Technology Capital: The Price of Admission to the Growth Club

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Abstract

We assess long-run patterns of global agricultural productivity growth in developing countries between 1970 and 2005 and examine the relationship between investments in technology capital and productivity. To measure agricultural total factor productivity (TFP) we employ a Solow-type growth accounting method to decompose output growth into input and TFP growth. For technology capital we construct two indexes reflecting national capacities in agricultural research and education-extension for 87 developing countries. We then correlate technology capital levels with long-term growth rates in agricultural TFP. Our findings show that average agricultural TFP growth in developing countries accelerated in the 1980s and 1990s but fell marginally in the early 2000s. TFP performance was very uneven across countries and regions. TFP growth rates by individual countries were significantly influenced by their levels of technology capital. Marginal improvements to research capacity, given a minimal level of extension and schooling existed, were associated with faster TFP growth. However, marginal increases in extension-schooling without commiserate improvements in research capacity did not improve productivity performance.

Key words: agricultural development, agricultural extension, agricultural research, land quality, agricultural cost shares, growth accounting, total factor productivity (TFP)

JEL Classification: Q10, Q16, O13, O30, O47, O57

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Introduction

For low income countries, most of which share an economic structure heavily dependent on agriculture, increasing agricultural productivity is a precondition for sustained economic growth (Johnson and Mellor, 1961). Since the onset of the "Green Revolution" era in the 1960s, many developing countries have successfully sustained productivity growth in agriculture, and some of these have since graduated to "newly industrialized country" status. However, many others have failed to do so. Some remain bound by traditional farming methods while others appear to have only been able to achieve short and unsustained spurts of productivity growth. Our hypothesis is that a key factor separating the growth from the non- (or unsustained)-growth club is domestic capacity to develop and extend locally-adapted agricultural technology, a capacity we broadly term "technology capital." While many studies have found high average returns from public investments in agricultural research and extension (see Evenson, 2001, and Alston et al. 2000 for reviews of this literature), the evidence linking these investments to sector productivity growth remains fragmentary (Pingali and Heisey, 2001). It may be that in many countries investments in agricultural R&D have simply been too limited to make much dent in the overall sector performance. The relevant measures for making international comparisons possible have also proven difficult to assemble.

Our objectives in this paper are to develop internationally-comparable measures of technology capital and long-run growth in agricultural total factor productivity (TFP), and then examine the correlations between them. To measure productivity, we use a Solow-type decomposition of agricultural output growth into changes in inputs and total factor productivity (TFP) for nearly all developing countries from 1970 to 2005. Then, for 87 countries we construct two indexes of technology capital – one measuring capacity to invent or innovate new technologies (research) and one for the capacity to master the new techniques (agricultural extension and education). Regressing TFP growth against these measures of technology capital allows us to explore how they contribute to productivity as well as the degree to which these two forms of technology capital act as compliments or substitutes in the growth process.

Previous studies on the factors influencing agricultural productivity growth in developing countries have found positive correlations between investments in research and extension-education and improvements to productivity (Hayami and Ruttan, 1985; Evenson and Kislev, 1975; Craig et al., 1997). None of these studies, however, developed estimates of agricultural TFP or examined interactions between research and extension-education in the growth process. The limitations have largely been empirical. Measures of national capacities in agricultural extension in particular are sparse and fragmented. A survey of by Judd et al. (1991) found that during the 1960s and 1970s, many developing countries gave more attention to expanding agricultural extension than agricultural research under the assumption that relevant technology could be borrowed from other countries. However, the main lessons from Evenson's (2001) review of the impacts of agricultural extension were that impacts were highly variable and seemed to be most effective where research systems were functioning and where farmers had at least basic schooling. We investigate these interactions formally by examining the growth performance of developing countries that employed different combinations of technology capitals. The results have important implications for agricultural development policy.

