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African Agricultural Productivity Growth and R&D in a Global Setting

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Abstract

Relative to other regions of the world, most African economies are still heavily reliant on agriculture as a source of income and employment. And with more than 70 percent of the continent's poor residing in rural areas, the production and productivity performance of African agriculture is pivotal to overall economic growth and the well-being of the poorest people in the region. After a dismal decade of output growth in the 1970s, the rate of aggregate agricultural output growth picked up for each of the subsequent three decades, and averaged 2.83 percent per year during the 2000s. With population growing at still record rates by world standards, per capita output grew much more slowly, just 0.36 percent per year during the past decade.

The productivity evidence is mixed and difficult to summarize. The rate of African crop yield growth (at least for the four crops given closer attention in this paper: corn, wheat, rice and soybean) is generally slower than elsewhere in the world, and in keeping with patterns seen elsewhere there has been a slowdown in the pace of average crop yield growth in Africa since around 1990. African land and labor productivity levels also generally lag those found elsewhere in the world, although aggregate land productivity in Africa outperformed that of Australia and New Zealand, another region of the world with challenging agricultural soils and heavy reliance on erratic (and often agriculturally marginal) weather. The reported rates of growth in multi-factor productivity (MFP) for African agriculture are also low by world standards, but the body of available evidence suggests that African MFP growth rates picked up in recent years. Unfortunately, the lack of reliable data and differences in the analytical details between the available studies makes it hard to reconcile the evidence and reach robust conclusions about MFP performance throughout sub-Saharan Africa.

Productivity levels and growth rates are affected by a host of factors, not least the technologies linking inputs to outputs and, by implication, the amount, nature and effectiveness of the innovative effort that develops and deploys these technologies. Although overall investments in African public agricultural research and development (R&D) have increased during the past decade or so, the growth in spending is not especially widespread and dominated by growth in just a few countries. Nigeria and Ethiopia account for half the region's increase in agricultural R&D spending from 2000-2005—the latest year for which data are presently available. The intensity of public investment (i.e., agricultural R&D spending relative to the value of agricultural output) has increased as well. However, during the 2000-2005 period Africa spent just $0.54 on public research for every $100 of agricultural output, almost half the corresponding rest-of-world intensity ($1.05) and one-fifth of the rich country average ($2.70). Fragmented and typically small research agencies, and unstable funding streams still bedevil African agricultural research endeavors and undermine efficiencies in agricultural research that are intrinsically long-term in nature. Turning around these research realties in a meaningful and sustained fashion will be critical to realizing the long-term growth in African agriculture productivity that will be required to grow that sector in particular and the region's economies more generally.

African Agricultural Productivity Growth and R&D in a Global Setting

Introduction

In 2009, 13.1 percent of Africa's gross domestic product (GDP)—just 1.64 percent of world GDP—came from agriculture. If the more prosperous South African and Nigerian economies were set aside the agricultural GDP share for the remaining 44 countries would increase to an average of 18.1 percent of total output (World Bank 2012).[1] Although Africa is urbanizing faster than any other continent on earth, in 2010 its rural residents still accounted for 62.6 percent of the region's total population (Economist 2009; FAO 2012).[2] Moreover, estimates indicate that more than 70 percent of the region's poor live in rural areas and depend largely on agriculture for their livelihoods (IFAD 2012). Clearly the fate of Africa's economic future, and, especially, the well-being of the poorest people on the continent rest in ramping up the performance and productivity of agriculture.

A fundamental driver of sustained productivity growth is the technical changes embodied in improved inputs such as seeds, fertilizers, and machinery, as well as the improved production practices that directly stem from investments in R&D (Lipton 1988; Lipton 1989). The next 30 years and beyond will call for even more of the same kinds of technological changes and productivity growth. This need is especially great for many countries in Africa whose economies remain heavily reliant on agriculture, particularly as a major source of employment. In this paper I review the available, and, unfortunately, comparatively thin, sometimes questionable, and often difficult to reconcile evidence on the productivity performance of African agriculture and juxtapose this evidence against what is know about agricultural R&D in the region.

The structure of production

African agriculture is quite different from agriculture elsewhere in the world in many important respects. In 2010, sub-Saharan Africa produced 6.5 percent by value of the world's food and agricultural output compared with 5.6 percent in 1961.[3] It was Asia's output that grew the fastest—an average of 3.3 percent per year from 1961-2010, compared with 2.6 percent per year for Africa. Although during the past three decades African agricultural growth (2.9 percent per year) substantially outpaced rich-country growth (0.8 percent per year), it still lagged growth in Asia (3.4 percent per year).[4] While these aggregate growth relativities help position African

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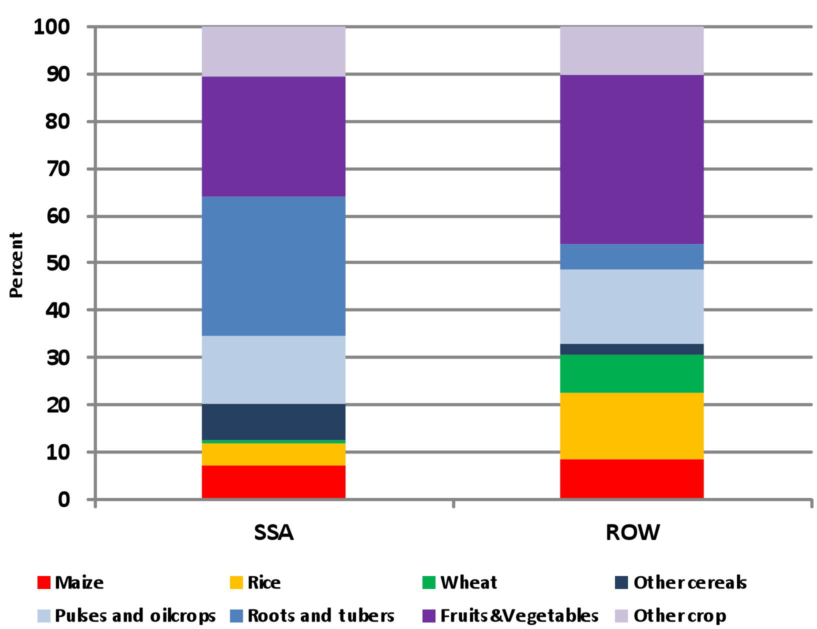
[1] In 2009, Africa's agricultural GDP totaled US$153.7 billion, representing 6.97 percent of world agricultural GDP.
[2] In this paper Africa will be taken to mean sub-Saharan Africa. According to FAOSTAT (2012), by 2033 half of Africa's population will be living in urban areas; whereas in 2010, urban population percentage for Asia was 40.5, 79.3 for Latin America and the Caribbean, and 77.4 for high-income countries.
[3] Here I refer to the gross value of production and, unless otherwise stated, these values are expressed in an average of 2004-6 international agricultural purchasing power parity prices obtained from FAO.
[4] The pattern of aggregate agricultural output growth has been uneven. During the 1960s and 1970s, the constant priced value of agricultural output grew by 3.30 percent per year and 1.33 percent per year respectively. In the 1980s it was 2.58 percent per year, picking up to 2.88 percent per year in the 1990s, and 2.83 percent per year during the past decade (2000-2010). On a per capita basis aggregate output grew by 0.76 percent per year in the 1960s, -1.44 percent per year in the 1970s, -0.27 percent per year in the 1980s, 0.22 percent per year in the 1990s, and 0.36 percent per year in the 2000s.

agricultural output performance vis-à-vis other regions of the world, they conceal substantial differences in the composition of that output.

