the basis of comparative advantages. That is the supply side of knowledge. The demand side is the notion that the value of the marginal product of knowledge lies in the manner in which knowledge facilitates decision-making. The demand for knowledge is a derived demand as economists would say, and Sowell’s book deals with that subject.[5]

2.2. Technology and production

It is reasonable to conclude that knowledge is fundamental to technology and hence to economic performance. As Keith Lewin (2006) puts it, “knowledge matters [a lot] for development”. It is not hard to list examples of the influence of knowledge on technology, and vice versa (Driouchi, Azelmad, and Anders, 2006). Jared Diamond’s (1999) *Guns, Germs, and Steel* is a recent popular account, and Carlo Cipolla (1965) is another. In fact, the whole Industrial Revolution hinged upon technological progress (Henderson, 1968). Technological progress depends on knowledge (Mokyr, 2005). The seminal studies of human capital such as T.W. Schultz (1981) and Gary Becker (1993), and reviews like Cohn (1979) are all examinations of varieties of knowledge. Larry Samuelson (2004) sought a general model for knowledge in economic analysis in which...., but most growth studies represent knowledge as education and/or literacy. These studies are defensible on quantitative grounds; some of them are even groundbreaking. However, knowledge is a lot more than education. Robert Lucas Jr (1993) in his study of Asian growth miracles came to the conclusion that there were really no Asian miracles. What has happened is that Asian economies learned to integrate “objects” and “ideas” in ways that promoted growth (see Romer,1993, 1989, 1990).

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student of economics, with an interest in the sociology of business organizations as agents of change.

[5]Charrtrand (2002, 2006) has assembled a searchable database containing over 1000 papers on the global technological competitiveness of knowledge-based economies.

In an incisive chapter B.J. Loasky (1999) makes clear that observed growth rate differences across economies, insomuch as such differences can be attributed to technological gaps, are essentially "the problem of knowledge" (Von Hayek, 1937, 197?). To paraphrase, "the problem of knowledge" is due to the incompleteness, uncertainty and fallibility of information, the complexity of life itself, and the limited absorptive capacity and inability of people to manage change in real time (cf. Kneller and Stevens, 2006). From Stiglitz (1986, 2000) we already know the problems associated with incomplete, uncertain, and imperfect information. Loasky's new insight is that the uses of knowledge are almost always logical while outputs of knowledge are non-logical. That alone makes the organization of knowledge into a useful technology very difficult, because technology itself is a complex and multidimensional matrix. Just take one popular definition of technology: "Techonology is *all* the technical information about the combination of inputs necessary for the production of ... output. [T]echnology differs from the production function which presupposes technical efficiency and states the maximum output obtainable from every possible input combination" (Henderson and Quandt, 1980, p. 66). The distinction between technology and the associated production function arises because picking the "best input combination is a technical problem; [selecting] the best input combination for the production of a particular output level is an economic question" (p. 66). Even so, the relationships between knowledge and technology, and technology and production performance are hard to miss. Hence, it is not surprising that Parente and Prescott (1994) argue that economic performance is constrained by barriers to technology. A chief barrier to technology is *world knowledge*, both *general and scientific*. The higher the barriers, the lower the level of technology, the more investment in world knowledge is needed to lift economic performance. (Italicized phrases are Parente and Prescott's phrases). Using John Kay's (2005) catch phrase knowledge can be "big", "small", "precious", as well as base in the sense of Max Lerner (1939).

Production can go on with a given level of technology in the short-run as the textbook suggests; in the long run production requires technological change, and change requires knowledge. Joel Mokyr (2005) describes the history of technology and the effects of technology on long-run economic growth. The description demonstrates that technology presupposes knowledge. For a given level of knowledge, a production activity can be characterized as

$$Y = AX^{\alpha}, \; A > 0, \quad \alpha > 0, \tag{1}$$

where Y is some output , A is a level of exogenous technology as knowledge, and X is a matrix of inputs (factors of production). Pioneering growth accounting models of the general form (1), among them Solow (1957, 1956) and Swan (1956, 2002), stunned observers with the finding that $\partial Y/\partial A > \partial Y/\partial X$. The difference, $\ln A = \ln y - \alpha \ln X \neq 0$, became known as the "Solow/Swan residual" and is a "measure of our ignorance" (Abramovitz, 1979, 1986) resulting from incomplete specification (e.g. wrong or simplistic functional form) of (1), or misspecification (missing or wrong variables) of X. It made good sense that the missing suspects became entrepreneurship, human capital, and real time. Including these variables allows X to drive A and vice-versa so that (1) can be restated as

$$Y = X_i^{\alpha}(AX_j)^{1-\alpha},\ i \neq j,\quad 0<\alpha<1. \tag{2}$$

Eq. (2) gives different perspectives of the role of technology in production. It reveals that when Jan Fagerberg (1994) and Fagerberg, Knell, and Srholec (2004) find that technology gaps explain international growth rate differences, they are agreeing with Romer (1989, 1990, 1993) that $A = f(\text{human capital} \equiv \text{knowledge})$, implying that $Y = f(\text{knowledge})$. To say limited technology undermines Africa's economic performance, for instance, is to imply a kind of knowledge deficit there.

We assume that a country's level of economic activity, and therefore its performance, depends, besides conventional factors of production, on its level of technology. Technology is a composite knowledge from different sources. JM Keynes (1973) said it well that "part of our knowledge is direct; and part by argument" (p. 3). This paper suggests that published works are organized arguments; arguments are knowledge, and knowledge is technology. And so, we can argue that for a given level of technology ($A_i(t)$) at time period *t* a country's measure of economic performance ($Y_i(t)$) depends on it population ($N_i(t)$), its stock of physical capital ($K_i(t)$), its initial conditions as measured by its level of economic performance in year t = 0, ($Y_i(0)$), and its other variables ($Z_i(t)$), i.e.,

$$Y_i(t) = A_i(t) N_i^{\alpha}(t) K_i^{\beta}(t) Y_i^{\gamma}(0) Z_i^{\delta}(t). \tag{3}$$

In recent years international organizations such as the World Economic Forum have constructed indices of policy variables that would fit in Z. Unfortunately such data is available only for the most recent years. Two popular conventional elements of $Z_i(t)$ for which data is available are inflation rate ($\Pi_i(t)$) and trade openness ($T_i(t)$). Taking these variables as a part of Z, and plugging them into (3) we get[6]

$$Y_i(t) = A_i(t) N_i^{\alpha}(t) K_i^{\beta}(t) Y_i^{\gamma}(0) \mathrm{T}_i^{\delta_1}(t) Z_i^{\delta_2}(t) \Pi_i^{\delta_3}(t). \tag{3'}$$

Next we deflate (3') by dividing both sides by $\Pi_i(t)$. Further division of the result by $Y_i(0)$ gives real economic performance relative to initial conditions. Ignoring the time subscript, from (3) per capita performance is

$$y_i(t) = A_i(t) k_i^{\beta}(t) \tau_i^{\delta_1}(t) z_i^{\delta_2}(t),\quad i=1,2,3;\ t=1,2,\ldots,M. \tag{4}$$

[6]For simplicity we write Z, when we really mean Z' = Z - τ - π.

where $y_i(t)=Y_i(t)/N_i(t)$, $k_i(t)=K_i(t)/N_i(t)$, $\tau_i(t)=\mathrm{T}_i/N_i(t)$.