Measuring Total Factor Productivity in Agriculture

A. <u>Methods for TFP Measurement</u>

To measure changes in agricultural total factor productivity (TFP) by country over time, we use a Solow-type decomposition of economic growth. Expressed as logarithms, changes in output (Y) growth over time can be decomposed into changes in aggregate inputs (X) and changes in TFP:

Equation 1

$$\frac{d\ln(Y)}{dt} = \frac{d\ln(X)}{dt} + \frac{d\ln(TFP)}{dt}.$$

In agriculture, output is a composed of multiple commodities produced by multiple inputs, so Y and X are vectors. Chambers (1988) shows that when the underlying technology can be represented by a Cobb-Douglas production function and where (i) producers maximize profits so that output elasticities equal input shares in total cost and (ii) markets are in long-run competitive equilibrium so that total revenue equal total cost, then Equation 1 can be written as:

Equation 2

$$\ln\left(\frac{TFP_t}{TFP_{t-1}}\right) = \sum_i R_i \ln\left(\frac{Y_{i,t}}{Y_{i,t-1}}\right) - \sum_j S_j \ln\left(\frac{X_{j,t}}{X_{j,t-1}}\right).$$

where R_i is the revenue share of the ith output and S_j is the cost-share of the jth input. Output growth is estimated by summing over the output growth rates for each commodity after multiplying each by its revenue share. Similarly, input growth is found by summing the growth rate of each input, weighting each by its cost share. TFP growth is just the different between the growth in aggregate output and aggregate input.

A key limitation in using Equation 2 for measuring agricultural productivity change is a lack of representative cost share data for most countries. We extend an approach originally developed by Avila and Evenson (2004), who constructed careful estimates of input cost shares for two large developing countries (India and Brazil) from farm census data and from these derived representative cost shares for other developing countries. For our analysis, we assembled cost share estimates for two additional countries (China and Indonesia) and then assign the cost shares from these four countries to be representative of agricultural production for different developing regions. We describe this more thoroughly in the section on "input cost shares" below.

B. Output and Input Data

To assess changes in agricultural productivity over time we use FAO (2008) annual data on agricultural outputs and inputs over 1970-2005 and for some variables adjust data for quality or augment data with improved statistics from other sources.

For output, FAO publishes data on production of crops and livestock and aggregates these into a production index using a common set of commodity prices based on the 1999-2001 period. The FAO index of real output excludes production of forages but includes crop production that may be used for animal feed.

For agricultural inputs, FAO publishes data on cropland (rainfed and irrigated), permanent pasture, labor employed in agriculture, animal stocks, the number of tractors in use and fertilizer consumption. FAO data were augmented with improved national statistics for China, Brazil and Indonesia and well as more up-to-date fertilizer statistics from The International Fertilizer Association (2008). See (Fuglie, 2008) for a complete description of data and sources.

Inputs are divided into five categories. *Farm labor* is the total economically active population (males and females) in agriculture. *Agricultural land* is the area in permanent crops (perennials), annual crops, temporary fallow, and permanent pasture, adjusted for quality. The method for land quality adjustment is described in Fuglie (2008). The method uses regression analysis to compare average productivity of different land classifications for different regions of the world and uses these as weights to aggregate agricultural land in terms of "rainfed cropland equivalents." A higher weight is given to irrigated land and a lower weight to permanent pasture.

Livestock is the aggregate number of animals in "cattle equivalents" held in farm inventories with each species weighted by its size according to the weights developed by Hayami and Ruttan (1985, p. 450). *Fertilizer* is the amount of major inorganic nutrients applied to agricultural land annually, measured as metric tons of N, P_2O_5, and K_2O equivalents. *Farm machinery* is the number of riding tractors in use. This variable probably understates the growth in farm mechanization in many developing countries because it excludes two-wheel tractors, which are especially important in Asia. We augmented FAO tractor data with estimates of total tractor horsepower (including two wheel tractors) for China, Indonesia and the Philippines (see Fuglie, 2008, for sources and methods).

While these inputs account for the major part of total agricultural input usage, there are some inputs for which complete country-level data are lacking, namely, use of chemical pesticides, seed, animal feed, veterinary pharmaceuticals, other farm machinery, energy and farm buildings and irrigation costs. However, data on many of these inputs are available for the four country case studies we use for constructing the representative input cost shares. To account for these inputs we assume that their growth rates are correlated with one of the five input variables described above and include their cost in the related input: service flows from farm structures and irrigation costs are included with the agricultural land cost share; the cost of chemical pesticide and seed are included with the fertilizer cost share; costs of animal feed and veterinary medicines are included in the livestock cost share, and other farm machinery and energy costs are included in the tractor cost share. So long as the growth rates for the observed inputs and their unobserved counterparts are similar, the model will capture the growth of these inputs in the aggregate input index.