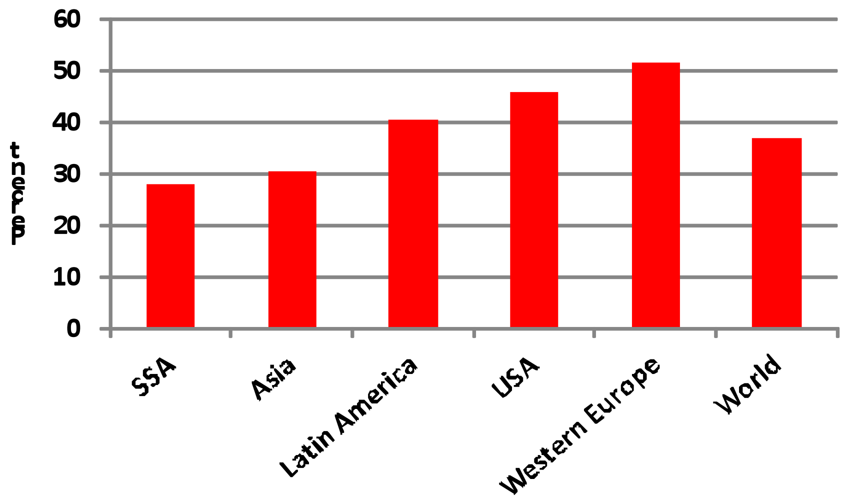
Averaging over the period 2008-2010, the three basic crop staples (maize, wheat and rice) accounted for barely 12.7 percent of the value of African crop production; less than half the corresponding rest-of-world share of 30.5 percent (Figure 1). More dramatically, the U.S. maize share alone accounted for 35.0 percent of that country's crop output: with all three staple cereals totaling 44.9 percent of U.S. crop output. Rest-of-world (i.e., the world excluding sub-Saharan Africa) production is also much more heavily oriented towards income-elastic fruits and vegetables compared with Africa. Nonetheless, the constant-priced value of African fruits and vegetables output grew more rapidly (2.40 percent per year from 1990-2010) than the value of output of cereals and other crops (including treenuts, spices, coffee, cocoa, and various fiber crops). However, the growth in African roots and tuber production (3.86 percent per year) as well as pulses and oils (2.77 percent per year) outpaced that of fruits and vegetables. Although these growth rate differentials over the past several decades resulted in substantial structural shifts in the composition of production, a large share of African crop production is still concentrated in roots and tubers. Crops such as cassava, sweet potatoes and potatoes dominate this crop category, although more than 43 percent of the continent's production comes just from Nigeria. Setting aside the five largest producers of roots and tubers (Nigeria, Ghana, the second largest producer with 10 percent of the region's total production in 2008-2010, plus Cote d'Ivoire, D.R. Congo and Angola), the rest-of-Africa share of roots and tubers in total crop production almost halved to 16.1 percent (compared with 29.2 percent overall). Panel b shows that the 2008-2010 livestock value share (i.e., including meat, milk, wool, eggs, skins, and all other livestock products) in Africa was just 27.9 percent compared with a rest-of-world share of 37.5 percent.

Figure 1. The commodity composition of African agricultural production, 2008-2010

Panel a: Crop composition



Panel b: Crop vs. livestock shares



Source: Calculated by author based on data from FAO (2012). Data represent share of the 2008-2010 value of agricultural production denominated in 2004-2006 purchasing power agricultural prices.

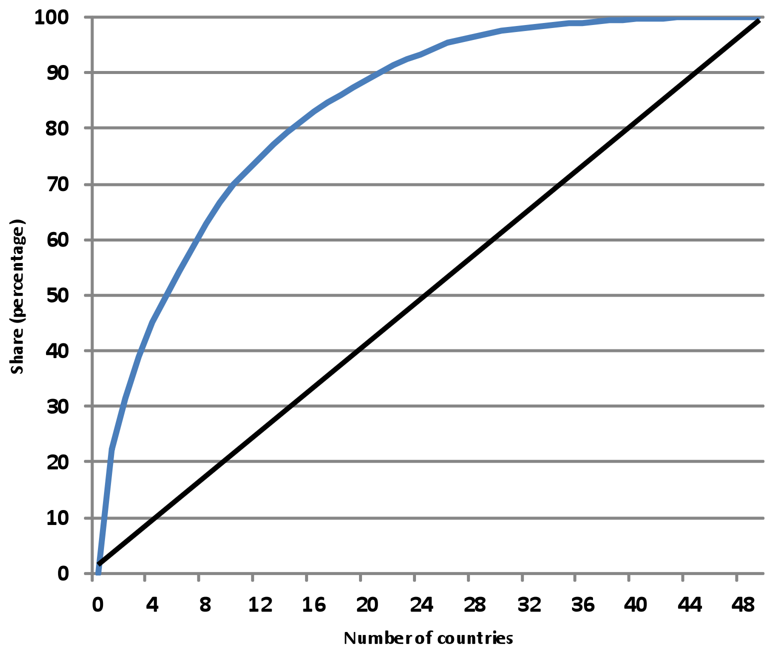
The growth in real per capita incomes in Africa has recovered of late—averaging -0.8 percent per year during the 1980s, -0.5 percent per year in the 1990s, and 2.1 percent per year since 2000. If that trend continues or accelerates, one would expect the composition of African agriculture to continue to respond to changing demand realities and begin diversifying beyond roots and tubers with a commensurate shift in the composition of production towards fruits, vegetable and livestock products (Frazão et al. 2008). This change would have a kick-on effect, increasing the demand for livestock feed, including maize production. Notably, during 2008-2010 African agriculture produced more maize by value than wheat and rice combined, and, since 1990, maize output has grown by 2.1 percent per year. This is about the same rate of expansion of wheat production (2 percent per year) but slower than the growth in rice output (2.7 percent per year).[5]

African agricultural production is spatially concentrated. The horizontal axis in Figure 2 arrays countries from the largest (left) to the smallest (right) by value of production, while the vertical axis reports the cumulative share of production as one moves to countries with an ever smaller share of the region's output. A plot tracking the 45-degree line would indicate that each country in the region produced the same value of agricultural output in 2008-2010 (i.e., they had equal shares of the region's output). The marked convexity of the plot indicates that just a handful of countries account for the lion's share of the continent's agricultural output. Nigeria is the largest agricultural economy, producing almost one-quarter of the region's total output. Add-in South

[5] However, rice production is also highly concentrated, with only two countries (Nigeria and Madagascar) accounting for 44 percent of sub-Saharan Africa's total rice output. Rice output in Madagascar grew by 3.3 percent per year from 1990-2010 and declined by 0.1 percent per year in Nigeria over the same period. In contrast, output from Rwanda, Sudan and Benin (each of whom produced less than 0.7 percent of the region's rice output in 2010) reported output growth of more than 10 percent per annum since 1990. African cassava production, meanwhile, increased by 2.9 percent per year since 1990.

