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Private and Public Values of Higher Education in Developing Countries: Guidelines for Investment

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Abstract

This paper argues that while scientific and technical "knowledge " is an international public good, the conversion of knowledge to inventions and innovations is not. Knowledge conversion is affected by natural (soil, climate) and economic (prices, wages) conditions. This means that the conversion of knowledge to economic growth production is quite location specific. Knowledge conversion is also subject to high technology "mastery" requirements. Technology mastery also requires specialization by field of technology. These knowledge conversion conditions place a high premium on applied science and engineering skills. The "price of admission" to the economic growth club is high. This, in turn, means that Higher Education programs creating these skills have a "public" externality value that is much higher than the private value of these skills in labor markets. This public value is high enough to justify investments in foreign degree training and in programs to create graduate programs in the invention/innovation fields in many African universities.

Résumé

Le « savoir » scientifique et technique est un bien public international, contrairement à la conversion du savoir en inventions et en innovations. La conversion du savoir est déterminée par les conditions naturelles (sols, climat) et économiques (prix, salaires). Cela signifie que le type de conversion du savoir en croissance économique est spécifique à l'endroit où l'on se trouve. La conversion du savoir est également sujette à une réelle maîtrise de la haute technologie. La maîtrise technologique exige également une spécialisation dans un domaine de la technologie. Dans le cadre de ces conditions de conversion

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du savoir, la science appliquée et le savoir-faire en ingénierie occupent une place de choix. Le « prix à payer » pour intégrer le club fermé de la croissance économique est élevé. Cela signifie que les programmes de l'enseignement supérieur produisant ce savoir-faire ont une valeur « externe » publique qui est beaucoup plus importante que la valeur privée de ce savoir-faire au niveau du marché du travail. Cette valeur publique est suffisamment élevée pour justifier des investissements dans le domaine de la formation étrangère diplômante et au niveau de programmes diplômants dans le domaine de l'invention/innovation dans plusieurs universités africaines.

Introduction

Knowledge in the form of codified understanding of social and natural phenomena is an international public good. Knowledge is produced in universities and research institutions. Knowledge is also mastered in universities and other higher education programs. Because investment in higher education varies greatly from country to country, the capacity to produce new knowledge varies from country to country. The degree to which populations master knowledge varies as well. Knowledge is converted to technology by the act of invention. Inventions are "reduced to practice" by innovative activities. Technology, like knowledge, must be mastered and understood to be employed.

The "transferability" of technology from one location to another location depends on two sets of factors. It depends first on differences in natural (soil, climate) and economic (prices, wages) conditions between the two locations. This is because natural conditions affect the performance of crops and animals and even humans. These natural conditions govern the natural evolution of plant and animal breeding (genetic improvement) programs dedicated to achieving improved performance. Price differentials also matter because they affect costs. In many low-wage economies, activities that are performed by machines in high-wage economies are performed by hand (e.g., rice harvesting). The second factor is the "tacit" understanding or mastery of technology by agents in the transferee location. Technology transfer simply does not take place without transferee competence and understanding. Much of this transferee competence in modernizing developing countries is associated with foreign direct investment (FDI) programs. But much of it is created by higher education programs.

Many economic development programs are based on the proposition that technology is highly transferable and that tacit mastery does not require high levels of skills. Most African countries have made limited investments in the higher education programs associated with the mastery of knowledge and with technology mastery. Unfortunately, forty years of development experience in

Africa lead one to conclude that “easy” technology transfer simply does not take place.

When technology transfer is inhibited by natural and economic conditions, the transferee country must have adaptive invention/innovation capability. The inhibition of crop genetic improvement (CGI) technology by soil and climate conditions is well understood and factored into policy design. No serious observer of agricultural development in Africa (or Asia or Latin America) expects productivity improvement without years of building plant breeding adaptive innovation capacity located in each agro-ecology zone (AEZ). If this capacity has not been built for the AEZ, the AEZ does not have significant productivity growth.

While agricultural development practitioners generally understand that local adaptive innovation capacity is essential to take advantage of knowledge and technological developments originating outside the country, the low-cost technology transfer model has endured for other forms of technology, and this model has clearly failed for African countries. This failure is manifest in two empirical observations. The first is that no African country has achieved significant productivity growth in the industrial sector if it has not already achieved productivity growth in the agricultural sector. The second is that no African country has achieved significant productivity growth in the industrial sector unless the country has either “exploited foreigners” through foreign direct investment (FDI) arrangements or developed Research and Development (R&D) capabilities in domestic industrial producing firms (Evenson 2002).

In this paper, I develop further evidence for these statements and show that building capacity in higher education programs is essential if African countries are to achieve “modern economic growth.” I will also argue that this implies a high public value to the specific types of higher education that are essential to imitations and adaptive innovation capacity. These high public values are sufficient to justify higher levels of public investment in specialized higher education programs.

The next section of this paper assesses these growth-related values. The operative question is whether the public values of higher education programs linked to economic growth can justify more investment in higher education programs in Africa. I then discuss growth production skills in relation to the dynamic long-term building of “technology capital” (TC), followed by a discussion of policy issues associated with the international migration of skill holders.