C. Input Cost Shares

To derive input cost shares we draw upon other studies that reported carefully measured input cost share calculations for selected countries and then we assume these cost shares are representative of agriculture in different regions of the world. In Table 1 we show the input cost shares from the four country studies (India, Indonesia, China and Brazil) and the regions to which the various cost-share estimates were applied for constructing the aggregate input indexes. For example, the estimates for Brazil were applied to Latin American and Caribbean countries, North African and Middle Eastern countries, and South Africa, and the estimates for India were applied to other countries in South Asia as well as countries in Sub-Saharan Africa other than

South Africa. These assignments were based on judgments about the resemblance among the agricultural sectors of these countries. Countries assigned to cost shares from India, for example, tended to be low income countries using relatively few modern inputs. Countries assigned to the cost shares from Brazil tended to be middle income countries and having relatively large livestock sectors.

While assigning cost shares to countries in this manner may seem fairly arbitrary, an argument in favor is that there is a remarkably degree of congruence among the cost shares reported for the country shown in Table 1. Cost shares ranged from 0.40 to 0.46 for labor, 0.22 to 0.25 for land, and 0.14-0.25 for livestock, while cost shares for fertilizer and machinery inputs were not more than 14 percent of total output. There was a tendency for the labor factor share to fall and the fertilizer and machinery input cost shares to rise with agricultural development, reflecting embodiment of new technology in these inputs. The fact that the input cost shares show a consistent pattern lends support to using them as representative of agriculture in developing countries.

E. Defining Technology Capital

The circumstantial sensitivity of agricultural technology to specific agronomic conditions limits the degree to which new technology can be transferred from other regions. Therefore, at least some domestic capacity in technology capital is necessary in order to close the productivity gap between countries. Two broad types of national technology capital are (i) the capacity to develop or adapt new technology and (ii) the capacity of users (farmers) to master the new techniques. Unfortunately, systematic information on investments in different kinds of capital is generally not available or exceedingly difficult to obtain on an aggregate basis (Evenson and Westphal, 1995). What are available instead are various indicators related to distinct aspects of technological capacity. Weiss (1990) compiled several such indicators for a wide range of developing countries and from these assigned each country to one of a typology of "levels" of technology capability. We propose a similar approach for developing indexes for technology capital specific to agriculture.

To represent the capacity to develop or adapt new agricultural technology we construct an "Invention-Innovation" (II) capital index based on two indicators, the number of public-sector agricultural scientists per thousand hectares of arable land and the UNESCO indicator of research and development as a percentage of GDP. Agricultural scientists per crop area represent capacity to breed and adapt appropriate varieties and agronomic practices for the range of crops and environments in a country. The UNESCO indicator is primarily an indicator of industrial R&D and should capture a country's capacity to adapt and manufacture appropriate industrial inputs for agriculture. The number of agricultural scientists per country is from Pardey et al. (1991) and updated from ASTI (2008).

Countries are given an **II** index values of 1, 2, or 3 based on the following "break points" or threshold values:

(i) Agricultural Scientists per thousand hectares of arable land

AgSci = 1	if value is .02 or lower
AgSci = 2	if value is .021 to .06
AgSci = 3	if value is greater than .06

(ii) R&D/GDP

RD = 1	if value is .002 or lower
RD = 2	if value is .0021 to .006
RD = 3	If value is greater than .006

The threshold values for AgSci are based on subjective judgment but capture the range of capacities in agricultural research investment by developing countries. In 1970-75, about one-fourth of the developing countries in our sample where at the AgSci=1 level, while by 1990-95 about one-third of the sample had achieved AgSci=3. For R&D/GDP, the threshold values are taken from Weiss (1990) who classified countries into a typology of technology development levels based on a set of technology indicators. Weiss (1990)[1] classified countries having R&D/GDP at 0.2 percent or below (RD index=1) as using "traditional technology", while countries having R&D/GDP of at least 0.6 percent (RD index=3) were in transition to newly-industrialized status. Countries in between these thresholds were at an intermediate stage. The sum of the two indicators is the **II** index (**II** = AgSci + RD). Thus the minimum **II** index is 2, the maximum is 6.