Africa, and these two countries alone produce almost one-third of the regional total. Including Ethiopia, Sudan and Tanzania yields half of Africa's total agricultural production. In contrast, the smallest 24 agricultural economies (i.e., almost half of the region's 49 countries) produce just 5.6 percent of the region's output. Clearly changes in regional and even sub-regional production (and productivity) trends will be heavily skewed by developments in a handful of countries.

Figure 2. The country concentration of African agricultural production, 2008-2010

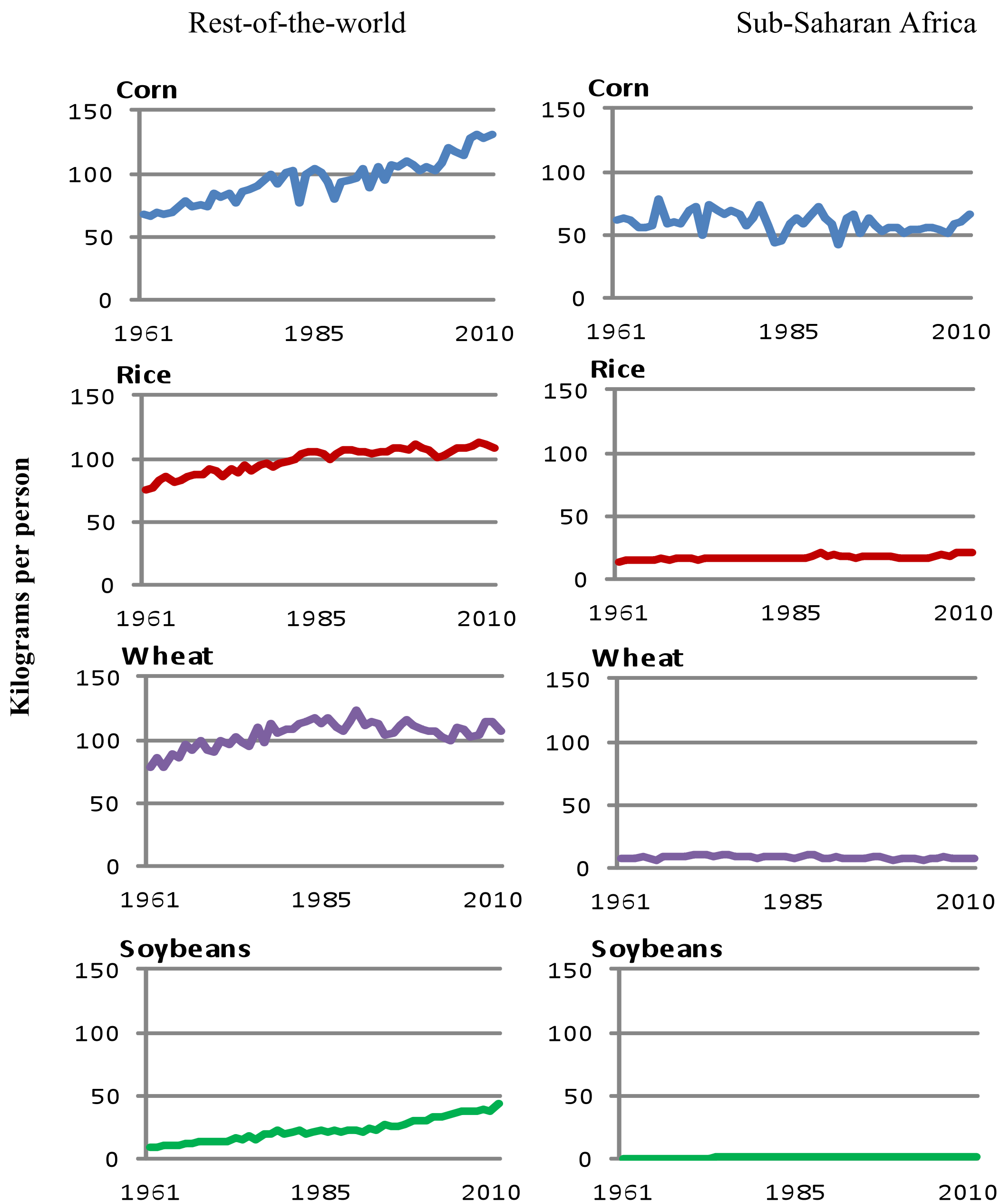


Country	Cumulative Share
	(percent)
Nigeria	22.2
South Africa	31.3
Sudan	39.0
Ethiopia	45.1
Tanzania	49.8
Kenya	54.3
Ghana	58.7
Uganda	62.8
Ivory Coast	66.7
Cameroon	69.8

Source: Calculated by author based on data from FAO (2012).

Figure 3 provides an indication of how agricultural supply has evolved vis-à-vis demand over the past half a century for sub-Saharan Africa and the rest-of-the-world. Overall, the growth in the real value of production in total—including 155 agricultural commodities—in Africa (2.6 percent per year) has slightly outpaced growth in the rest-of-the-world (2.3 percent per year) since 1961. This is also true for wheat, rice, and soybeans. However, population growth in Africa averaged 2.7 percent per year, substantially faster than growth elsewhere in the world (1.5 percent per year), and so the longer-run per capita growth in agricultural production of the four crops in Figure 3 has uniformly flat lined or trended downward in Africa, with the opposite trend elsewhere in the world. Moreover, even though output growth in Africa for 61 crop commodities outpaced the rest-of-world growth since 1961, for almost half of these commodities (accounting for 30 percent of the region's total value of agricultural production in 2010), the growth rate differences were less than one percent per year.

Figure 3. Per capita production of maize, wheat, rice and soybeans, 1961-2010



Source: Calculated by author based on data from FAO (2012).