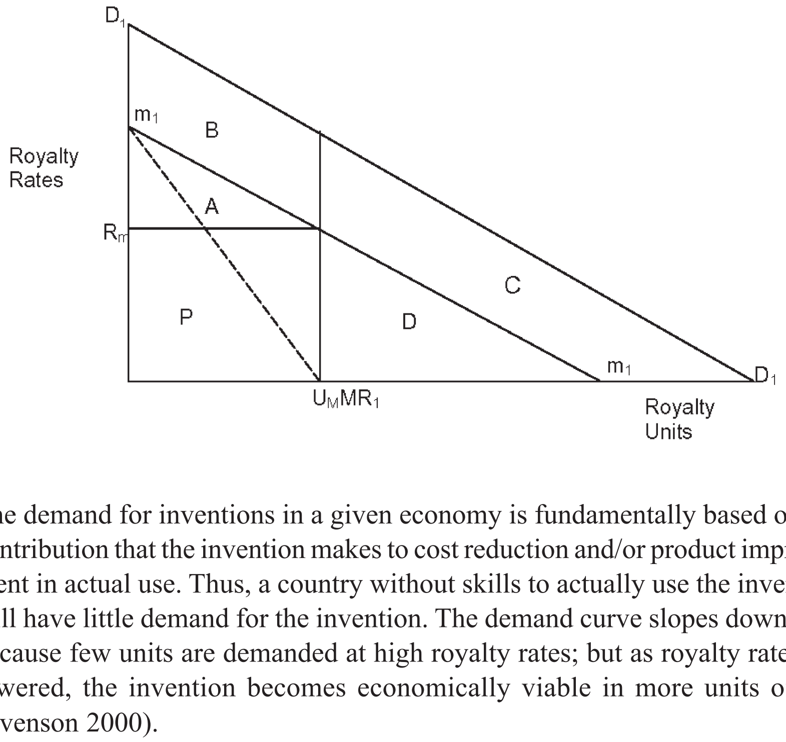
Invention and Technology Acquisition Skills: Public/Private Values

In this section, the model of invention with Intellectual Property Rights (IPRs) serves as a starting point to illustrate the relationship between private and public values of invention skills. I then present a model of public-sector invention to illustrate similar relationships, followed by a consideration of methods of technology acquisition. A review of data from studies of returns to research and extension programs in both public and private R&D organizations assesses public-private value magnitudes.

The Invention Model with Intellectual Property Rights (IPR)

Consider the basic economics of an invention model in which the demand for an invention when the invention is commercialized (i.e., an innovation) is expressed in present-value terms. Figure 1 depicts this demand in terms of royalty rates and royalty units, and denoted as $D_1D_{1.}$

Figure 2: Public Sector Inventions



The demand for inventions in a given economy is fundamentally based on the contribution that the invention makes to cost reduction and/or product improvement in actual use. Thus, a country without skills to actually use the invention will have little demand for the invention. The demand curve slopes downward because few units are demanded at high royalty rates; but as royalty rates are lowered, the invention becomes economically viable in more units of use (Evenson 2000).

IPRs provide IPR owners with a limited or partial monopoly right (i.e., the right to exclude) and the effective monopoly demand is depicted as m_1m_1. The M_1M_1 curve lies below the d_1–d_1 demand curve because monopoly rights are limited in terms of time (17 to 20 years) and scope. But, perhaps more importantly, they are limited by competitive inventions. There is a good chance that this invention will have a reasonably close substitute before many years have passed. (This is one of the features of an effective patent IPR. The requirement that the invention be disclosed stimulates subsequent invention.) The monopoly rents that the IPR owner can collect then will be p (where mr = 0) and the royalty rate will ber_m, and u_m units will be sold.

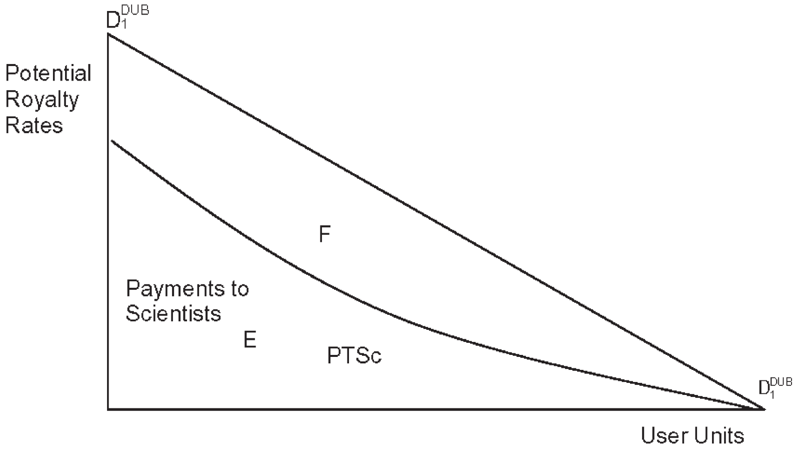
In the case of this IPR-protected invention then, the private value will be p and the public value will be a + b. The area a can be thought of as the "normal" economic surplus associated with this invention and the inventive effort and innovative effort required to produce it.[1] The area b represents an "extra" public value associated with the limited monopoly right and with disclosure-induced substitutes for this invention. Note that with IPRs, the areas c + d are not realized until the IPR expires. It is sometimes argued that the area c + d constitutes a "welfare loss," but that is not a proper interpretation if this invention would not have been produced in the absence of IPRs. In that case, the areas b + A represent welfare gains that would not have been realized otherwise.[2]

Figure 2 also depicts a situation where the public sector undertakes the invention and does not charge a royalty fee. This would be the situation for an agricultural experiment station developing new crop varieties. The average costs of scientists are depicted in Figure 2 as E and total public value is E + F, the full area under the demand (or average revenue). Evidence presented below in the section on "Dynamic Technology Capital Issues" indicates that the ratio of F to E in Figure 2 is approximately the same as the ratio of a + b + c + d to p in Figure 1.

A natural question to ask regarding these figures is why countries use IPR systems for invention when these systems do not allow full public value to be captured (i.e., the areas c + d are not realized) until after the IPR expires? Note, however, that if IPR systems are the only alternative (i.e., public programs are unwilling or unable to invent), then the IPR system does create public value in terms of the areas a + b that would not otherwise be available to society.

IPRs are widely regarded as a very "blunt" instrument for providing incentives for invention. But their use is almost universal in all developed market economies, and the strength and scope of IPRs are steadily increasing in all developed market economies Kremer (1998) discusses issues associated with attempting to capture the area c + d.

Figure 2: Public Sector Inventions



Are public sector R&D organizations unable and unwilling to invent? No, there are many fields where IPR systems have not been effective in stimulating private sector invention (or available to do so) and where public sector invention systems have emerged. The agricultural experiment station is a case in point. Traditional patent protection was not available to plant and animal breeders in the United States until the 1970s when courts broadened the scope of patent protection.[3] The public agricultural experiment station research "model" was developed in the mid-1800s to provide biological inventions for agriculture. And those public experiment stations have achieved a distinguished record of invention in the form of modern plant varieties and animal improvements. But chemical, mechanical, and electrical invention for agriculture has been dominated by private firms even in cases where the public sector has attempted to compete. With the expansion of IPRs to plants and animals and potentially to biotechnology inventions, the competitive edge of private firms has become pronounced in all fields of agricultural inventions.