Capacity to extend and adopt agricultural technology is represented by an index of "Technology Mastery" (**TM**) capital. Our **TM** index is also a composite of two indicators, the number of extension workers per thousand hectares of arable land and the average years of

[1] See also Evenson and Westphal (1995), table 37.1, pp. 2242-3.

schooling of males over 25. Comprehensive statistics on national agricultural extension services are lacking, but we have compiled what information is available from Judd, Boyce and Evenson (1991) with updates from Swanson (1990). The average years of schooling for adult males in the labor force are from Barro and Lee (2001). Countries are given **TM** value of 1, 2, or 3 based on the following:

(i) Extension workers per thousand hectares of cropland

AgExt = 1 if value is .2 or lower

AgExt = 2 if value is .21 to .6

AgExt = 3 if value is higher than .6

(ii) Average schooling of males over 25.

Sch = 1 if value is less than 4 years.

Sch = 2 if value is 4 to 6 years.

Sch = 3 if value is greater than 6 years.

The threshold value for AgExt is comparable to that of AgSci, since in developing countries extension workers are roughly 10 times as numerous as agricultural scientists (so the threshold values are 10 times larger). For schooling, achievement of basic literacy in the labor force is consistent with a Sch index value of 2, while Sch=3 implies a substantial share of the labor force has acquired some additional technical skills. The sum of the two indicators is the **TM** index (**TM** = AgExt + Sch). The minimum **TM** index is 2, the maximum is 6.

The measurement of technology capital by these broad index measures circumvents many of the issues encountered when trying to construct such indicators from sparse data of variable quality. Unlike measures of program expenditure, the index values are stable over long periods of time and do not require assumptions about currency exchange rates for international comparability. Although simple counts of research and extension personnel do not reflect differences in staff quality, the general pattern is for quality (measured by education level of program staff) to improve along with the staff numbers in systems that are expanding, particularly for research (Pardey, Roseboom and Anderson, 1991).

Changes in the index values represent significant improvements in a country's established capacity to invent and diffuse new technology. We have attempted to select threshold values that are robust to measurement errors in national science, technology and education statistics. One criterion for the selection of thresholds is to obtain adequate numbers of observations at each level (e.g., to divide observations roughly by 1/n across n levels). Another criterion is to pay attention to where there may be a natural gap in the data, so that country index values are not sensitive to small changes in threshold values. But there is no mechanical way to derive threshold values for indexes of this type, and some professional judgment is required. We did experiment with a number of perturbations of the model and feel that the results capture the broad dimensions of influences of technology capital on agricultural productivity growth and are robust to modest changes in model characteristics.

Table 2 reports II and TM indexes for two periods, 1970-75 and 1990-95, for 87 developing countries with a 2000 population of 750,000 or more.[2] The countries are grouped according to their II index scores in the two periods, with the TM index scores shown in parenthesis after the country name. For example, Afghanistan scored 22 for both the II and TM indexes. This means that Afghanistan achieved the lowest possible score (2) in 1970-75 and again in 1990-95 for both measures. Brazil, on the other hand, scored 56 (46), meaning that it's II score increased from 5 to 6 and its TM score from 4 to 6 between the two periods. By the early 1990s, Brazil had sufficiency technology capital in agricultural research and extension to generate and rapidly diffuse a broad set of improved agricultural technologies.

If we consider an II index of 2 as a characterization of a country in "traditional agriculture," 21 of the 87 countries were in traditional agriculture in 1970-75. By 1990-95 nine of these countries remained in traditional agriculture while one country (Guinea Bissau) had reverted to traditional agriculture levels of technology capital between 1970-75 and 1990-95. Of the twelve countries that moved out of traditional agriculture, six moved to II class 3 and six to II class 4, by 1990-95. All moves to II class 3 and most moves to II class 4 were based on an increase in public agricultural research rather than industrial R&D. In no case did the industrial R&D index move ahead of the agricultural scientist index. Thus, an II index of 5 means that the agricultural scientist index was 3 and the R&D/GDP index was 2. By 1990-95, at least 31 of the 87 countries were investing in significant agricultural research (AgSci=3). We point out that the

[2] The set of 87 countries is fairly comprehensive, missing only nine developing countries with a population of more than 750,000 due to insufficient data on some of the technology capital variables. The nine are Cuba in the Caribbean, Fiji, Papua New Guinea, Lebanon and North Korea in Asia-Pacific, and Liberia, Namibia, Swaziland and Lesotho in Africa. We have excluded countries with less than a 750,000 people because these nations face a unique set of problems associated with very small country scale.

components of each of the indexes are not perfect substitutes and are more likely to be complementary (e.g., extension services will be more efficient with a literate farm population). Most of the advances in the Technology Master index that occurred in our sample between the two periods were due to increases in schooling rather than extension.