These data point to the enormity of the challenge that lays ahead in meeting the region's food demand for a population that is expected to grow by 1.8 percent per year over the next four decades and total 1.8 billion by 2050 (FAOSTAT 2012). The key to rebalancing these supply-demand trends is to expand production at a rate that exceeds the expected rate of population growth.[6] Given that 55 percent of the region's population is presently engaged in agriculture (and 66 percent if the better off, diversified economies of South Africa and Nigeria are excluded)[7] this outcome will mean ever greater reliance on increasing agricultural (including labor) productivity at higher rates going forward than has been the norm hitherto.

Productivity patterns

Much has been written by economists on how to measure productivity and how to interpret the measures (e.g., Jorgenson and Griliches 1967; Alston et al. 1998; Morrison-Paul 1999). Different concepts and corresponding measures of productivity may be appropriate for different purposes, though they all express some measure of output relative to some measure of input.

The simplest measure of all is a measure of output of a single commodity per unit of a single input, such as yield in tons per hectare of wheat per year. This measurement seems straightforward. However, even such a seemingly simple and intuitive measure is prone to conceptual and measurement problems. For instance, land quality varies such that individual hectares are quite unequal in their productive capacity. Do economists use planted or harvested areas (that exclude abandoned areas or areas that fail to produce a measurable grain yield) and measure seasonal or annual acreages when forming measures of yields? Should the units of land be adjusted for quality to make the individual hectares more nearly comparable? If not, how should changes in observed yields that may reflect changes in the intensity of use or average quality of the land input be interpreted?

Similarly, on the output side, wheat quality varies significantly, depending on protein content and other attributes that are not independent of the physical yield—in particular, higher yield tends to be associated with lower quality (James 2000). What should be done about changes in output quality? If nothing is done to correct for variations in the quality mix over space and time, how should the measures be interpreted? Further complications arise from the implicit aggregation over time. For instance, in some cases multiple crops are grown on the same fields within one year; in other places a crop is grown in a multiyear rotation with other crops or with fallow years. How should the measures of yield per hectare per year be adjusted to allow for these characteristics of the production process so as to make the measures comparable over space and time?

Individual grain yield is an example of a *partial factor productivity* (PFP) measure. It is "partial" in the sense that it only accounts for changes in the amount of land used in production. It does not account for changes in the quantities of other inputs—such as labor, capital, fertilizer, rainfall, or irrigation—that also affect production. By the same token, grain yield per hectare of a particular crop also does not account for changes in other outputs that might be associated with the crop in question, such as crop biomass or other by-products. Thus yield and other partial measures can be seen as partial with respect to their treatment of outputs as well as inputs. At the opposite end of the spectrum are measures of *total factor productivity* (TFP), the aggregate

[6] To the extent this will increase standards of living generally, ramping up the growth in agricultural output is likely to shift the expected rates of population growth to the lower end of the projected growth spectrum.
[7] In 2010, South Africa's per capita GDP was $9,477 (2005 international dollars) and Nigeria's was $2,135, compared with $1,430 on average for the rest of sub-Saharan Africa.

quantum of all outputs divided by the aggregate quantum of all of the inputs used to produce those outputs. TFP is a theoretical concept. All real-world measures omit at least some of the relevant outputs and some of the relevant inputs, and therefore it is more accurate to refer to the real-world measures as *multifactor productivity* (MFP) measures. Particular MFP measures differ in the extent to which they fall short of the counterpart ideal TFP measure because of methodological differences as well as differences in the consequences of incomplete coverage of the inputs and outputs.

Here I briefly review the evidence on partial- and multi-factor productivity developments in agriculture over the past half a century using the range of measures at my disposal. Developments in Africa will be placed in a global context, but interpretation of the evidence is subject to the limitations broached above and other aspects, including the spatial dimensions of production discussed briefly below.

Crop yields

During the almost 50-year period from 1961-2010, global average maize and wheat yields rose worldwide by 1.53 and 1.62 percent per year respectively (Table 1). Average rice and soybean yield rose much more slowly, both growing closer to 1.00 percent per year on average. Notably, yields for the top 20 producing countries worldwide rose more rapidly than the world average for all four crops and substantially exceeded the average growth in crop yields throughout sub-Saharan Africa. Crop growth in sub-Saharan Africa also lagged average growth rates in the "other producers" category (i.e., countries other than the top 20 producers and those in sub-Saharan Africa) with the exception of rice. Rice was the only commodity in this group for which African yields—growing by 1.19 percent per year—outperformed growth in the other country group (0.99 percent per year).

Table 1. Worldwide crop yield growth for maize, wheat, rice and soybeans, 1961-2010

	Maize			Wheat			Rice			Soybeans		
	1961-1990	1990-2010	1961-2010	1961-1990	1990-2010	1961-2010	1961-1990	1990-2010	1961-2010	1961-1990	1990-2010	1961-2010
World	1.33	1.79	1.53	2.44	1.03	1.62	1.32	1.11	1.17	1.33	0.78	0.92
Sub-Saharan Africa	0.75	1.12	1.03	1.65	0.90	1.11	1.62	0.65	1.19	1.38	-0.52	0.31
Top 20 producers	2.22	2.12	2.32	2.69	1.17	1.98	1.72	1.44	1.64	1.92	1.56	1.76
Other producers	1.43	2.10	1.62	2.72	1.04	1.74	0.98	1.32	0.99	1.06	1.13	0.92

Source: Calculated by author based on data from FAO (2012). Growth rates calculated as differences of natural logarithms. Some sub-Saharan African countries fall within the top 20 producer group for some commodities, i.e., Madagascar (rice), Nigeria (rice, maize, soybeans), and South Africa (maize and soybeans).

These longer-run changes mask a worrisome feature in the pattern of crop yield growth. Crop yield growth for the period following 1990 is generally slower, and in some instances substantially slower, than yield growth before 1990.[8] The exception is maize, a crop subject to substantial private-sector research interest and a continuing stream of new technologies, and where yield growth since 1990 has matched (and for some of the groupings in Table 1) exceeded the pre-1990 pace.

As Alston, Pardey and Beddow (2010) pointed out, the interpretation of average global and regional crop yields is problematic for several reasons. One of the most confounding (but often ignored) factors is that countries located in tropical and temperate regions of the world differ considerably in terms of their propensity to plant multiple crops per year, and cropping intensities have changed considerably over time for certain regions of the world.[9] The yield data used here (and by most other observers) report yields on the basis of harvested area, which will count the same land twice if it is cropped twice in a given calendar year. An alternative is to report yields on the basis of arable area, which will count the land area only once per year regardless of how often it is cropped. Reporting yields on the basis of harvested area would understate the rate of growth in crop yields compared with crop yields measured on the basis of arable area if the intensity of crop plantings per year had increased over time.[10]

Other partial productivity measures

Figure 4 uses the graphical technique developed by Hayami and Ruttan (1971) to track land and labor productivity movements globally and for ten regions of the world, including sub-Saharan Africa (Pardey 2012). The horizontal axis is a measure of labor productivity and the vertical axis a measure of land productivity for the period 1961-2010. The productivity loci were formed by taking a ratio of the value of aggregate output and the respective land and labor inputs. Output is a FAO estimate of the total value of agricultural production (spanning 155 crops and livestock commodities for sub-Saharan Africa and 185 commodities for the world) expressed in 2004-

[8] These comparative yield growths are sensitive to end point choices. Breaking the periods in years other than 1990 changes the specifics of the growth rates but splitting the data at different years around this date does not alter the general finding of a widespread (but by no means universal) slowdown in growth.