But private sector invention is itself located in a larger system of public research and public and private academic system support. The modern agricultural invention system in public sector programs features the development of the applied agricultural sciences. These science fields support both private and public sector inventors (Huffman & Evenson 1993).

International Issues: Why Should Developing Countries *Recognize the IPRs of Developed Country Inventors?*

Two issues govern the internationalization of IPR systems. The first is the relative competitiveness of domestic versus foreign inventions. The second is the location or country specificity of technology.

International patterns in invention data inform the first issue. Most OECD countries are characterized by approximate competitiveness between domestic inventors and inventors in other OECD countries. This competitiveness is reflected in the fact that inventors in one country often obtain IPR protection in other countries (including developing countries). They thus have a “technology seller’s” stake that is important. By contrast, inventors in developing countries protect few of their inventions in other countries. Most of their domestic inventions are adaptations of “upstream” inventions. They have very limited technology seller’s stakes to protect.

One measure of the degree of location specificity of invention is the ratio of domestic inventions protected abroad to total domestic invention. For agricultural crop inventions (i.e., modern crop varieties), inventions made in one country have low rates of use in another country. The proportion of crop varieties developed in a National Agricultural Research System (NARS) and released in another country is typically less than 10% of varieties developed domestically. The proportion of varieties developed in international agricultural research centers (IARCs) and released in several countries is much higher. Virtually no crop varieties produced for developed countries are actually planted in developing countries (Evenson & Gollin, 2002, chap. 21).

These two issues create policy problems for developing countries. The asymmetry between the technology sellers’ and technology buyers’ interests in OECD countries is low and these countries have long recognized each other’s IPRs. But the asymmetry between the technology sellers’ rights of developed and developing countries has long been expressed in the form of efforts by developing countries to avoid or evade the recognition of the IPRs of developed country inventors. It has also inhibited the development of IPR systems in developing countries to stimulate domestic adaptive invention and related tacit knowledge acquisition vital to their growth.

When location specificity is high, as it is in agriculture, the policy remedy is simple and straightforward. You either build adaptive invention programs or you don’t get technology-based growth. For agricultural invention, the tradition of public sector research in the absence of effective IPRs has led to a broad-scale development of invention capacity. The Green Revolution was created by public sector national and international experiment stations. But for

Table 1: Internal Rates of Return (IRR) Estimates Summary

	Number of IRRs Reported	Percent Distribution of IRRs by IRR Range						
		0-20	21-40	41-60	61-80	81-100	100+	Approx. median IRR
Extension	81	0.26	0.23	0.16	0.03	0.19	0.13	41
By Region:								
OECD	19	0.11	0.31	0.16	0	0.11	0.16	50
Asia	21	0.24	0.19	0.19	0.14	0.09	0.14	47
Latin America	23	0.13	0.26	0.34	0.08	0.08	0.09	46
Africa	10	0.40	0.30	0.20	0.10	0	0	27
Applied Research	375	0.18	0.23	0.20	0.14	0.08	0.16	49
By Region:								
OECD	146	0.15	0.35	0.21	0.10	0.07	0.11	40
Asia	120	0.08	0.18	0.21	0.15	0.11	0.26	67
Latin America	80	0.15	0.29	0.29	0.15	0.07	0.06	47
Africa	44	0.27	0.27	0.18	0.11	0.11	0.05	37
Pre-invention science	12	0	0.17	0.33	0.17	0.17	0.17	60
Private sector R&D	11	0.18	0.09	0.45	0.09	0.18	0	50
Ex ante research	87	0.32	0.34	0.21	0.06	0.01	0.06	42

Source: Evenson (2002)

many other fields of invention, hostility in developing countries to IPRs has meant that they have not built domestic adaptive invention capabilities, and many have not built a capacity to effectively "imitate" foreign origin technology.

Rate of Return Evidence and Relevance to

Higher Education Programs

In this section, I summarize rate of return evidence for agricultural research and extension programs and consider the magnitudes of public values (areas A and B in Figure 1 and area F in Figure 2). It should be noted that this evidence is from programs where a high degree of location specificity is present.

Table 1 reports a summary of calculated "internal rates of return" (IRR) to agricultural research and extension programs.

These estimates are reviewed in detail in Evenson (2001) and are summarized here. The review considered 81 estimates of IRRs for extension programs from 50 different studies and 375 estimates of IRRs for public sector agricultural research programs from 175 different studies. I report percentage distributions of these IRRs by region for IRR classes (0–20, 21–40, etc.) and report median IRRs as well. In addition, I report IRRs in the same format for studies of pre-invention or basic science research, private sector R&D programs producing inventions "used" in the agricultural sector and for *ex ante* studies of expected research impact.

Two features characterize all classes of IRR estimates. The first is that the range of estimates is broad, ranging from zero IRRs, indicating no measurable program impacts on agricultural production to very high IRRs, measuring high program impacts. The second feature of these estimates is that the median IRRs are high and generally well above "equilibrium" returns to investments in a market economy. The methodology employed in the studies reviewed captured the "social" or public return to investment in research and extension programs (area *a*+*b* in Figure 1 and area *F* in Figure 2). I counted both surpluses for both producers and consumers as benefits. In a world of efficient resource allocation, these social returns and investment would be roughly equivalent to private returns; but in the real world of inefficient public sector resource allocation, these high median IRRs are consistent with the observation that IRRs to private sector R&D are much lower than the social returns reported in Table 1.

Actually, the IRRs reported for private sector R&D programs are entirely in the form of external benefits realized in the agricultural sector. That is they include area *A*+*B* in Figure 1 but not area p, because private returns (area p) are captured in the prices that farmers paid for farm machinery, chemicals, and seeds from the private sector. Using the time weights in the IRR studies, we can estimate the ratio of the area a+b to p in Figure 1, assuming that private sector returns are in the 20 to 25% range. This ratio is approximately 4.