3. Empirical specifications: Technology as knowledge and economic performance

To estimate the role of technology-as-knowledge in economic performance we set up a practical econometric model and outline the estimation procedure before describing key variables and data, and presenting the results.

3.1. Econometric model

In logarithmic terms, we specify the econometric model as

$$\ln y_i = \ln A_i + \beta \ln k_i + \delta_1 \ln \tau_i + \delta_2 \ln z_i + e_i. \qquad (5)$$

We estimate a Kmenta-type Cross-sectionally Correlated and Time-wise Autoregressive Model (Kmenta, 1986, pp. 622-625, cf. Baltagi, 1999). We put forward different specifications in four broad versions: Version 1, Version 2, Version 3, and Version 4. Some the versions assume that Ai is homogenous. However, we also follow J. Benhabib and M. Spiegel's (1994) account of knowledge (human capital) (a) as a factor of production, and (b) as a technological force affecting performance through an unspecified Nelson-Phelps channel. This is in recognition of the fact that knowledge is more than an educated labor force alone; knowledge depends on the "quality of the population" in the sense of Schultz (1981) and Becker (1993). For that reason, we let

$$\begin{aligned} A_i(t) &= A(0)e^{\phi q_i(t)} && (a) \\ A_i(t) &= A(0)e^{\phi \ln q_i(t)} = q_i^{\phi}, && (b) \end{aligned} \qquad (6)$$

where A(0) is the initial level of technology, $q_i \supseteq S_i$ is some measure of knowledge, in our case publications, and S_i is a measure of human capital, such as years of schooling in Jones (1997) among many other authors. Then, we can restate (5) as

$$\begin{aligned} \ln y_i &= \phi q_i + \beta \ln k_i + \delta_1 \ln \tau_i + \delta_2 \ln z_i + e_i && (a) \\ \ln y_i &= \phi \ln q_i + \beta \ln k_i + \delta_1 \ln \tau_i + \delta_2 \ln z_i + e_i && (b) \end{aligned} \qquad (7)$$

3.2. Estimation procedure

The estimation procedure pools together three cross-sections and 29 time-series data into 87 observations. Then we take 4 distinct steps. The first set of regressions assumes the level of technology to be the constant term. The second set of regressions introduce "aggregate knowledge" (Q_i) in the process. The third step disaggregates Q_i into four distinct components: science (q_1), social science (q_2), arts-and-humanities (q_3), and interdisciplinary (q_4). In other words, $Q_i = q_1 + q_2 + q_3 + q_4$. The specification of Q_i assumes that technology is a function of knowledge, and that knowledge falls into four broad faculties: pure science, pure social science, pure arts-and-humanities, and everything else in between. Hence, to the extent economic performance is a function of technology, $y = f(A, X)$, $A = g(q,t)$, and $X = h(A, S, t)$, it follows that $y = f(g(q,t), h(A,S,t)) = f(g(q,t), h(g(q,t), S, t))$. This gives four solutions for q, S, and t, with A acting as the variable of integration (Amavilah, 1998).

The final step assesses *apparent conditional convergence* across the three cross-sections. "Convergence" is estimated as,

$$\Delta \ln y_i = a_0 + a_1 y_i^* + a_2 \Delta \ln q_i + e_i, \tag{8}$$

where $\Delta \ln y_i \equiv [\ln y_i(t)) - \ln y_i(t-1)]$, $\Delta \ln q_i(t) \equiv [\ln q_i(t) - \ln q_i(t-1)]$, y^* indicates change in y of Botswana and Namibia relative to South Africa from the perspective of 1976, and $y^* \neq y(0)$, see (10) and (11) below. In this case economic performance is "converging" if $a_1 > 0$, and it is converging because knowledge is converging if $a_2 > 0$. In other words, cross-country performance differences narrow with an increased level of economic development and with reduction in the difference of the level of knowledge across economies. The opposite is not necessarily true.

4. Measurement issues: Variables, data, and data sources

Unless otherwise stated we designate real gross variables with uppercase letters and per capita real variables with lowercase letters. Whenever appropriate variables are in constant 2000 U.S. dollars and are dated, although the t-subscript may be skipped for convenience.

The dependent variable is gross domestic product ($\mathbf{Y_i}$, $\mathbf{y_i}$). For any ith country (Y, y) depends on its population (N_i), the rate of investment in physical capital ($\mathbf{K_i}$, $\mathbf{k_i}$), and the country's degree of openness to foreign trade (τ_i). For brevity's sake we also drop the i-subscript unless absolutely necessary.

The ratio of government spending to GDP (**G**) and the ratio of GNP to GDP (**E**) are also important considerations. Government's share of spending in GDP is an expression of how well government uses public resources. In developing countries governments finance the largest components of human capital building: education and health. A positive impact of G on *y* would suggest good government policies in a variety of ways (see Lee (1996) for the case of South Korea); from a negative coefficient one can infer growth-retardant factors, like corruption, see, e.g., Mauro (1995, 1998) and Choi (1983, Chapter 7).

Table 1a. Basic Statistics, Botswana, Namibia, and South Africa - 1976-2004

NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM
RGDPCH	87	5958.0	1698.1	0.28837E+07	2207.8	9145.9
CI	87	14.280	6.3543	40.377	4.8600	33.210
OPENC	87	91.111	34.363	1180.8	37.910	159.17
SCI	87	287.84	492.55	0.24261E+06	1.0000	1961.0
SOCSCI	87	115.48	153.62	23600.	5.0000	600.00
ARTHUM	87	40.126	55.071	3032.8	1.0000	168.00
INTER	87	28.529	42.744	1827.1	0.00000E+00	197.00
TKNOW	87	415.08	649.11	0.42135E+06	7.0000	2518.0
INIT	87	6.9655	15.013	225.38	-18.000	38.000
CY	87	0.96645	0.38395	0.14741	0.19600E-01	1.6299
G	87	27.323	6.1859	38.266	14.500	39.550
CGNP	87	96.234	5.8173	33.841	77.460	107.07

Table 1b - Descriptive Statistics, Botswana - 1976-2004

NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM
RGDPCH	29	5064.1	1947.5	0.37927E+07	2207.8	9051.7
CI	29	20.909	5.2246	27.296	12.780	33.210
OPENC	29	103.82	15.208	231.27	77.500	132.25
SCI	29	45.966	35.598	1267.2	8.0000	122.00
SOCSCI	29	27.552	11.214	125.76	11.000	50.000
ARTHUM	29	4.6207	3.0870	9.5296	1.0000	12.000
INTER	29	6.4828	4.5326	20.544	0.00000E+00	21.000
TKNOW	29	72.379	44.072	1942.3	17.000	154.00
INIT	29	24.000	8.5147	72.500	10.000	38.000
CY	29	0.54713	0.33497	0.11220	0.19600E-01	1.0204
G	29	22.473	4.7014	22.103	14.500	32.100
CGNP	29	96.788	5.4859	30.095	87.130	107.07

KEY

RGDPCH ≡y = real per capita GDP chained.
CI ≡ k = Investment share of real GDP.
OPENC ≡ τ= (export + imports)/real GDP.
SCI ≡ q1 = Annual number of science papers published.
SOCSCI ≡q2 = Annual number of social science papers published
ARTHUM ≡ q3 =Annual number of arts and humanities papers published.
INTER ≡ q4 = Annual numbers of papers not identified as q1, q2, q3, or q4.
TKNOW ≡ Q = q1 + q2 + q3 + q4.
INIT ≡ z = Number of years since independence.
CY = y* = Level of development.
G =Government share of real GDP.
CGNP ≡ E = GNP/GDP ratio, economic penetration.