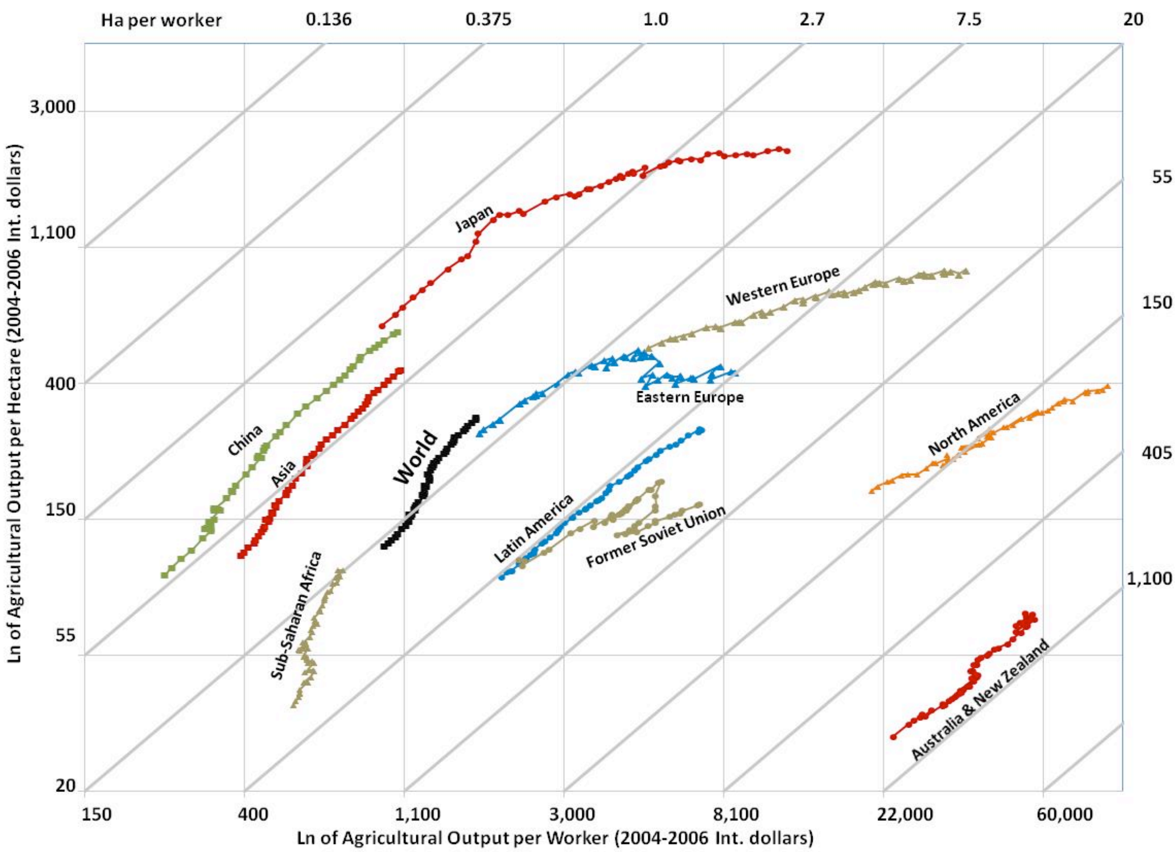
[9] Wood et al. (2000) developed measures of cropping intensities worldwide that expressed the annual harvested area as a proportion of total cropland (including land in use and fallowed land). Swidden agriculture, for example, relies on maintaining a significant share of production in fallow every year (thus having a cropping intensity of less than one) whereas some irrigated areas in the tropics can produce up to three crops a year from the same physical area (thus having a cropping intensity of three). In 1997, the global average annual cropping intensity was estimated to be about 0.8 (Wood et al. 2000, p. 23). In South Asia, with its extensive use of irrigation, the average intensity was 1.1, whereas in Western Europe and North America the intensities were in the 0.6 to 0.7 range. The estimated intensity for sub-Saharan Africa was 0.9. Wood et al. (2000, p23) observed this "… is surprisingly high and implies a greater intensity of farming than expected of a region with little irrigation and the common use of fallow periods. But this finding might simply reflect data weaknesses, in this case associated with the under reporting of agricultural lands, where fallow lands, land farmed under subsistence crops, and crops that grow within forested areas are often not correctly accounted for in agricultural land use statistics."

[10] For example, Alston, Pardey and Beddow (2010) noted that if rice yields averaged 2 tons per harvested hectare in 1961 and doubled to 4 tons per harvested hectare by 2007, that would be equivalent to an average annual yield growth of 1.5 percent per harvested hectare per year. In contrast, if yields per harvested area doubled from 2 to 4 tons per hectare from 1961 to 2007 while the cropping intensity also increased from one to two crops per calendar year, yields reported on the basis of arable area would have grown from 2 to 8 tons per arable hectare, or 3.1 percent per year.