We can also compute the ratio of public values to "normal" private values (20% IRRs) for extension programs using extension time weights (which are shorter) and for public sector research program using the time weights estimated in the research studies. This is the ratio of the area f and to the area e in Figure 1. These estimates for extension programs range from 2 to 3. They are roughly 3 for countries outside Africa and 2 for Africa. The "extra" surplus (as measured by b in Figure 1) is one to two times P (Figure 1).

For research programs, these ratios are higher. They range from 5 to 7, being approximately 5 for African programs and 7 for Asian programs. The "extra" public values from these calculations range from three to five times *p* or *e*. (See below for calculations based on these publications.)

For agricultural invention, the IRR evidence is quite clear. Many of these IRRs were estimated for plant breeding programs. Effective development of modern crop varieties requires "frontier" technical capabilities. The breeding problems of genetic resource evaluation, of identifying sources of host plant resistance to plant diseases and insect pests, and of host plant tolerance to abiotic stresses require advanced skills. Progress requires years of commitment and of scientific exchange by specialized breeders, plant pathologists, entomologists, geneticists, physiologists, and other scientists. Such demands generally mean Ph.D. training, especially Ph.D. training at the "frontier." It also means long-term commitments of people and institutions. Plant breeders often invest ten or more years of effort before the release of their first variety.

Not only are crop inventions demanding in terms of skills and of institutional support for skills, but the demands for success are also, if anything, higher in the poorest countries where production environments are often highly unfavorable. Thus, in many African countries the challenges for biological inventions are great, and the public value of highest level skills is highest in this context.

Dynamic Technology Capital Issues and Technology

Acquisition by Low-Income Countries

Only about 35 to 40 of the 90-plus developing countries with populations over 1 million have anything approaching a viable IPR system to stimulate private sector inventions. In Africa, only South Africa and Zimbabwe have functioning IPR systems. Certainly there is some private sector adaptive invention and innovation access in countries without IPR systems, but growth evidence indicates that it is very limited. Still, some hold the view that adaptive invention is not needed in the chemical, electrical, and mechanical fields. This is the "anyone can read a blueprint" perspective on development. Yet the economic growth experience of developing countries is that no countries without a significant adaptive invention capacity in private-sector-producing firms have achieved significant economic growth. (See the following section.)

For chemical inventions, and to a lesser degree, for modern electrical inventions, a strong higher education component appears to be critical. A study of successful inventors in India (one of the few studies of inventors available) concluded that the skill levels for domestic inventors in India engaged in adaptive invention were as high as those characteristic of inventors in developed countries (Evenson 1996). The high proportion of successful inventors with foreign degrees in developing countries attests further to the value of specialized training. In short, Indian inventors aren't competitive unless they have an advanced degree, and they are more successful if the degree is from a foreign university program.

To consider these issues further, I have used a classification of levels of technological capital (TC) in studies of agricultural growth. I briefly review that application here, then calculate the public values of increasing TC.

Technological Capital

The terms "social capital," "institutional capital," and "infrastructural capital" have been used in recent years to describe the conditions under which economic activity takes place in different countries. The term "technological capital" is similarly designed to describe the conditions (the knowledge and the transaction costs associated with knowledge acquisition) specific to the implementation of technology by producers in an economy. These conditions affect the actual use of techniques at a given point in time and hence, the public value of skills associated both with the adoption and diffusion of existing techniques of production and with the adaptive invention of improved techniques over time.

The technology capital classification developed here is motivated by studies of agricultural technology but has more general relevance. An important distinction is made in agricultural studies between activities designed to move farmers closer to the "best practice" technology frontier and designed to move the best practice frontier itself through adaptive invention. The skills required for these two types of activities differ in degree of difficulty and in the required training. In general, the skills required to move the frontier are of a very high level, as noted above. They require doctoral training in applied science fields (plant pathology, entomology, genetics, agronomy). Skills required for moving farmers toward the frontier are advisory skills. These skills are less specialized than those of the researcher and are usually acquired in bachelor's and master's degree programs.

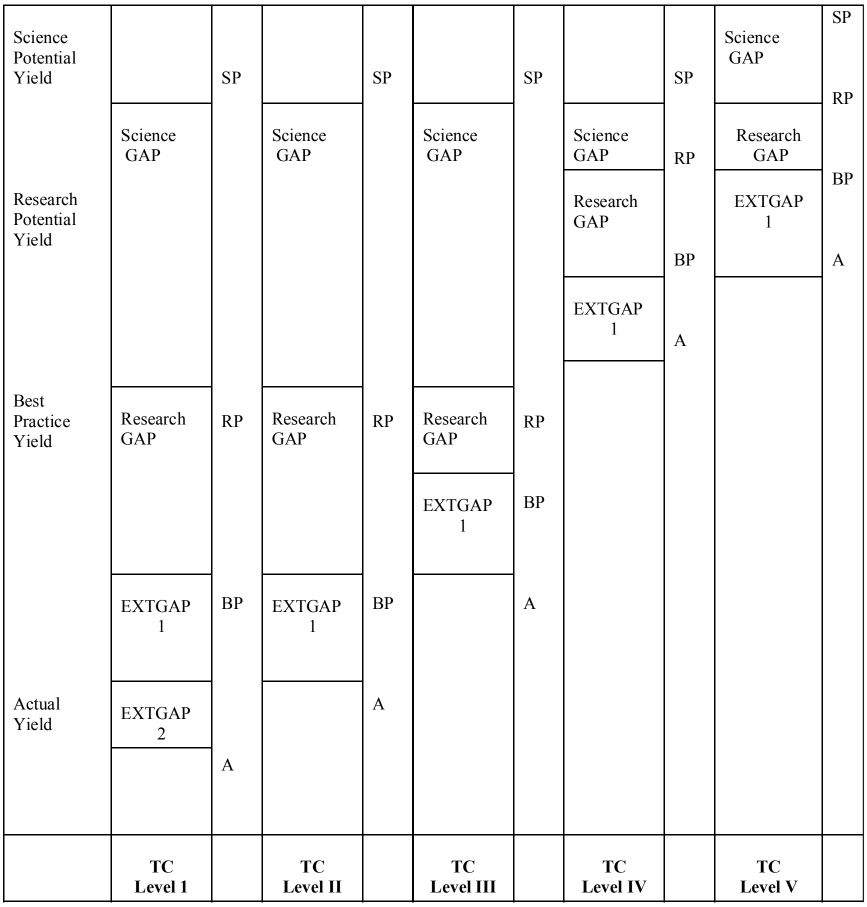
Consider Table 3, which displays five different levels of technology capacity. For each, a set of yield levels is depicted for a typical crop. These yield levels should be considered to be standardized for fertilizer, water, labor, and other inputs. Four yield levels are depicted. The first is the actual yield (A) realized on the average farmer's fields. The second is the "best practice" yield (BP) which can be realized using the best available technology. It is possible that some farmers obtain best practice yields but the average farmer typically does not. The third level is the "research potential" (RP) yield. That is, it is the hypothetical best practice yield that would be expected to be attained as a result of a successful applied research program directed toward this crop. The fourth is the "science potential" (SP) yield. This is also a hypothetical yield. It is the research potential yield attainable if new scientific discoveries (e.g., in biotechnology) are made and used in an applied research program.