Table 1c - Descriptive Statistics, Namibia - 1976-2004

NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM
RGDPCH	29	5109.3	283.72	80495.	4504.6	5814.5
CI	29	12.694	4.1145	16.929	4.8600	22.950
OPENC	29	120.49	21.496	462.10	89.050	159.17
SCI	29	60.586	48.116	2315.2	1.0000	141.00
SOCSCI	29	20.241	7.4530	55.547	5.0000	38.000
ARTHUM	29	6.5172	3.6314	13.187	1.0000	16.000
INTER	29	3.6552	2.5812	6.6626	0.00000E+00	9.0000
TKNOW	29	83.690	52.877	2796.0	7.0000	169.00
INIT	29	0.51724	8.9587	80.259	-14.000	15.000
YEAR	29	1990.0	8.5147	72.500	1976.0	2004.0
CY	29	1.2550	0.22162	0.49113E-01	0.88650	1.6299
G	29	34.442	3.3887	11.483	24.410	39.550
CGNP	29	95.143	8.4315	71.091	77.460	105.12

Table 1d - Descriptive Statistics, and South Africa - 1976-2004

NAME	N	MEAN	ST. DEV	VARIANCE	MINIMUM	MAXIMUM
RGDPCH	29	7700.5	515.50	0.26574E+06	7016.3	9145.9
CI	29	9.2379	2.3113	5.3419	6.7500	15.520
OPENC	29	49.020	6.0803	36.970	37.910	61.450
SCI	29	756.97	632.10	0.39955E+06	83.000	1961.0
SOCSCI	29	298.66	141.95	20150.	127.00	600.00
ARTHUM	29	109.24	43.235	1869.3	42.000	168.00
INTER	29	75.448	46.479	2160.3	17.000	197.00
TKNOW	29	1089.2	763.80	0.58339E+06	230.00	2518.0
INIT	29	-3.6207	8.9339	79.815	-18.000	11.000
YEAR	29	1990.0	8.5147	72.500	1976.0	2004.0
CY	29	1.0972	0.73378E-01	0.53843E-02	1.0000	1.3035
G	29	25.054	1.3228	1.7498	23.190	27.940
CGNP	29	96.771	0.95129	0.90495	95.490	98.220

KEY

RGDPCH ≡y = real per capita GDP chained.
CI ≡ k = Investment share of real GDP.
OPENC ≡ τ= (export + imports)/real GDP.
SCI ≡ q1 = Annual number of science papers published.
SOCSCI ≡q2 = Annual number of social science papers published
ARTHUM ≡ q3 =Annual number of arts and humanities papers published.
INTER ≡ q4 = Annual numbers of papers not identified as q1, q2, q3, or q4.
TKNOW ≡ Q = q1 + q2 + q3 + q4.
INIT ≡ z = Number of years since independence.
CY = y* = Level of development.
G =Government share of real GDP.
CGNP ≡ E = GNP/GDP ratio, economic penetration.

Figure 1a - Log real GDP per capita, Botswana, Namibia, South Africa, US$ - 1976-2004

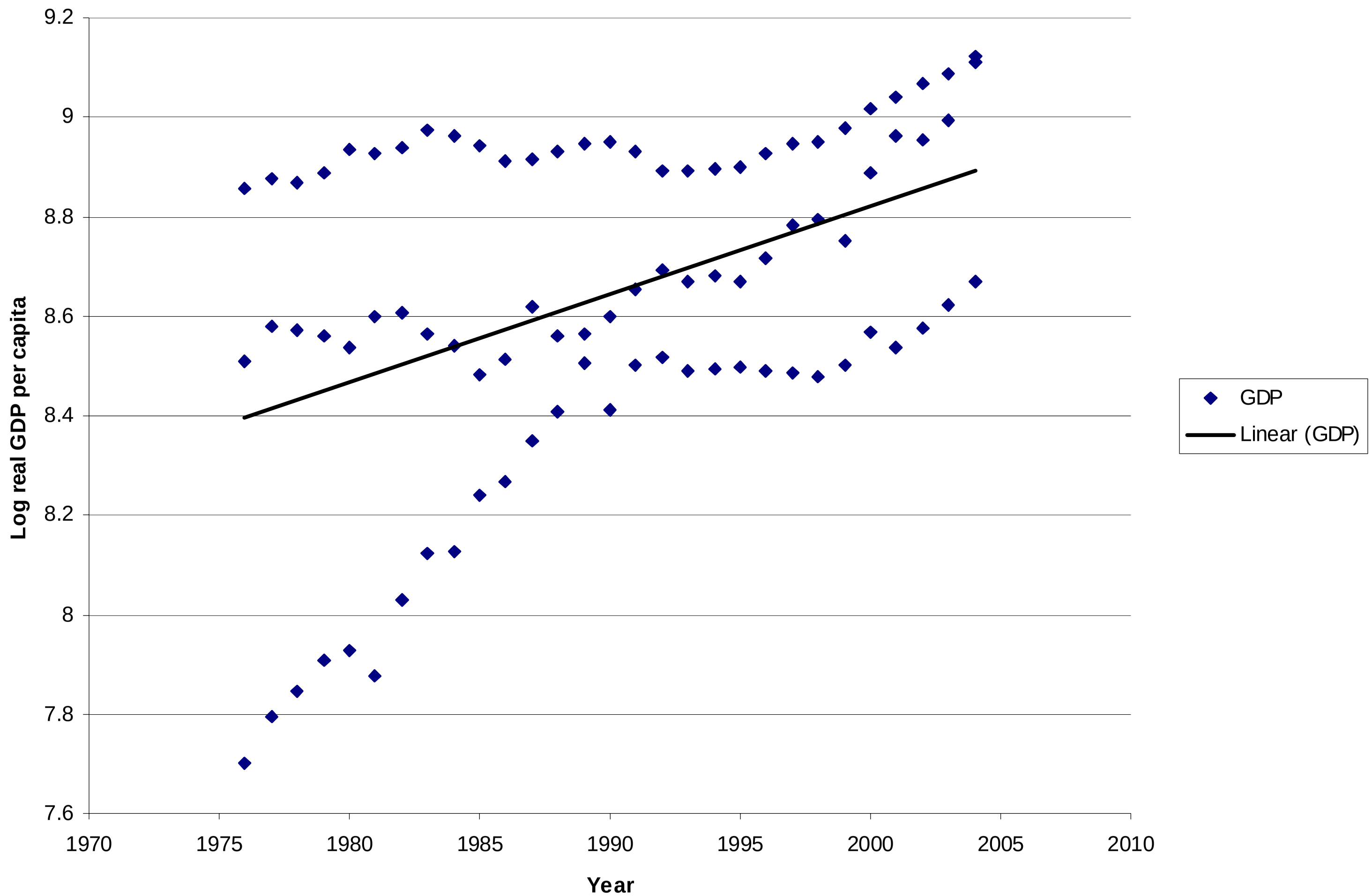


Figure 1b - Log real GDP per cpaita, investment, and openness, Botswana, Namibia, South Africa - 1976-2004