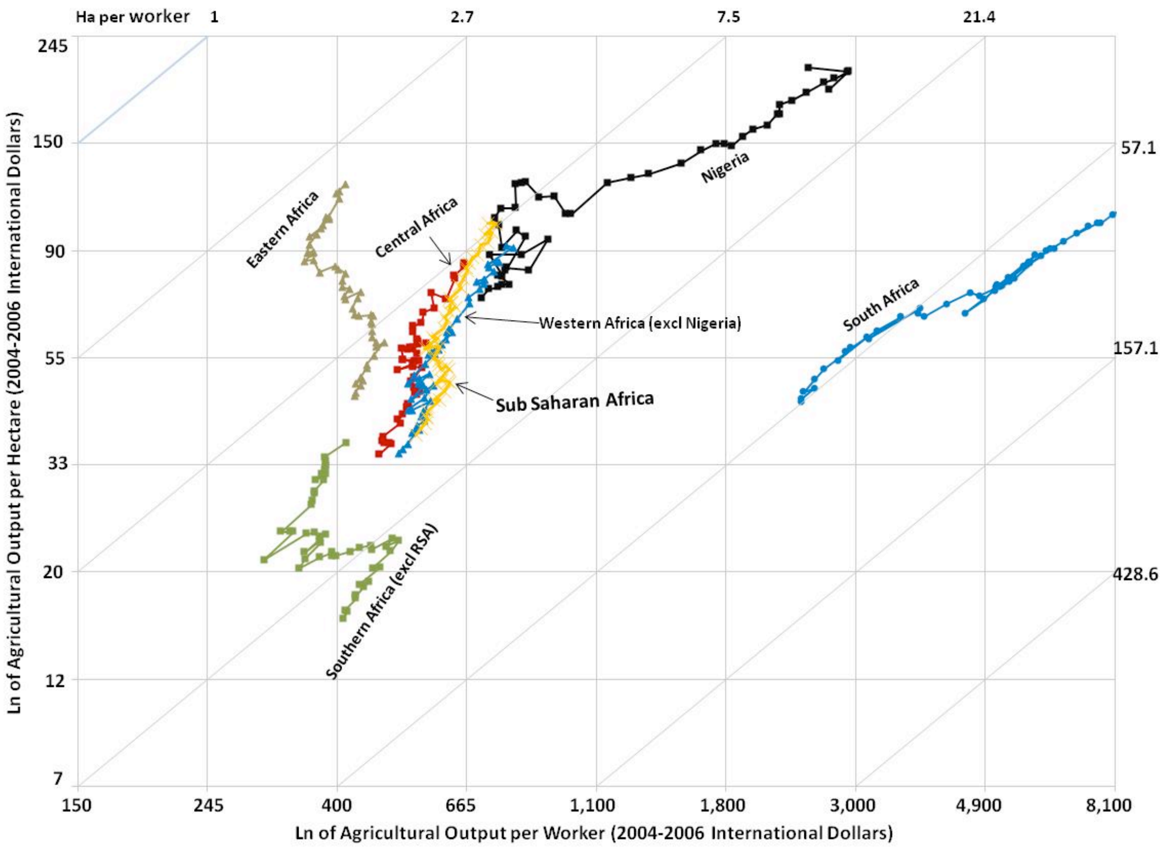
2006 average purchasing power parity agricultural prices (FAO 2012). Land is a measure of harvested and permanently pastured area, and labor is a head count of the total economically active workers in agriculture. Both axes are measured in natural logarithms so that a unit increase in either direction is interpreted as a proportional increase in land or labor productivity, and the length of the productivity locus is an indication of the average annual rate of change in productivity. Most, but by no means all, of the productivity paths move generally (but not uniformly) in a northeasterly direction, starting in 1961 and ending in 2010, indicating productivity growth.

Figure 4. Agricultural labor and land productivity patterns, 1961-2010

Panel a. Global trends



Panel b: Sub-Saharan Africa trends



Source: Pardey (2012) based on data from FAO (2012). Scales of axes and plots represent natural logarithms of the respective values. Axes labels are antilogs of the respective values.

Moving beyond crop yields to these more broadly construed productivity measures, global productivity trends show a 2.6-fold increase in aggregate output per harvested area since 1961 (equivalent to annual average growth of 2.0 percent per year) and a corresponding 1.8-fold increase (or 1.2 percent per year growth) in aggregate output per agricultural worker (Figure 4, Panel a). These productivity developments reflect a comparatively faster rate of growth in global agricultural output against relatively slower growth in the use of agricultural land and labor (0.3 percent and 1.1 percent per year, respectively).

The diagonals indicate constant land-to-labor ratios. As the productivity locus for a particular country or region crosses a diagonal from left to right, it indicates a decrease in the number of economically active workers in agriculture per harvested acre in that region. Substantive but gradually changing differences can be seen in the land-labor ratios among countries and regions. In Japan's case, land-labor ratios rose from 1.5 hectares per worker in 1961 to 5.8 in 2010. Land-labor ratios in Australia and New Zealand have changed little, whereas they doubled in North America (from 111.9 ha per worker in 1961 to 229.6 ha per worker in 2010). They also rose, albeit very slowly, for the Latin America and Caribbean region, consistent with the region's labor productivity growing slightly faster than its land productivity. Sub-Saharan Africa has become much more labor-intensive so its land-labor ratios have declined. In 1961, the region averaged 14.4 hectares per agricultural worker, but by 2010 the land-labor ratio had halved to 7.0 hectares per worker.

The relative positions of the productivity loci are revealing as well. In the terminal year of the data series, 2010, low-income countries as a group averaged just $527 of output per agricultural worker, compared with $1,473 per worker for middle-income counties and $34,035 per worker for high-income counties when taken as a group. The land productivity relativities are less clearly tied to per capita incomes. For example, middle-income countries as a group had similar output per hectare in 2010 ($335 per hectare) as the high-income countries ($365 per hectare). And, according to these data, in 2010 the average land productivity in sub-Saharan Africa ($105 per hectare) exceeded that of Australia and New Zealand ($75 per hectare).[11]

These broad, regional productivity trends fail to reveal the significant local variation caused by a host of agro-ecological, market-, and policy-related factors. Figure 4, Panel b plots productivity loci for four regions in sub-Saharan Africa plus Nigeria and South Africa.[12] The sub-Saharan locus masks a large amount of variation in productivity performances within the continent. Notably, the South African and Nigerian productivity loci follow distinctly different paths than the other regions of sub-Saharan Africa plotted in Panel b. Both countries had increases in land and, especially, labor productivity that were at considerably higher rates than the rest of Africa. Moreover, the value of output per unit of labor in 2010 for both countries was also considerably higher than the rest-of-Africa: $11,356 per worker in the case of South Africa and $2,503 per worker for Nigeria compared with an average of just $547 per worker for the rest-of-Africa.

South Africa is distinctive in that it is the only entry in the figure for which the land-labor ratio increased substantially over time (implying more pronounced growth in labor versus land productivity): from 54.5 hectares per worker in 1961 to 85.0 hectares per worker in 2010. In Nigeria, the land-labor ratio (starting from a much smaller initial value) increased a little: from 9.8 to 11.8 hectares per worker over the comparable period. In almost all the other regions depicted, real output per worker stagnated or in the case of Eastern Africa actually declined, although land productivity in all regions improved over time. Thus the horizontal spans of the productivity loci were smaller than their vertical spans so that land-labor ratios were smaller on average in 2010 than they were half a century earlier.

For the region as a whole, labor productivity grew by just 0.58 percent per year for the period 1961-2010 (compared with 1.29 percent per year for the rest-of-the-world). Nigeria and South Africa are the only entries in Figure 4, Panel b where average labor productivity growth exceeded 1.0 percent per year during this period. Labor productivity in Eastern Africa declined, and in Southern Africa (excluding South Africa) it barely budged from $413 per worker in 1961 to a still lowly average of $425 in 2010. These labor productivity trends speak to the dismal record of poverty and chronic food insecurity that befall a large share of the populations in these parts of Africa.