F. Modeling Influence of Technology Capital on TFP Growth

To examine the relationship between technology capital and productivity growth, we hypothesize that technology capital in period t will influence TFP growth in that period and in subsequent years. Since we have the technology capital index measures for two periods, we effectively have a two-period panel dataset. We let the **II-TM** level in 1970-75 explain average annual TFP growth during 1970-1989 and **II-TM** level in 1990-95 explain TFP growth during 1990-2005. We establish causality between technology capital and productivity through the lag structure (i.e., present technology capital stock affects future growth performance). To capture the interaction between research and extension-schooling, we construct a series of dummy variables representing different combinations of **II** (research) and **TM** (extension-education) capacities. The estimation equation is:

Equation 3

$$TFP_{c,t} = \sum_{II=2}^{6} \sum_{TM=2}^{6} \delta_{II,TM}\, IITM_{c,t}.$$

where $TFP_{c,t}$ is the growth rate in country c's agriculture in period t and **II-TM** $_{c,t}$ takes on a value of 1 if both **II** $_{c,t} = 1$ and **TM** $_{c,t} = 1$, and 0 otherwise for that country and period. Thus, in **Error! Reference source not found.**, there is a potential for 25 **II-TM** class combinations, although only 19 are present in the data. Each of these **II-TM** combinations is represented by a dummy variable. The dummy variable coefficient's $\delta_{II,TM}$ measure the average TFP growth rate for the countries with this **II-TM** combination. To get a meaningful R^2 and F-statistic for the regression, a constant term was added to the model and one of the **II-TM** classes was left out.

Equation's 2 and 3 describe a "two-stage" decomposition of output growth (Evenson and Pray, 1991, pp. 81-91). In the first stage (Equation 2), TFP growth is estimated as the difference between output growth and input accumulation. In the second stage (Equation 3), this estimate of TFP growth is modeled as a function of technology capital. This two-stage framework helps to avoid the multicollinearity problem that arises when estimating an agricultural "metaproduction function," in which output growth is modeled econometrically as a function of both conventional inputs and non-conventional factors such as research and education. As mentioned previously, a high correlation between research and the use of modern inputs like fertilizer and machinery causes econometric estimates from multi-country agricultural metaproduction functions to be sensitive to model specification. In the two-stage approach, the contribution of modern inputs to output is accounted for by their cost share, and any increase in output over cost is attributed to productivity.

In addition to technology and human capital, TFP will be affected by errors in measurement, "left-out" factors of production, weather fluctuations, civil disturbances, economies of scale, gains in allocative efficiency from market liberalization and other variables. However, several of these omitted variables are probably not relevant to our model because of the long period over which we measure TFP change (i.e. we take average TPF growth over a 20 year period and a 16 year period). Thus, short-run fluctuations to output or TPF due to natural or civil disturbances will tend to be averaged out. Regarding scale economies, Hayami and Ruttan (1985) found no evidence that scale economies accounted for differences in productivity among developing countries. Market liberalization and institutional reforms that improve allocative efficiency will also cause TFP to grow, although the effect may only be temporary. Once resources have been reallocated to realize the efficiencies, growth will again stagnate unless improved technology is also forthcoming.

An advantage of the model in Equation 3 is that it allows us to examine the marginal effects of changes in the two types of technology capital, given levels of the other. Holding $\mathbb{II}$ (research capacity) at some level J and then examining how the coefficients $\delta_{J,2}...\delta_{J,6}$ vary allows us to examine how marginal increases in $\mathbb{TM}$ (agricultural extension and schooling) affect TFP growth. Similarly, holding $\mathbb{TM}$ fixed at some level K and examining the values of coefficients $\delta_{2,K}...\delta_{6,K}$ allow us to say something about the marginal effect of research capacity.