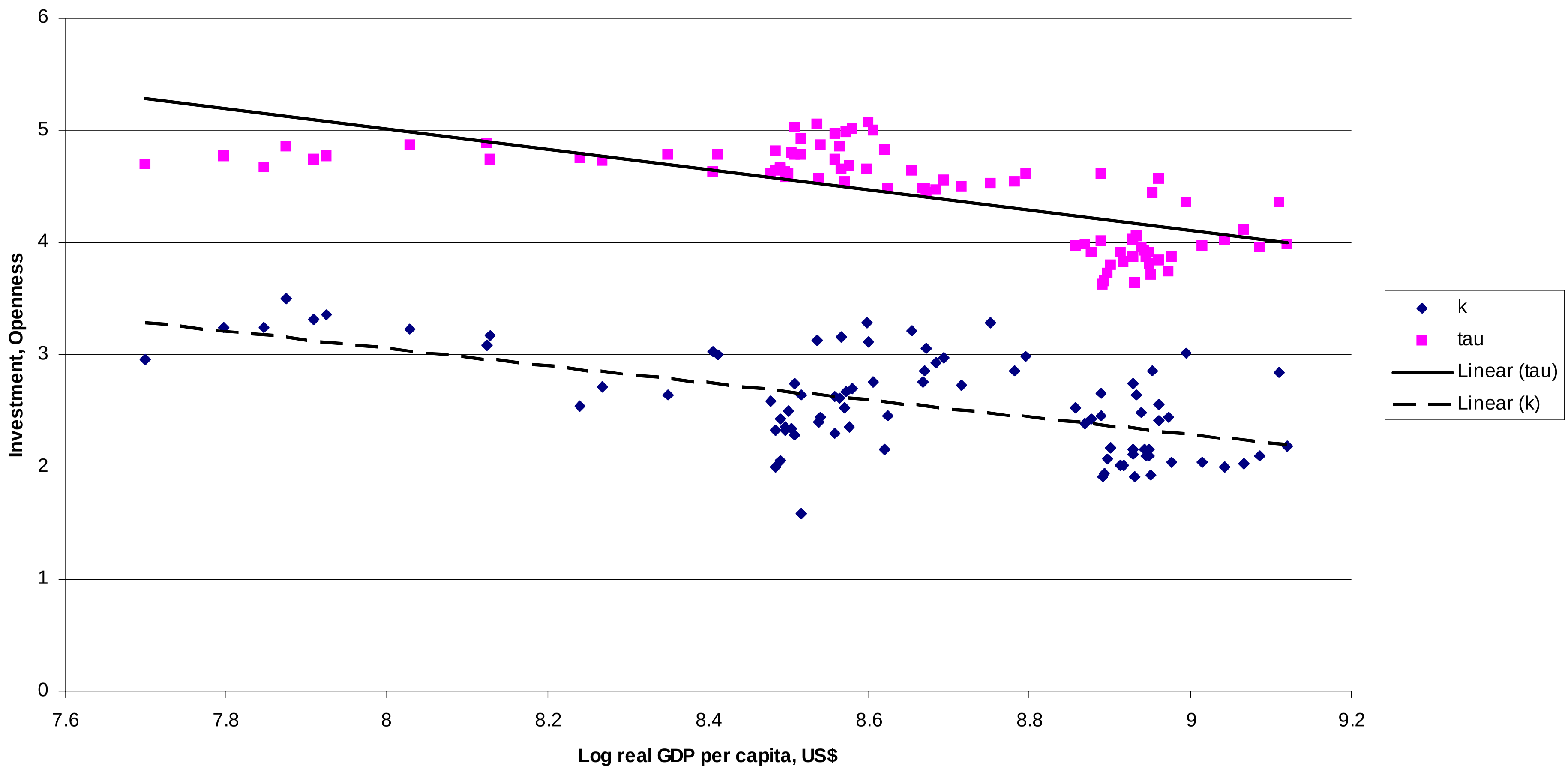


Figure 1b - Log real GDP per cpaita, investment, and openness, Botswana, Namibia, South Africa - 1976-2004