Notably, the lackluster growth in labor productivity in Central, Eastern and Western Africa (excluding Nigeria) belie their comparatively rapid rates of growth in total output. These three

[11] Part of story here is that 83 percent of the land area in Australia and New Zealand is classified as (likely less productive) pasture, compared with just 59 percent in sub-Saharan Africa (and 41 percent for the rest-of-the world).
[12] The series presented here is an updated and revised series from that reported in Liebenberg and Pardey (2012).

regions report real agricultural output growth in the range of 2.48 percent to 3.03 percent per year over the period 1961-2010, in some instances much faster than the comparative rates of growth in total output for South Africa, which averaged just 2.0 percent per year. However, South African agriculture ended the period with fewer agricultural workers than it had in 1961, whereas the economically active population in agriculture in the rest-of-Africa regions (like their populations generally) grew in the range of 0.21 percent to 2.61 percent per year. Thus, the poor labor productivity performance of Central, Eastern, and Western Africa (excluding Nigeria) reflects a failure of labor to leave agriculture for gainful employment elsewhere in these economies rather than a comparatively low rate of growth in agricultural output. Moreover, although the land area in agriculture has continued to expand in these parts of Africa, it has done so at a rate less than the rate of growth in agricultural workers. With land-labor ratios ranging from 3.3 to 11.1 hectares per worker in these regions, it is difficult to envisage raising output per worker to substantial levels, especially given the generally poor rural infrastructure and other market and environmental constraints that limit the transition to higher-valued forms of agricultural output.

Multifactor productivity estimates

Turning to an assessment of the differential rates of growth in aggregate input and output measures, Table 2 summarizes estimates of multi-factor productivity (MFP) growth for various countries in sub-Saharan Africa and average rates of growth for the region as a whole. Extracting plausible patterns from this evidence is difficult, in part because of substantive differences in the specific details of the treatment of the data used, differences in estimation methods, and the varying periods for which growth rates are reported. Overarching all of these aspects is a fundamental lack of data required to construct meaningful MFP estimates, forcing analysts to rely on incomplete, inconsistent or proxy measures (especially with respect to agricultural inputs), which have implications for the resulting MFP estimates that are difficult if not impossible to discern.

Table 2. Estimated African MFP growth rates

Authors	Publication Date	Region	Crop/Industry	Methodology	Sample Period	Average Annual Growth Rate
						Percent per year
Thirtle, Sartorius von Bach, and van Zyl	1993	South Africa	Agriculture	Tornqvist	1947-1991	1.26
					1947-1965	0.0
					1965-1981	2.15
					1981-1991	2.88
Thirtle, Atkins, Bottomley, Gonese, Govereh, and Khatri	1993	Zimbabwe	Agriculture	Tornqvist		
			Commercial		1970-1989	3.43
					1970-1979	3.87
					1980-1989	3.98
			Communal		1970-1989	4.64
					1970-1979	-1.99

					1980-1989	7.26
Block	1994	Sub-Saharan Africa	Agriculture	Regression cum growth accounting	1963-1968	0.02 to 1.45[a]
					1968-1973	-0.83 to 9.20[a]
					1973-1978	-0.46 to 4.50[a]
					1978-1983	-6.20 to -0.02[a]
					1983-1988	-3.10 to 2.15[a]
Thirtle, Hadley and Townsend	1995	Sub-Saharan Africa	Agriculture	Malmquist	1971-1986	0.84
Lusigi and Thirtle	1997	Sub-Saharan Africa	Agriculture	Malmquist	1961-1991	1.27
Schimmelpfennig, Thirtle, van Zyl, Arnade, Khatri.	2000	South Africa	Commercial agriculture		1947-1997	1.20
					1947-1964	0.0
					1965-1983	2.13
					1984-1997	1.5
Irz and Hadley	2003	Botswana	Agriculture:	Input Distance		
			Traditional farmers		1979-1996	-2.3
			Commercial		1968-1990	1.16
Fulginiti, Perrin, and Yu	2004	Sub-Saharan Africa	Agriculture	Semi-nonparametic	1960s	0.68
				Fourier production function	1970s	-0.32
					1980s	1.29
					1990s	1.62
					1961-1999	0.83
Dhehibi and Lachaal	2006	Tunisia	Agriculture	Tornqvist	1961-2000	3.6
Ludena, Hertel, Preckel, Foster, and Nin	2006	Middle East & North Africa	Crops	Malmquist	1961-2000	-0.03
			Ruminants		1961-2000	-0.02
			Non-Ruminants		1961-2000	0.64
			Average		1961-2000	0.03
		Sub-Saharan Africa	Crops		1961-2000	0.15
			Ruminants		1961-2000	0.36
			Non-Ruminants		1961-2000	0.5

			Average		1961-2000	0.21
Nin-Pratt and Yu	2008	Sub-Saharan Africa	Agriculture	Malmquist	1964-1973	-2.35
					1974-1983	-1.67
					1984-1993	1.65
					1994-2003	1.83
Alene	2010	Africa (incl. Sub-Saharan and North Africa)	Agriculture	Malmquist	1970-1980	-0.9
					1981-1990	1.4
					1991-2004	0.5
					1971-2004	0.3
				Sequential Malmquist	1970-1980	1.4
					1981-1990	1.7
					1991-2004	2.1
					1971-2004	1.8
Conradie, Piesse, and Thirtle	2009	South Africa			1952-2002	1.87
Block	2010	Sub-Saharan Africa	Agriculture	Regression	1960-1984	0.14
					1985-2002	1.24
					1960-2002	0.61
Avila and Evenson	2010	Africa (incl. Sub-Saharan and . North Africa)	Agriculture	Growth accounting	1961-1980	1.20
					1981-2001	1.68
					1961-2001	1.44
			Crops		1961-1980	1.03
					1981-2001	1.74
					1961-2001	1.49
			Livestock		1961-1980	1.09
					1981-2001	1.20
					1961-2001	1.68
Liebenberg and Pardey	2012	South Africa	Agriculture	Tornqvist	1947-1970	0.62
					1970-1988	3.98
					1988-2007	0.02
					1947-2007	1.49

Notes: The input distance function used by Irz and Hadley (2003) is a conventional measure of the largest factor of proportionality by which the input vector can be scaled down to produce a given output vector with the technology that exists at a particular time. The premise of the sequential Malmquist TFP index used by Alene (2010) is that past production techniques are also available for current production activities. The distance metrics in this instance are calculated using linear programming techniques formulated with respect to a "sequential" technology frontier.

[a] Reports four MFP growth rates per period based on different measures of output.