III. Agricultural Productivity and Technology Capital

Table 3 shows the growth patterns in real agricultural output, inputs and total factor productivity by decade since 1970, for different developing regions and selected countries. For developing countries as a whole, productivity growth accelerated in the 1980s and the decades following while input growth steadily slowed but was still positive. Two large developing countries, China and Brazil, sustained markedly high TFP growth rates since the 1980s. Sub-Saharan Africa, the Caribbean and Oceania are exceptions to the general pattern, with TFP growth lagging significantly behind other developing regions. Results at the country level give further evidence on where agricultural productivity was growing and where it was not. Besides Brazil and China, a number of mid-size countries achieved respectable levels of agricultural productivity growth: Chile, Costa Rica, Colombia, Malaysia, South Africa, Jordan, Lebanon Libya, Saudi Arabia, and Tunisia all achieved average agricultural TFP growth rates of over 2 percent per year over 1970-2005. Within Sub-Saharan Africa, no country sustained this rate of TFP growth over the whole period although Angola, Benin, Ghana, Mozambique and Nigeria did achieved average annual TFP growth of over 2 percent during 1990-2005.

Our findings on the relationship between capacities in technology capital and long-term growth in agricultural total factor productivity are reported in Table 4 . The regression coefficients are arrayed in a matrix corresponding to the II-TM class they refer to. The coefficient estimates reflect the average annual TFP growth rate (in percent) for all countries having technology capital in that II-TM class in either the 1970-1975 or 1990-1995 period. The numbers in parentheses below the coefficients indicate the number of observations that fell in that class. There were 18 countries that fell in the class characterized by little or no technology capital (II class = 2 and TM class = 2) in one of the periods. These countries as a group achieved a mean annual TFP growth of 0.40 percent, which was not significant from zero. At the other end of the technology capital scale there were two countries in II-TM class 66, and they achieved an average annual TFP growth rate of 3.45 percent. These countries are Brazil and China, large countries that have invested heavily in agricultural research and extension. There is a clear progression of higher TFP growth as countries increase II-TM technology capital. However, countries needed a minimal capacity in both research and extension-schooling in order to sustain significant productivity growth. When either II capital or TM capital were at very low levels (class 2), mean TFP growth rates were not significantly different from zero. However, with one exception, II-TM levels of 33 and higher were all associated with positive and significant TFP growth. The exception is II-TM class 35, which consists of only two countries – Panama in 1970-1989 and Zimbabwe in 1990-2005. Both of these countries suffered from political instability and poor macroeconomic performance over these periods, which may likely account for their low agricultural productivity growth despite significant levels of extension-schooling and some research capacity.

The F-statistics reported in the final column and row of Table 4 examine the marginal effects of research and extension holding the other fixed. Casual observation indicates that TFP growth rates tended to rise at higher levels of either II or TM capital (holding the other fixed), but the F-statistic test the hypothesis that all of the row (or column) coefficients are equal. In other words, it tests the hypothesis that there was no significant increase in TFP growth with a marginal increase in one of the kinds of technology capital. Neither II capital (research) or TM capital (extension and schooling) was effective at raising agricultural TFP growth without at least a minimal capacity in the other. But in the case of research, TFP growth rose significantly with marginal increases in II capital in three of the four cases where TM capital was at level 3 or higher. TFP growth also rose in the fourth case – where TM capital equals 5 – but the growth was not statistically significant. On the other hand, in no case did marginal increases in TM capital significantly increase TFP growth when II capital remained constant. In other words, agricultural extension and schooling were not substitutes for research and development capacity. Improved capacity to invent and adapt new technology to country-specific conditions was a requisite for sustaining TFP growth in agriculture.

The results show a clear impact of research capacity on achieving long-term productivity growth in agriculture. It is also useful to examine whether some countries were able to achieve TFP growth without it. Among the 174 country-period combinations in our sample, there were only four cases in which countries with the lowest II level (II=2) achieved average annual TFP growth of 1.4 percent or higher (in other words, that were in the top 40 percent of the sample). Three of these cases, Angola, Mozambique, and Cambodia during 1990-2005, reflect the influence of war recovery. The rapid increase in TFP measured in these countries was a return to pre-war productivity levels as labor once again became more fully employed on farms. The fourth case was Benin, which achieved a TFP growth rate of 1.9 percent per year during 1970-1989 despite having an II level of 2 during 1970-1975. This was one case that was sensitive to how we defined the variables in the model. Benin began to build its agricultural research capacity starting around 1970 and by the second half of the decade has graduated to an II class 3 country. Thus, for most of the 1970-1989 period Benin was no longer in "traditional agriculture." It is difficult to find a single example of a country that was able to achieve long-run productivity growth in agriculture without first establishing domestic capacity in agricultural research.