Associated with these yields, we can define three "gaps." The "extension-infrastructure gap" is the difference between best practice (BP) and average (A) yields. Extension programs and infrastructure investments are designed to close this gap. The "research gap" is the difference between research potential (RP) yields and best practice (BP) yields. Applied research programs, if successful, will close this gap and will thus open up the extension-infrastructure gap. Similarly, a "science gap" exists between science potential (SP) and research potential (RP) yields.

Consider technology capital (TC) level I. This is a level where little extension, research, or science is being undertaken. Farmer schooling levels are low, markets are poor, and infrastructure is lacking.[4] The extension gap is large in this stage; thus, there is considerable scope for a high payoff to extension and infrastructure on investment, even if there are few effective research programs that are raising best practice yields. After extension programs have achieved a transition to Level II, the extension gap will have been reduced to some fraction of its original size (EXTGAP 1). In fact, the economy now becomes dependent on closing the research gap to open up the extension gap. As the economy is transformed from Level II to Level III, a direct link between research and extension is forged. Extension programs now become responsible for extending relatively newly developed technology to farmers.

When more basic or "pre-invention" science becomes more effective, the research potential yield (RP) is raised; and with active research and extension programs, the economy may move into Level IV. Further progress, i.e., to Level V and beyond, depends on effective pre-invention science, research, and extension programming.

Table 3: Schematic Crop Yields (and GAPs) by Technological Capacity Level



Source: Evenson (2000)

Consider the situation in Africa and Asia. It appears that much of Africa has not yet made the transition to Level II and no country appears to have achieved a transition to Level III where research systems are producing significant flows of new technology suited to farmers in many regions. In contrast, in both South and Southeast Asia by the mid-1960s many economies were already in Level II, and green revolution technology in rice, wheat, corn, and other crops after 1965 enabled them to make the transition to Level III. Today in many Asian and Latin American countries, Level IV infrastructure exists. (See below for specifics.)

In theory, it is possible that research systems can raise best practice yields before economies have made the transition to Level II. In practice, few countries have done so. Most research gains have been realized in economies that have already achieved Level II or III market and infrastructure and skills levels. We do not yet fully appreciate the factors that initiate a successful closing of this research gap. In some cases, such success has been induced by the development (often in international centers) of genetic resources and methods that increase the RP yield levels. In Africa these RP yield levels for some countries may be quite low because of limited genetic resources and difficult disease and insect problems, so that the research gap is actually quite small. If this is the case, "stimulus from above" in the form of improvements in science (closing of the science gap) may be required to achieve better research performance.

Technology Capacity in Developing Countries

Many discussions of developing countries utilize a simple north/south distinction. But this distinction masks the degree of diversity of innovation/imitation competence or capacity among developing countries.

Table 4 defines four technology capacity (TC) classes using six objective indicators. For a given period, a country can be placed into a unique TC class based on these indicators. The imitation indicators include literacy and agricultural extension. The innovation indicators include agricultural research programs (almost entirely public until recent years), R&D in manufacturing firms, foreign direct investment, and IPRs.

Based on these indicators, countries can be grouped in classes I to IV for each of three periods, 1961–1976, 1971–1986, and 1981–1996. The 93 developing countries in these classes are shown in Table 5 in classifications ranging from "111" through "444."

The "111" countries have remained in the lowest In/Im class for three periods. They are basically "failed states." They do not have the capacity to enforce laws and regulations. Some cannot even deliver the mail. They have not realized green revolution technology and have no gene revolution capacity.

The "112" countries have began to develop TC-2 capacity in period 3. None, however, has achieved productivity-driven industrial growth. A few have achieved green revolution gains, but these are very marginal. The 300 million people in the 20 "111" and "112" countries have realized little or no growth in per capita income. (See Table 2.) They remain almost completely excluded from the development process.

Table 4: Technological Capital Indicators for Developing Countries

INDICATORS	*TC-I*	*TC-II*	*TC-III*	*TC-IV* Adult male literacy
Less than 50%	More than 50%	More than 50%	More than 65%	Agricultural research investment/Agr VA
Less than .1%	.2% to 3%	More than .2%	More than .3%	Agricultural extension/Agr VA
Less than .1%	.1% to .2%	.1% to 2%	2% to 1%	Foreign direct investment/GDP
Little or none	Less than .3%	More than .2%	More than 2%	R & D in manufacturing firms/value added
None	None	Less than .3%	More than .3%	Intellectual property rights
None	None	Weak	Moderate	

Source: Evenson, (2000)