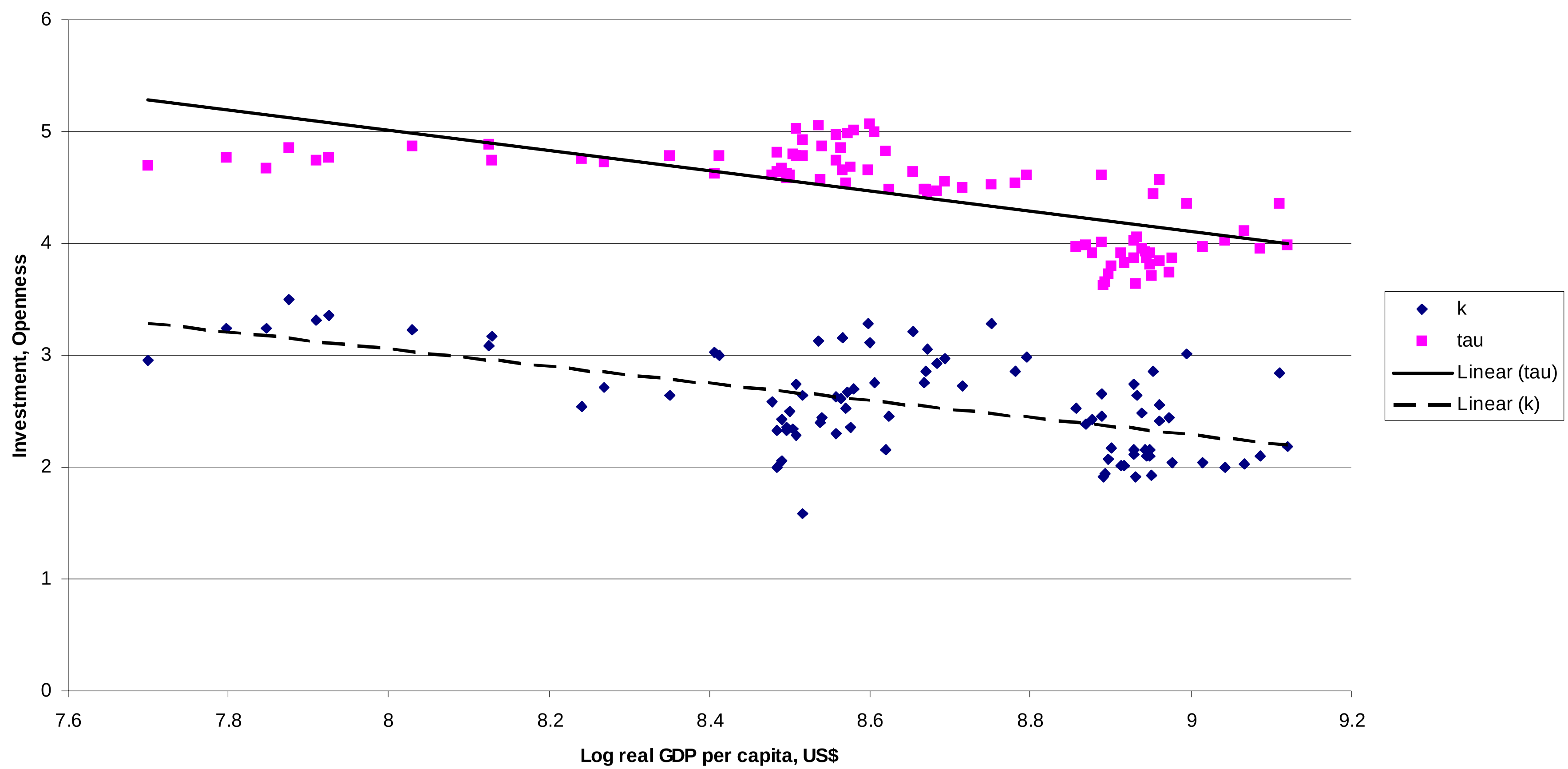
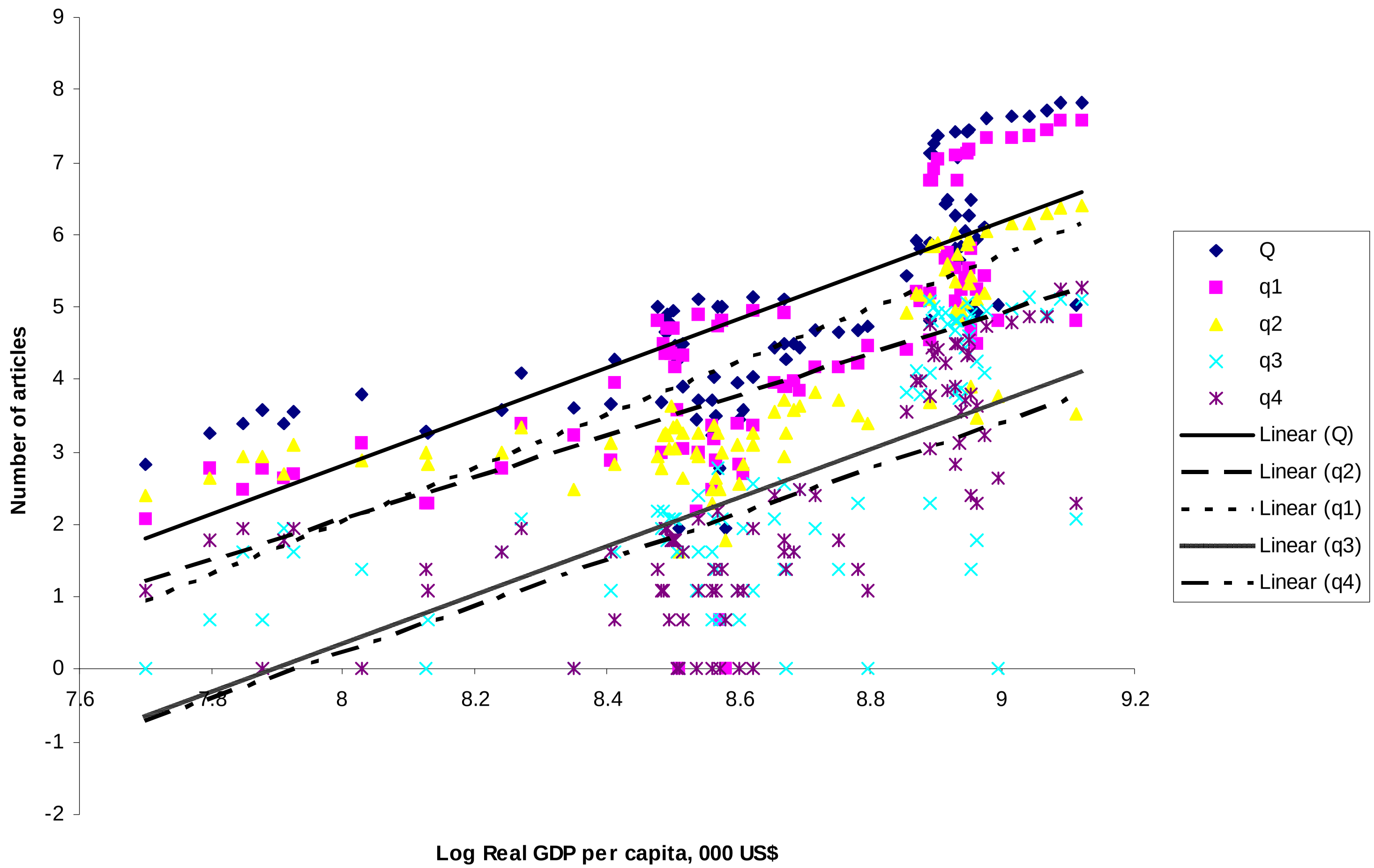


Figure 1d - Real GDP per capita and knowledge across Botswana, Namibia, and South Africa, 1976-2004



The variable E ≡ GNP/GDP measures the depth of the distribution of income, see, e.g., Bertocchi and Canova (1996). A high E represents a large discrepancy between GNP and GDP, reflecting competitive interactions between elements of expropriatory and appropriatory institutions (Acemoglu, Johnson, and Robinson, 2002, 2001a, 2001b).

The data source for *y, k, τ, G*, and *E* is the Penn World Table (PWT) 6.2 (Heston, Summers, Aten, 2006). General definitions for these variables are at the bottom of Table 1; for technical issues see the PWT Data Appendix and Technical Documentation.

The aggregate knowledge variable ($\mathbf{Q_i}$) is the annual number of papers on the ith country:

$$Q_i = q_{i1} + q_{i2} + q_{i3} + q_{i4},$$

where q_{i1} represents science papers, q_{i2} represents social science papers, q_{13} is for arts-and-humanities papers, and q_{i4} are interdisciplinary papers. The latter came about because in some cases $Q_i \neq \sum_{i=1}^{T=4} q_i$, which means that some papers counted more or less than once. Since knowledge is cumulative, including this variable independently is appropriate because it does not have the effect of double counting, and perform a function similar to an interaction term. The data source for (Q, q) is Thomson Scientific (2006) available at http://portal.isiknowledge.com.

Since PWT data are stated in real terms already, that is net of inflation; it is fine for us to assume that $\mathbf{z_i}$ is simply a country specific dummy variable of many unspecified dimensions. It is defined as the number of years since a country attained its political independence. For example, in 1976, Botswana, Namibia, and South Africa had been independent for 10 years, -14 years, and -18 years, respectively. By 2004 Botswana was 39 years old, Namibia was 15, and South Africa only 11. The coefficient of this variable estimates the impacts of factors like political freedom and democracy (Levine, 1995, Perssons, 2005, Schumpeter, 1950, Landes, 1998).