IV. Conclusions and Implications

Despite a general improvement in agricultural productivity growth in developing countries, TFP growth performance remains uneven across regions and countries. Countries that sustained high agricultural TFP growth over long periods of time include China and Brazil, two of the largest agricultural producers in the world, plus a number of other countries in Asia, Latin America, and North Africa. The largest group of countries in the low growth category are in Sub-Saharan Africa, but it also includes many countries in the Caribbean, Oceania as well as some others. We examined the relationship between average long-run TFP growth and national investments in technology capital for 87 developing countries over two periods of time. In our measure of technology capital we distinguish between capacities in research and capacities in agricultural extension and labor-force schooling. Our econometric results showed that rising agricultural TFP growth rates were correlated with increases in both forms of technology capital. Among these two forms of technology capital, our results argue in favor of giving greater emphasis to strengthening research capacity as an agricultural growth strategy. While some countries have sought to achieve rapid improvements in agricultural productivity by expanding agricultural extension services at the expenses of agricultural research, marginal improvements to extension and schooling, without commiserate improvements in research capacity, were not associated with increased productivity growth, while marginal improvements to research capacity often were.

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Table 1. Agricultural input cost shares

Study	Country / Period	Labor	Land & Buildings	Livestock & Feed	Machinery & Energy	Chemicals & Seed	Regions to which these factor shares are assigned:
Developing countries							
Evenson et al. (1999)	India 1967,77,87 avg	0.46	0.23	0.25	0.01	0.04	South Asia Sub-Saharan Africa
Fuglie (2004, 2007)	Indonesia 1961-05 avg	0.46	0.25	0.22	0.01	0.05	SE Asia, Oceania developing
Fan & Zhang (2002)	China 1961-97 avg	0.40	0.22	0.23	0.06	0.09	NE Asia developing
Avila & Evenson (1995)	Brazil 1970, 90 avg	0.43	0.22	0.14	0.14	0.07	LAC, MENA, South Africa
All developing countries		0.35	0.21	0.23	0.10	0.10	Average, weighted by production shares

Table 2. Country index scores for Innovation-Invention (II) and Technology Mastery (TM) in 1970-75 and 1990-95
(II index underlined and TM index in parentheses)

22	23	24	
Afghanistan (22)	Benin (34)	Dominican Rep. (24)	
Angola (22)	Burkina Faso (43)	Ecuador (33)	
Cambodia (22)	Burundi (22)	Guinea (33)	
Congo (22)	Central African Rep. (33)	Mali (34)	
Congo, Dem Rep. (23)	Rwanda (44)	Nicaragua (34)	
Ethiopia (23)	Somalia (22)	Togo (34)	
Mongolia (44)			
Mozambique (22)			
Niger (22)			
32 *	33	34	35
Guinea Bissau (22)	Chad (22)	Algeria (34)	Guatemala (44)
	Gabon (32)	Cameroon (34)	Kenya (45)
	Haiti (33)	Guyana (44)	Panama (56)
	Honduras (24)	Indonesia (25)	Peru (45)
	Laos (33)	Iran (23)	Venezuela (34)
	Madagascar (22)	Libya (34)	
	Mauritania (33)	Malawi (44)	
	Myanmar (33)	Morocco (44)	
	Paraguay (34)	Nepal (34)	
	Zambia (34)	Nigeria (34)	
		Senegal (33)	
		Sudan (22)	
		Syria (35)	
		Tanzania (34)	
		Tunisia (24)	
		Uganda (34)	
		Uruguay (44)	
		Vietnam (34)	
		Yemen (23)	
43 *	44	45	46
Saudi Arabia (23)	Bangladesh (33)	Argentina (44)	India (24)
Zimbabwe (45)	Bolivia (33)	Botswana (45)	Pakistan (24)
	Colombia (44)	Egypt (35)	Turkey (25)
	Cote d'Ivoire (23)	Iraq (22)	
	Gambia (22)	Malaysia (35)	
	Ghana (34)	Mauritius (56)	
	Jamaica (45)	Mexico (35)	
	Jordan (45)	Sri Lanka (56)	
	Sierra Leone (44)	Thailand (45)	
	Trinidad & Tobago (45)		
55	56		
Costa Rica (44)	Brazil (46)		
El Salvador (25)	Chile (35)		
Philippines (46)	China (56)		
South Africa (46)			

Explanation to table:

The scores gives the value of the index in each period. For example, 22 means that Afghanistan's II index score was 2 in 1970-75 and 2 in 1990-95. Afghanistan also achieved the minimum TM index scores (22) in each of the periods.