Table 5: Country TC Classifications 1961-1976, 1971-1986, 1981-1996

111	*112*	*222*	*223*	*233*	*333*	*334*	*344*	*444*
Zaire (Congo)	Angola	Burki. Faso	Bangladesh	Dominican Rep.	Barbados	Algeria	Chile	Argentina
Congo/ Brazza.	Benin	Cote d’Ivoire	Botswana	Gabon	Cyprus	Bolivia	China	Brazil
Ethiopia	Burundi	Guatemala	Cameroon	Ghana	Guadalupe	Ecuador	Colombia	Costa Rica
Somalia	Cambodia	Laos	Guyana	Kenya	Indonesia	Egypt	Malaysia	South Africa
Afghanistan	Chad	Malawi	Madagascar	Nigeria	Iran	El Salvador	Mexico	
	Gambia	Sudan	Mali	Paraguay	Iraq	Honduras	Morocco	
	Guinea	Togo	Mongolia	Peru	Jordan	India	Thailand	
	Guinea Bissau	Uganda	Namibia	Senegal	Libya	Jamaica		
	Haiti		Nicaragua	Sierra Leone	Martinique	Saudi Arabia		
	Mauritania		Swaziland	Sri Lanka	Mauritius	Tunisia		
	Mozambique		Tanzania	Surinam	Pakistan	Turkey		
	Nepal			Vietnam	Panama	Uruguay		
	Rwanda			Zambia	Philippines	Zimbabwe		
	Yemen				Reunion			
					Syria			
					Trinidad-Tobago			
					Venezuela			

Table 2: Economic Indicators by Technology Capital Class

Country Code	Total Population		GDP per Capita		Rural Population Density	Irrigated Land		Fertilizer Consumption		Cereal Yield		Agricultural Productivity		Competitive Industrial Performance Index	
	1998 (Million)	**Annual Growth Rate (%)**	**Annual Growth Rate (%)**	**PPP (US$)**	**People per Km^2. of Arable Land**	**% of Crop Land**		**100 Grams per Hectare of Arable Land**		**Kg per Hectare**		**Agricultural Value Added per Worker 1995 $**		**Source: UNIDO Scoreboard database**	
		1978-	**1962-**	**1999**	**1999**	**1979-**	**1997-**	**1979-81**	**1997-99**	**1978-81**	**1998-**	**1979-81**	**1998-**	**1985**	**1998**
111	142	2.81	2.30	707	487	9.6	9.8	25	13	908	844	249	264		
112	132	2.78	-0.76	1256	504	8.8	12.9	61	115	940	1157	274	284	0.001	0.006
Group I *	**274**	**2.80**	**0.83**	**971**	**495**	**9.2**	**11.3**	**42**	**62**	**923**	**995**	**261**	**274**	**0.000**	**0.003**
222	108	2.66	0.32	1302	309	5.2	4.9	149	264	1038	1167	834	878	0.008	0.017
223	232	2.27	1.12	2797	843	17.4	35.4	755	936	1808	2384	325	424	0.008	0.009
233	311	2.46	1.37	1817	550	11.5	25.3	278	1091	1612	2242	620	821	0.012	0.013
Group II*	**651**	**2.43**	**1.11**	**2081**	**615**	**12.6**	**25.5**	**426**	**899**	**1587**	**2115**	**550**	**689**	**0.010**	**0.012**
333	586	2.48	2.61	3383	468	33.2	37.8	637	1230	1954	2767	1055	1432	0.026	0.076
334	1222	2.09	2.31	2814	444	25.2	34.6	494	1168	1477	2504	457	633	0.036	0.054
Group III*	**1808**	**2.21**	**2.40**	**2998**	**452**	**27.8**	**35.7**	**541**	**1189**	**1632**	**2589**	**651**	**892**	**0.033**	**0.061**
344	1517	1.40	3.93	4181	617	40.2	36.5	1329	2643	2861	4486	444	689	0.031	0.133
444	206	1.75	2.38	7991	67	3.9	4.9	795	1097	1635	2819	2963	5404	0.135	0.147
Group IV*	**1723**	**1.45**	**3.74**	**4636**	**551**	**35.8**	**32.7**	**1265**	**2458**	**2715**	**4287**	**745**	**1252**	**0.044**	**0.135**

* Values are the *sum* of the population in each group (in millions), and the rest are the population-weighed average of each indicator in the group.

The “222,” “223,” and “233” countries have innovative capacity in agriculture. Most have plant breeding programs. All have realized some green revolution gains. Few of these countries have gene revolution capabilities, although Kenya has a program. This group of 32 countries (“222,” “223,” and “233”) with a population of 700 million people exhibits an important feature of developing country diversity, namely, that these countries have had some success in public sector innovation through plant breeding (a partial green revolution), but none can be described as having imitation success. That is, by and large they have not had productivity-driven growth in industrial employment. All are ranked very low on the UNIDO competitiveness indicator (UNIDO 2003, Table 2). Many early development modelers actually expected modernizing industry to “transform” traditional agriculture. This industry-driven transformation did not happen. Many of these countries are members of WTO but basically lack functioning IPR systems. Some have IPR laws but lack enforcement mechanisms.

The 1.8 billion people in the 30 countries in classes “333” and “334” have reached the stage of industrial competitiveness or near competitiveness. They have made the requisite investments in TC to realize per capita economic growth in the 4% range. Many are realizing this growth. (See Table 2.) Those not realizing this growth are engaged in civil conflict or in macro-economic mismanagement. For the largest country in the group, India, growth has been limited by an unwillingness to achieve openness.

The 1.8 billion people in 12 countries in the “344” and “444” classes have invested in the capacity to achieve very high economic growth (up to 8% per capita). As with the “333-334” group, countries not realizing this growth are usually engaging in macro-economic mismanagement (Argentina). The Asian Tiger economies (Hong Kong, Singapore, Taiwan, and South Korea) are no longer considered developing countries according this classification, while a number of former Soviet Union Republics (not considered here) have reverted to developing country status.

Economic Performance and Imitation Capacity

Table 2 reports economic performance indicators for the agricultural sector and for the economy generally by technology class. For purposes of organizing the data, I define four groups.

Group I includes the “111” and “112” countries. The 21 countries in this group had an average population in 1998 of 13 million. Their GDP per capita is low and is growing very slowly. The countries in this group have not achieved a significant green revolution in agriculture; only 1% or so of their cropped area is planted with modern varieties. Productivity growth in agriculture is negligible. Their industries are not competitive. The proportion of their labor force in agriculture is high and is not changing.