Lastly, the level of economic development (y*) is important to economic performance. To capture that difference we consider the change in the level of economic activity for Botswana and Namibia relative to South Africa, taking the initial year (1976) as the base, i.e.,

$$y_i^*(t) = \frac{y_{sa}(t) - y_i(t)}{y_{sa}(0) - y_i(0)}, \ 0 < y_i^*(t) \leq 1, \ i = Botswana, \ Namibia, \ sa = South \ Africa, \tag{10}$$

where the numerator is the difference in the level of development between the ith economy and South Africa in the *tth* year and the denominator is the difference in the same in the initial year (t = 0). Then relative to its own level of development in 1976, the level of development of the South African economy in the tth year becomes

Table 2 - Determinants of Real GDP per capita, US$, Botswana, Namibia, and South Africa - 1976-2004 (Version 1 Specifications)[a]

Variable	**Version 1.1**	**Version 1.2**	**Version 1.3**
ln (Constant ≡ A)	9.8256 (29.811)	8.9400 (10.212)	8.6958 (7.9459)
ln (Investment-GDP ≡ k)	-0.0238 (-0.8615)	-0.0069 (-0.1741)	0.0085 (0.1889)
ln (Openness ≡ τ)	-0.155 (-3.5695)	0.0127 (0.1564)	-0.0123 (-0.2821)
ln (Country dummy = z)	-0.0102 (-0.5243)	-0.0392 (-2.132)	-0.0357 (-1.6767)
ln (“Knowledge” ≡ Q)		0.16871 (6.7452)	
ln (Science ≡ q_1)			0.0705 2.8791
ln (Social Science ≡ q_2)			0.0369 1.0895
ln (Arts-n-Humanities ≡ q_3)			0.0541 2.8904
ln (Government ≡ G)	0.0099 (0.1586)	0.3738 (5.2973)	0.5468 (6.7005)
ln (GNP/GDP ≡ E)			-0.4157 (-1.8615
Development Level ≡ y*			-0.4458 (-7.7980)
Buse R-square	0.3811	0.6722	0.7469
Buse Raw Moment R-square	0.9994	0.9997	0.9997
Std. Error Estimate	0.93004	0.98468	0.98154
Loglikelihood Function	-634.802	-651.534	-658.455
DW [ρ]	0.7288 [0.4266]	0.8878 [0.4233]	1.0054 [0.3964]
Normal t	-4.4934	-3.5580	-3.5210

[a]Parentheses are t-ratios at the 5% significance level. Square brackets are ρ statistics.

Table 3 - Determinants of Real GDP per capita, US$, Botswana, Namibia, and South Africa - 1976-2004
(Version 2 = Version 1 Specifications purged)[b]

Variable	Version 2.1	Version 2.2	Version 2.3
ln (Constant ≡ A)	9.1904 (22.772)	8.5532 (9.2562)	8.4442 (7.9104)
ln (Lagged y ≡ y(t-1)	0.0561 (4.5037)	0.0378 (3.1050)	0.0393 (3.0692)
ln (Investment-GDP ≡ k)	-0.0726 (-1.9226)	-0.0249 (-0.5986)	-0.0175 (-0.3959)
ln (Openness ≡ τ)	-0.3031 (-4.7405)	0.0056 (0.0631)	-0.0772 (-0.9179)
ln (Country dummy = z)	-0.0361 (-1.4721)	-0.0377 (-1.9627)	-0.0358 (-1.7195)
ln (“Knowledge ≡ Q)		0.1462 (5.2449)	
ln (Science ≡ q_1)			0.0539 (2.2406)
ln (Social Science ≡ q_2)			0.0406 (1.1916)
ln (Arts-n-Humanities ≡ q_3)			0.0487 (2.4173)
ln (Interactions ≡ q_4)			-0.0137 (-0.6716)
ln (Government ≡ G)	0.2579 (3.3472)	0.4060 (5.8318)	0.4955 (5.9521)
ln (GNP/GDP ≡ E)		-0.3927 (-1.8963)	-0.3102 (-1.4147)
Development Level ≡ y*	-0.3729 (-6.3728)	-0.3953 (-7.9163)	-0.4345 -(8.1348)
Buse R-square	0.6061	0.7415	0.7787
Buse Raw Moment R-square	0.9992	0.9997	0.9996
Std. Error Estimate	096611	0.98007	0.97751
Loglikelihood Function	-653.334	-649.845	-654.109
DW [ρ]	0.8025 [0.5534]	0.9735 [0.4491]	1.0536 [0.4214]
Durbin H	5.1974	4.2192	3.9589
Normal t	-5.2635	-3.9837	-3.5396

[b]Parentheses are t-ratios at the 5% significance level. Square brackets are ρ statistics.

Table 4 - Determinants of Real GDP per capita, US$, Botswana, Namibia, and South Africa - 1976-2004
(Version 3 = Version 2 specifications without a constant term)

Variable	Version 3.1	Version 3.2	Version 3.3
ln (Investment-GDP ≡ k)	0.0983 (1.3790)	0.1521 (2.3186)	0.2535 (3.2649)
ln (Openness ≡ τ)	0.9107 (9.4286)	1.0001 (11.278)	0.9211 (8.1097)
ln (Country dummy = z)	0.1790 (4.1697)	-0.0588 (-1.6242)	-0.0628 (-1.5844)
ln (“Knowledge ≡Q)		0.4377 (14.071)	
ln (Science ≡ q_1)			0.2029 (5.1040)
ln (Arts-n-Humanities ≡ q_3)			0.2008 (6.4849)
ln (Government ≡ G)	1.1837 (10.983)	0.6625 (5.7213)	0.9654 (7.0086)
Development Level ≡ y*	-0.4206 (-4.042)	-0.5274)-6.1234)	-0.6087 (-7.1971)
Buse R-square	0.2300	0.2328	0.5916
Buse Raw Moment R-square	0.9979	0.9978	0.9988
Std. Error Estimate	0.99378	0.98901	0.98822
Loglikelihood Function	-710.675	-696.394	-711.556
DW [ρ]	1.7717 [0.40165]	1.5063 [0.1771]	1.5428 [0.1688]
Normal t	-0.5580	-0.9158	-1.3924

Table 5 - Determinants of Real GDP per capita, US$, Botswana, Namibia, and South Africa - 1976-2004
(Version 4 = Version 3 specifications with a lagged y and no constant term)

Variable	Version 3.1	Version 3.2	Version 4.3
ln (Lagged y ≡ y(t-1))	0.0599 (2.9267)	0.0151 (0.9218)	0.0349 (1.7470)
ln (Investment-GDP ≡ k)	0.0686 (0.9287)	0.1535 (2.2645)	0.2276 (2.9562)
ln (Openness ≡ τ)	0.7751 (8.0086)	0.9829 (10.879)	0.9241 (8.2368)
ln (Country dummy ≡ z)	0.1903 (4.0998)	-0.0677 (-1.8922)	-0.0571 (-1.4628)
ln (“Knowledge ≡ Q)		?	
ln (Science ≡ q_1)			0.2012 (5.1530)
ln (Arts-n-Humanities ≡ q_3)			0.1886 (5.8699)
ln (Government ≡ G)	1.2276 (11.899)		0.8893 (6.2865)
Development Level ≡ y*	-0.3942 (-3.5704)		-0.0349 (-6.8540)
Buse R-square	0.910	0.4788	0.6203
Buse Raw Moment R-square	0.98948		0.9988
Std. Error Estimate	0.99473		0.98422
Loglikelihood Function	-707.542		-710.687
DW [ρ]	1.7223 [0.0305]		1.5555 [0.1488]
Durbin H	0.29033		1.1423
Normal t	-0.4436		-1.8323

$$y_{sa}^{*}(t) \equiv y_i^{*}(t) = \frac{y_{sa}(0) + y_{sa}(t)}{y_{sa}(0)} = [1 + \frac{y_{sa}(t)}{y_{sa}(0)}]. \quad (11)$$

The coefficient on *y** is essentially the relative coefficient of "convergence", similar, not identical, to the so-called "catch-up effect."