* Note that these countries had a reduction in II capital between periods

Source: Authors' estimates based on data from ASTI (2008), Barro and Lee (2001), Judd et al. (1991) and UNESCO (2008).

Table 3. Agricultural output, input and TFP growth by region

Average annual growth rate (%) by period	Output Index (smoothed with Hodrick-Prescott filter)				Input Index (land adjusted for quality)				TFP Index			
	1970-79	1980-89	1990-99	2000-05	1970-79	1980-89	1990-99	2000-05	1970-79	1980-89	1990-99	2000-05
Sub-Saharan Africa	1.31	2.60	3.10	2.20	1.68	1.66	1.63	1.59	-0.37	0.94	1.47	0.61
Latin America & Caribbean	3.07	2.37	2.87	3.13	2.46	1.07	0.49	0.65	0.61	1.30	2.38	2.48
Brazil	3.83	3.73	3.29	4.41	4.38	0.60	0.29	0.75	-0.54	3.13	3.00	3.66
Middle East & North Africa	2.94	3.37	2.73	2.34	2.52	1.64	1.14	0.78	0.42	1.73	1.59	1.56
China	3.09	4.60	5.17	3.87	3.27	2.13	1.39	0.65	-0.19	2.47	3.78	3.22
Southeast Asia	3.68	3.59	3.13	3.54	1.67	2.63	1.52	1.37	2.01	0.97	1.60	2.16
South Asia	2.56	3.39	3.00	2.19	1.90	1.37	1.29	0.83	0.66	2.02	1.71	1.36
India	2.69	3.52	2.94	2.00	1.89	1.42	1.19	0.57	0.80	2.10	1.74	1.43
Developing Countries	2.82	3.46	3.64	3.09	2.27	1.79	1.34	1.01	0.55	1.67	2.31	2.08

Source: Author's estimates.

Table 4. Technology capital and agricultural TFP growth

Data sample: 87 developing countries over two periods

Technology Mastery (TM) class (Ag extension + schooling)	Invention-Innovation (II) class (Ag research + industry R&D): 2	3	4	5	6	F-test of marginal effect of II holding TM fixed
	coefficients show average annual TFP growth rate in percent (number in parenthesis is number of obs. with II-TM combination)					
2	0.40 (n=18)	0.54 (n=14)	0.36 (n=8)	0.50 (n=1)		F(3,155)= 0.04 ns
3	-0.09 (n=9)	0.86 *** (n=25)	1.33 *** (n=15)	1.25 * (n=2)		F(3,155)= 2.53 ^^
4	0.03 (n=4)	0.83 ** (n=12)	1.44 *** (n=29)	1.96 *** (n=8)	1.50 * (n=2)	F(4,155)= 2.16 ^
5		-0.30 (n=2)	1.19 ** (n=7)	1.44 *** (n=9)	1.90 ** (n=2)	F(3,155)= 1.29 ns
6				1.24 ** (n=5)	3.45 *** (n=2)	F(1,155)= 4.50 ^^
F-test of marginal effect of TM holding II fixed	F(2,155)= 0.51 ns	F(3,155)= 0.69 ns	F(3,155)= 1.61 ns	F(4,155)= 0.52 ns	F(2,155)= 1.37 ns	

*, **, *** indicate coefficients are significant from zero at 10%, 5%, and 1% significance level.

^,^^ indicate rejection of hypothesis that all coefficients in row or column are equal at 10% and 5% significance level and 'ns' indicates not significant - cannot reject hypothesis of equal coefficients.

Number of obs =	174	F(18, 155) =	2.25	Prob > F =	0.004
R-squared =	0.208	Adj R-sqr =	0.116	Root MSE =	0.125