Group I countries have effectively been excluded from the development process. Their own governments have failed them. And aid agencies have failed them. This failure is most clearly manifested in their capacity to innovate and imitate. And this, in turn, is a failure of higher education institutions.

The 32 countries in Group II are also relatively small, averaging a population of 20 million in 1998. These countries have had a partial green revolution. Their per capita income levels are double those of Group I; but even with the green revolution, these countries are growing slowly. The best performers in Group II have per capita income growth rates of 1.9%. Their industries remain uncompetitive, and competitiveness in industry is growing slowly.

The Group II countries represent an anomaly of development experience. Early development theorists stressed the "dual economy" model with a modern industrial sector and a backward agricultural sector. These models suggested that, with modest technology transfer, the industrial sector would be the leading growth sector in these economies. But that has not happened. These countries have had a green revolution because they invested in the higher education programs required to train agricultural scientists and make public sector investments to support these scientists.

But their industries remain uncompetitive because they did not invest in the engineering and technical skills to make them competitive, an investment which requires significant resources. Technology transfer simply does not take place unless the transferee has significant competence. A number of the countries in Group II are investing in that competence.

In contrast, the countries in Group III have industrial competence as well as green revolution competence. A majority of their cropland has planted in modern varieties. Their industrial sectors are reaching competence thresholds, and these industries are driving the growth process.

The Group IV countries have attained even further competence in industry, and both Groups III and IV are increasing this competence rapidly. They enjoy the benefits of both multi-generation green revolution growth and industrialization-led growth. Some countries have per-capita income growth rates exceeding 4%. Many, however, pursue macro-economic and trade policies that curtail this growth.

It is difficult to look at Tables 2 and 5 and conclude that African countries do not need higher education programs that will produce not just university graduates, but specifically inventors with scientific and engineering qualifications. African countries have been excluded from the modern growth process realized by Group III and IV because they have not invested in technological capital.

The Dynamic Public Value of Technological Capacity

The construction of the technological capacity index is based on all levels of schooling, including the achievement of literacy and the development of R&D capacity requiring scientists and engineers. Agricultural researchers and many scientists engaged in industrial R&D have Ph.D.-level training. Group III, and particularly Group IV, technological capacity benefits from scientists and engineers with international training and experience. Agricultural extension workers and many engineers in R&D generally require bachelor's-level training.

In the section on "Invention and Technology Acquisition Skills: Public/Private Values," I computed ratios of public values to private values and of public values to research costs in public research systems. These values were based on estimated research contributions and did not consider the added value associated with technology capacity enhancement and shortening the transition time required to move from one class to the next.

The average time to move one technological capacity class to the next was 20 years, with countries that did not move considered to have a 30-year period. The total factor productivity (TFP) increases associated with a one-step change was approximately 0.7%. The public value of making the move in 10 years instead of 20 was thus a 0.35% higher TFP growth rate. This dynamic element adds a further public value to investment in higher education for economic growth.

Policy Implications

Do public values associated with higher education change the investment implications based on private values only? This paper suggests that they do, but only for specialized types of higher education associated with economic growth production, i.e., with inventions and innovation. The paper also argues that some part of this public value is associated with international experience, which may be acquired in a higher education program in a developed country.

In this concluding section, I discuss three policy areas. The first is to review and refine public value calculations and relate them to costs. The second is the specialized nature of the calculations. Is it the case, for example, that a Ph.D. program in a developed country can be justified for an agricultural scientist, but not for an art historian? And third, how serious is the inherent risk of "brain drain" in international higher education programs.

Public Value Calculations

Private value calculations of returns to schooling show highest returns to primary schooling and literacy achievement, with lower returns to secondary schooling and lowest returns to college and graduate education. (However, see Paul Schultz's article, which reports high returns to college education for Africa.) In many low-income and low-TC countries, academic salaries are low, even when they include housing and related benefits. The added salary increments associated with completing a doctorate are also low. In low-TC countries, non-doctoral monthly salaries as low as $200 per month are not unusual, nor are increments to salaries associated with a doctorate of only $100 or $200 per month. As countries move to Group III and Group IV status, these numbers become much higher.

Clearly, an income stream increment of say, $200 per month cannot justify an international Ph.D. program investment. The present value of an income stream of $2,500 per year for 30 years is $24,000 using a 10% discount rate and $38,000 using a 5% discount rate. It is conceivable that these numbers could justify a domestic Ph.D. program but not a foreign degree program.

Can public values raise these numbers to more viable levels? And how do public values compare between primary, secondary, college, and graduate training? How do they compare between disciplines?

Consider whether the ratio of public value of an educated person changes the calculations based on private values. It is important to note that all workers generate "economic surplus." We normally associate this surplus with goods markets; but in principle, goods surpluses can be translated into factor market surpluses. The calculations based on inventions in Figure 1 are a case in point. Are public surpluses higher for workers with secondary schooling, college degrees, or graduate degrees? Are the public values/private values different? This paper suggests probably not, *except for inventors and innovators.*

For inventors/innovators, two sources of public value were identified. The first was illustrated in Figure 1 where "extra" economic surplus was associated with IPR system drive private sector inventions/innovations and with public sector underinvestment in research and possibly in extension (*B* in Figure 1).

Rate of return evidence suggested public value/private value ratios in the 2 to 4 range for extension type programs. Of this, the "extra" surplus might be in the 1 to 2 range. For invention/ innovation programs with larger pay-offs, the public value/private value ratios could be in the 5 to 7 range with the extra economic surplus being perhaps 3 to 5. Thus, for higher education programs producing inventors and innovators, one could reasonably multiply the private values noted above of 24,000 to 38,000 by a factor of 3 to 5. This would bring them into the range of viability for international degree programs.

A second source of public value is associated with a shorter transition from one level to the next. As noted above, pursuing an aggressive technological capacity strategy could halve the time required to move from one level to the next; 23 countries actually moved in 10 years instead of 20. The associated growth dividend is an added 0.35% per year. If this growth required an increase in public and private educational spending of 1% of GDP, the added growth component would increase the extra public value/private value ratio for research from 3 to 5 to 4 to 6.