Table 1 presents descriptive statistics on the key variables just discussed, first across the three cross-sections (Table1a), and then by country in Tables 1b-1d. Figure 1 plots various relationships between the dependent variable (Y,y) and independent variables as described above.

Table 1 is obvious; from the figures it is clear that real GDP has generally risen over the years. However, the rate of change *appears* to have been constrained by the accumulation of capital (k) and the expansion of trade (openness = τ). It also *appears* that the slack was picked up by the accumulation of knowledge measured by the number of published papers (Q, q). The results seek to quantify that appearance.

5. Results

On the assumption of a homogeneous level of technology (A) measured as the constant term in regression form, from the initial estimations of $y = Af(k, \tau, z, G, \Delta y, E)$, only G has a positive coefficient. The constant term (lnA = 9.822) is very large. Introducing Q into the estimation, assuming A is some linear function of Q and a random error term (μ), i.e., $A = aQ + \mu$, the results show that one publication adds seventeen cents ($0.17) to per capita income, while an increase of one dollar in government expenditure has the effect of raising real GDP per capita by about thirty-nine cents ($0.37). However, the key variables, k and τ, contribute very little to income per capita. In fact, an increase of one percentage point in the investment-GDP ratio reduces per capita GDP by 0.6%, whereas the contribution of openness to trade is only slightly over one percent (1.2%).

Disaggregating Q finds that $\frac{\partial \ln y}{\partial \ln q_1} > \frac{\partial \ln y}{\partial \ln q_2} > \frac{\partial \ln y}{\partial \ln q_3} > 0$. Specifically, $q_1 \uparrow \rightarrow y \uparrow$ by 7.1%, $q_2 \uparrow \rightarrow y \uparrow$by 4.5%, and $q_3 \uparrow \rightarrow y \uparrow$ by 5.9%. Although the inclusion of Q and it parts improved the generalized explanatory power measured by the Buse R-square, parameter estimates remained technically inefficient, and the constant term stayed above the mean of the dependent variable (8.6452). The very low Durbin-Watson statistics indicate serious correlation, motivating the inclusion of the lagged *y*, *y*(t-1).

The inclusion of *y*(t-1) merely redistributes the weights of the variables; the size of the intercept does not change much. In addition, τ now has a negative sign and *k* a positive, but both are statistically insignificant. The short run impacts of Q and its components are statistically strong. Econometric adjustments such as dropping all insignificant variables, do no more than just shifting the problems of insignificance and wrong signs elsewhere. Tables 2 - 5 reveal that technology explains much of the

Table 6.1 – Apparent Convergence across Botswana, Namibia, and South Africa - 1976-2004
(Uncorrected and corrected results with a constant term, Parentheses are t-ratios at 5% significance level)

Variable	**1a**	**1b**	**2a**	**2b**
Constant ≡ a_0	-0.0227 (-0.2222)	-0.045 (-0.8938)	-0.1179 (-.8849)	-0959 (-0.7424)
y*	-0.0155 (-0.1739)		0.1704 (1.2104)	0.1398 (1.0504)
ΔlnQ	0.9065 (14.120)	0.9017 (14.042)		
Δlnq1			0.2232 (3.1491)	0.2241 (3.1661)
Δlnq2			0.6225 (6.6214)	0.6341 (6.898)
Δlnq3			0.0696 (0.6834)	
Δlnq4			-0.1535 (-1.7455)	-0.1196 (-1.6637)
Buse R-square	0.7236	0.7201	0.6160	0.6120
Buse Moment R-square	0.7243	0.7206	0.6271	0.6232
SEE	0.3597	0.9385	0.88104	0.88422
LLF	-61.916	-61.6287	-62.5298	-62.8197
DW[ρ]	1.2483 [0.1562]	1.2476 [0.1577]	1.2668 [0.09477]	1.2542 [0.10525]

Figure 2 - Apparent convergence of income, and knowledge - Botswana, Namiba, and South Africa, 1976-2004

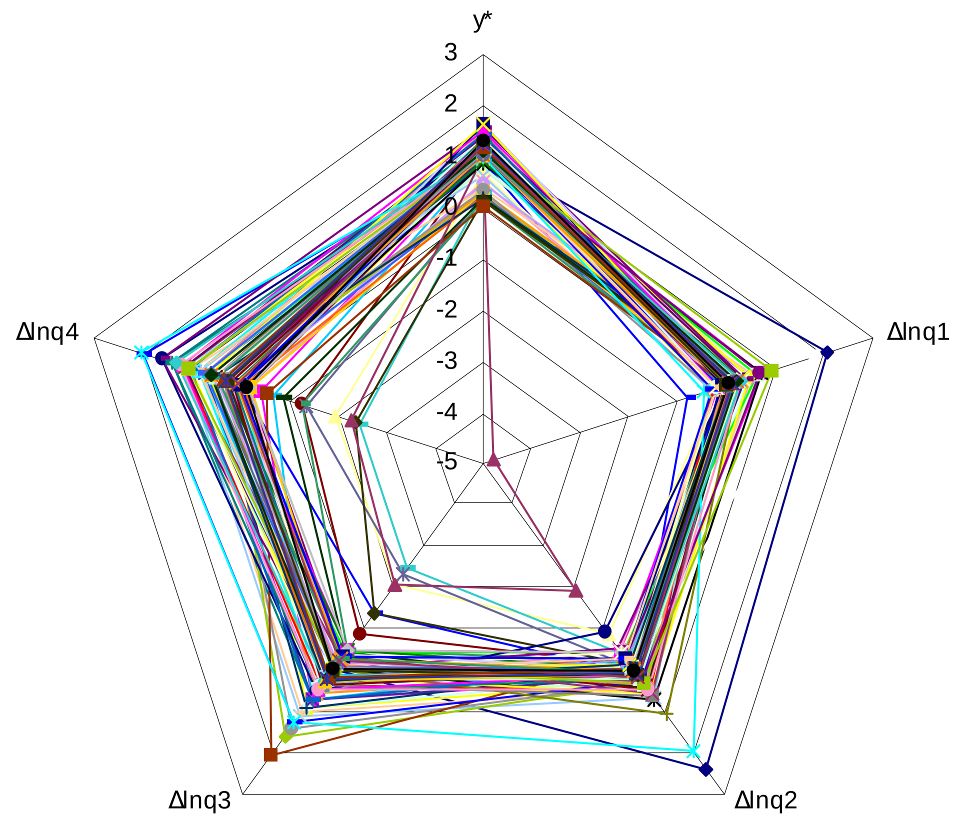


Table 6.2 – Apparent Convergence across Botswana, Namibia, and South Africa - 1976-2004
(Uncorrected and corrected results without a constant term, Parentheses are t-ratios at 5% significance level)