An additional source of public value is associated with the establishment of a training capacity in a developing country. India now has approximately 25,000 agricultural scientists in its public research system. A number of these scientists have graduate degrees from developed country programs, but most have graduate degrees from Indian universities. The quality of these Indian degree programs was at least partially the product of international higher education support programs. Many of the Indian degree programs had affiliations with U.S. land grant universities, and many faculty had obtained their degrees in earlier programs. Rockefeller Foundation programs in the social sciences were another source of support.

How much added public value is associated with the successful development of such degree-granting programs and the “leverage” created through students and through students of students? If each faculty member produces, say, 15 Ph.D. students over a career, the public value added can be quite considerable. At a discount rate of 10%, the present value of this contribution would roughly double the values calculated above.

It is also noteworthy that the effective conduct of agricultural research calls for international participation in the international science community. Almost all agricultural scientists working on rice in India have been to the International Rice Research Institute (IRRI), and all rice breeders in India use breeding germplasm produced by IRRI. The international system of rice nurseries administered by IRRI facilitates the use of this breeding germplasm. Science, applied science, and invention fields are inherently international in today’s globalized world, meaning that practitioners must be linked to the leading institutions producing new science, applied science, and inventions.

Invention/Innovation and Fields of Higher Education

The argument presented for the extra public values calculated above is couched in growth-production terms. Which higher education programs produce “growth producers”? That is, how are invention/innovation and technology acquisition skills acquired? And how does one weight the different fields of invention?

The arguments presented in this paper distinguished between specific invention/innovators and invention/innovation (In/Im) enhancing activities. TC enhancement entails a broader range of educational programs, including literacy achievement in primary and secondary educational programs. It also included college programs that support and spawn the growth producers. Many college programs support skill acquisition that is growth producing. But it is almost certainly the case that college curricula and fields of emphasis should emphasize the engineering-sciences and the “hard social sciences” more than the humanities relative to the curricula mixes in high-income countries.

The relative weight to different fields of invention activity should depend on the stage of development of the economy. For Group I countries with little industry, achieving agricultural productivity growth is of paramount importance. This is, first, because of the weight of agriculture in the economy and, second, because these economies lack the institutions and infrastructure to make anything else work. The experience of the past 50 years shows that Group I countries achieve TFP gains only in agriculture; and given limited investments, they achieve few gains there.

In Group II countries, agriculture also dominates TFP growth—but because they actually invest in agricultural research and extension. Many Group II countries have achieved agricultural gains from crop genetic improvement (CGI) or plant breeding inventions. The green revolution has reached many Group II countries but not many Group I countries, even though it is about their only option for growth. The Group II countries, however, receive considerable World Bank and other support for industrial growth. They do realize industrial growth but little industrial TFP growth. These countries do not acquire technology easily; and because the aid agencies have not stressed industrial R&D for these countries, their industrial growth comes at high cost.

For Group III countries, agricultural TFP growth is high and industrial TFP growth is beginning to emerge. They continue to underinvest in industrial invention, and most have great difficulty developing the IPR systems and associated institutions to move them into the rapid-growth class of the Group IV countries.

African countries face major challenges in upgrading their TC levels. Advanced training at the Ph.D. level is required. Nongovernment organization (NGO) programs have not invested in TC capacity, except marginally. Government support of higher education is required.

International Experience, Migration, and University Development

Investment levels in general science, the applied or pre-invention science and in R&D invention/innovation programs are such that developed economies are the natural originators of science findings and of inventions/innovations. The OECD countries share in this originating leadership role. Developing countries range from the Group I countries, who are largely outside the system except as buyers of products embodying inventions, to the Group IV NICs (and potential NICs) who specialize in adapting OECD inventions to meet demands in their own and upstream markets.

Yet for all TC levels, there is value to international experience, including obtaining degrees in developed country programs. For Group I and Group II countries, this is largely due to the fact that domestic programs, even at the M.A. level, are often not really available. For Group III and Group IV countries, even if good programs are available, there is added value in the international experience: the opportunities to observe and learn from originators.

The risk associated with international experience is that the potential inventor/innovator will not return. The brain-drain problem has been a factor for decades; and if anything, it is getting more severe as the income differentials between OECD countries and Group I and Group II countries widen. (See Kenneth Prewitt's article on replacement migration in this volume.) Past experience suggests that brain-drain problems are most severe in Group I and Group II countries and not too serious in Group III and IV countries.

Implications for Africa

Aid agencies provided vital support to high education programs in the 1950s, 1960s, and 1970s. This support enabled significant advances in technological capital in many Latin American and Asian countries. Less success was achieved in Africa in this period, at least partly as a result of Africa's inherited higher education capital.

In the 1980s and 1990s, aid agencies downgraded higher education support programs. They also implemented changes in development objectives, notably in the "sustainable development" movement that further downgraded the role of higher education programs, by stressing regulatory programs over invention/innovation programs.

This paper has argued that the TC route is the only practical route to income improvement. Many programs to increase the provision of public services have effectively improved real incomes by lowering the prices of such vital services as, for example, health care. But the escape route from the mass poverty now endemic in most African countries is improved income. This means invention and reinvention, innovation, and reverse engineering. Such processes require skills that can be produced only in higher education programs.

Notes

1 All factors of production can be thought of as having produced consumer surplus. In Figure 1 the area A is normal producer surplus. The area B is added surplus associated with IPR protection.

2 The section on "Dynamic Technology Capital Issues" below reviews the evidence from rate of return studies for agricultural inventions. It suggests that, at least in developing countries, areas A and B are large relative to P (3 to 5 times as large) and that the "extra" public value B is probably quite large (2 to 4 times P).

3 The Plant Patent Act (1930) provided patent protection to asexually reproduced plants, but it was not regarded as a major incentive for private sector breeding. In 1970, the Plant Variety Protection Act extended this protection to sexually reproduced plants. In the 1980s conventional patent protection was extended to plants and animals.

4 Many African countries "inherited" Class I Technology Capital from their colonial mother countries, and many have remained in Class I. (See Table 5.)

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