Variable	1a	1b	2a	2b
y*	-0.0329 (-0.7900)		0.0452 (0.9251)	0.0391 (0.84138)
ΔlnQ	0.9043 (14.098)	0.8970 (14.026)		
Δlnq1			0.1897 (2.7211)	0.1904 (2.7656)
Δlnq2			0.6007 (6.5374)	0.6073 (6.9446
Δlnq3			0.0459 (0.4551)	
Δlnq4			-0.1048 (-1.3081)	-0.0841 (-1.2613)
Buse R-square	0.7222	0.7138	0.5909	0.5908
Buse Moment R-square	0.7230	0.7141	0.6007	0.6007
SEE	0.88422	0.9514	0.8686	0.87325
LLF	-6.8197	-62.1361	-61.3310	-61.5015
DW[ρ]	1.2542 [0.1025]	1.2200 [0.1759]	1.2815 [0.06911]	1.2853 [0.07195]

observed variations in per capita income of developing countries like Botswana, Namibia, and South Africa. Tables 4 and 5 derive from the idea that the level of technology (A) has at least three components: one due to random error (μ_A), the second due to economic efficiency (A_E), and the third to technological progress (A_T), i.e, $A = A_E + A_T + \mu_A$. Using this argument, the inclusion of Q reduced A to 9.3588, a decrease of only 0.2331, leaving the residual still well above the mean of the dependent variable. More specifically the marginal impact of a publication on real per capita income is about sixteen cents ($0.155).

Disaggregate knowledge into four faculties: science (q_1), social science (q_2), arts-n-humanities (q_3), and an interdisciplinary term (q_4). The explanatory power of the regressions improves; it now ranges from 38% to 75% of the variations in per capita income being explained by the included variables. Three findings stand out. First, the time elapse since independence (***z***) has a negative partial coefficient, which is understandable. By 2004 Botswana had been independent for more than three decades. Interpreted as a measure of democracy, economic freedom, the rule of law, historical legacies, and so on, the negative sign on z is consistent with increasing evidence that show negative impacts of historical legacies on performance (Nunn, 2005, 2004, Bertocchi and Canova, 1996, Masanjala and Papageorgiu, 200, Lange, 2004). In this respect Namibia and South Africa have not even begun to recover and the situation weighs down on the average performance for the three nations. Also negative is the impact of economic penetration measured by the GNP-GDP ratio (E). For each one dollar's worth of an increase in this ratio, 40 cents' worth of real GDP per capita is lost. This captures the extractive nature of these three economies.

Likewise Botswana and Namibia have closed the *absolute gap* in the level of economic development between them and South Africa, that is, income increases as the gap narrows. However, the relative gap persists. For instance, Botswana's per capita income has converged to that of South Africa more than Namibia's has, which makes sense because Namibia and South Africa started off more similar and are now "diverging" as each country attempts to assert its political independence. South Africa has not progressed a lot past its 1976 level. This too is to be expected; prior to independence in 1994, most black South Africans were excluded from the modern accounting of the economy and so per capita income was overstated. The end of Apartheid meant the inclusion of many more people in the economy, and so per capita income fell.

The results are unchanged when y(t-1) is included . Notable from these tables is that $0.1400 < {}^{d\ln y}/_{d\ln Q} < 0.1700$, and ${}^{d\ln y}/_{d\ln q} \in [0.035, 0.071)$, with ${}^{d\ln y}/_{d\ln q_2}$ being the weakest link at the 5% significance level. These findings are encouraging, although the wrong signs on key variables k and τ are troubling. How can these results be corrected?

Tables 4 and 5 present results from estimations that set the constant term to zero, i.e., $A = aQ = a_1q_1 + a_2q_2 + a_3q_3 + a_4q_4$. As is the usual case with "noconstant" regressions, and in this case given that our pooled series has more time-series (T) than cross-sections (M), the "generalized proportion of variations" (Buse R-square) in *y* that is explained by the included variables is reasonable; it ranges from 23% to 78%.. Not bad at all, because it is possible for an R-square to be negative in situations like this one. And, the coefficients on both *k* and τ are positive and statistically significant at the 5% level. The marginal impact of technology as knowledge in the aggregate or in the disaggregate is also positively strong, especially for q_1 and q_3.

Table 6 and Figure 2 present tentative results for the estimation of (8) - apparent convergence. These are apparent, rather than convergence measures a la Mankiw, Romer, and Weil (1992) and the subsequent literature such as Islam (1995), Higgins, levy, and Young (2006), and Jones (1997, 2002). But it is consistent with Bernard and Jones (1995) in establishing the link between From the tables as well as Figure 2, it is abundantly clear that Q and q are important to real per capita GDP, with the contribution of science publications being the strongest. The level of development is also essential, but it is not clear whether it can explain convergence.

6. Conclusion

What do we conclude from the results, and what are the implications of the conclusion for policy and further research? This paper examines the marginal impacts of technology as knowledge on the economic performance of three Southern African countries: Botswana, Namibia, and South Africa. It imposes a simple production function on annual pooled observations of the three countries over the 1976-2004 period. Based on summary statistics the results of the examination agree with Robert Barro's (1991) conclusion that regression analyses often leave unexplained factors that determine the economic performance of developing countries. Primary factors such as capital, and secondary or higher resources like trade, and even Government, are important to economic performance. Even so, a more persuasive case than the factors of production is that the economic performance of countries like Botswana, Namibia, and South Africa depends increasingly on technology, technological change, and the basic knowledge that forms the foundation for both. Yet in developing countries quantitative assessments of the nexus between technology as knowledge and performance are limited. The analysis of this paper finds that, measured as a homogenous 'Manna from Heaven", technology is the strongest determinant of real per capita income in Botswana, Namibia, and South Africa. Moreover, there is a clear indication that some of what is going on in the black-box can in fact be explained by the knowledge underpinnings of technology, represented by aggregate Q and disaggregate q number of publications as proxies for that knowledge. Both Q and q are strongly correlated with the countries' economic performance. More precisely the economic performance of nations benefits most from science (q_1) and arts-n-humanities publications (q_3). Social science (q_2) publications have a positive but statistically insignificant effect on real per capita GDP.

Following Abramowitz's (1979,1986) interpretation the positive effect of science on real GDP per capita supports the notion of the increasing "social capability" of these countries. The strong correlation between arts-n-humanities and real income per capita signals improving "technological congruence" along with enhanced absorptive capacity. The positive, but weak, effect of social science on economic performance is a reflection of an excess supply of publications in this area, as well as associated deadweight losses as evident from the low marginal impacts.

The policy implication of the conclusion is that developing countries like Botswana, Namibia, and South Africa would gain from increased investment in knowledge-building activities including publishing - apparently a paper is worth more than its light weight. This potential gain justifies further research on the topic. For example, one may enlarge the sample size, and explore better and richer sets of data than those utilized here. Another may deploy alternative estimators and estimation techniques. A third, may use sophisticated functional forms which might yield better results than we have here. Despite its limitations, the results of this analysis are encouraging.

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