One fairly consistent finding is that the average longer-run rates of MFP growth in Africa are generally low compared with those reported for other countries or other regions of the world (see, for example, the cross-country evidence presented in Alston, Babcock and Pardey 2010). Summarizing the changing pattern of MFP performance over time, Nin-Pratt and Yu (2008) and Alene (2010) suggest that MFP growth in more recent times, beginning in the early- to mid-1980s, has increased relative to the rates typically reported for the preceding two decades. The empirical basis for this result is an increase in the measured rate of growth in aggregate agricultural output largely absent off-setting increases in the estimated rate of growth of aggregate input use.[13]

The weight to be given to even these limited "stylized facts" about MFP growth in sub-Saharan Africa is questionable. For example, there is a large variation in the reported longer-run average rates of MFP growth for the region included in Table 2. The large discrepancies among ostensibly similar MFP growth rates points to the overall fragility of the estimates.[14] They may also reflect more fundamental sources of variation in African agriculture which is heavily exposed to the vagaries of climate and related (and typically unmeasured) natural factors of production such as pest and diseases, thus making period MFP growth rates especially sensitive to fluctuations in (end-point) MFP values (Pardey 2012).

In stark contrast to the general notion that African MFP growth has recovered of late, Liebenberg and Pardey (2012) report evidence on the nature and rate of long-run MFP growth for South African agriculture using a detailed, newly compiled (but still less than ideal) series of aggregate inputs and outputs. They estimate that from 1947-2007 aggregate output grew by 2.69 percent per year, inputs by 1.20 percent per year and so MFP increased by 1.49 percent annually. However, since 1988 both aggregate output and input growth slowed, and so too did South African MFP growth, down to just 0.02 percent per year from 1988-2007.

[13] Commenting on this recovery in MFP growth rates, Nin-Pratt-Yu (2008, p.42) concluded that "The evidence in this study points to policy changes conducted by sub-Saharan Africa countries between the mid-1980s and the second half of the 1990s as one of the many factors determining the agricultural sector's improved performance."

[14] Notably, Lusigi and Thirtle's (1997) estimate is 1.27 percent per year (for the period 1961-1991), Fulginiti, Perrin and Yu (2004) report a rate of 0.83 percent per year (1961-1999), and Ludena et al. (2006) estimated 0.21 percent per year growth (1961-2000), which are all leas than Avila and Evenson's figure of 1.44 percent per year (1961-2001). And even for the earlier years where there is a consensus that MFP growth rates were comparatively low, the variance in the estimates is large. Block's (2010) recent estimate puts MFP growth for the 1961-1980 period at 0.14 percent per year, Nin-Pratt and Yu (2008) have much lower estimates spanning a similar period (specifically -2.35 and -1.67 percent per year for the 1964-1973 and 1974-1983 periods respectively), and Avila and Evenson (2010) report a much higher rate (namely 1.20 for the period 1961-1980).

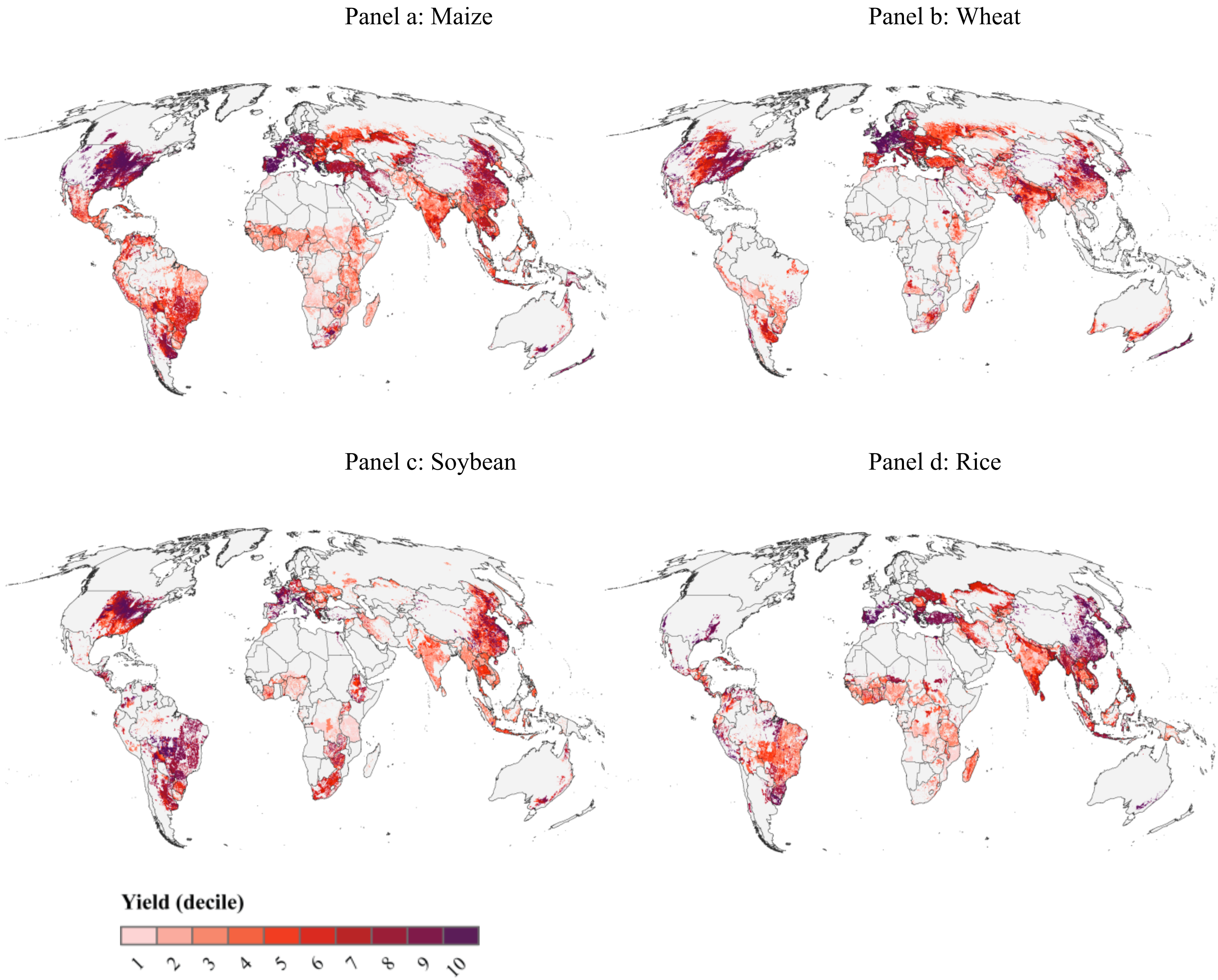
Spatial perspectives on productivity

Agriculture is a physically expansive sector. Ramankautty et al. (2008) estimated that that world's 15 million square kilometers of cropland occupy about 12 percent of the total ice-free land mass in 2000. It is also an inherently spatial process, with yields (and hence output) being greatly influenced by local factors such as weather and climate, soils, and pest pressures. Consequently, agricultural production and productivity are especially sensitive to spatial and inter-temporal variations in natural factors of production. Agriculture is also continually on the move, and this spatial shifting has profound (but hitherto largely ignored) implications for how productivity metrics can and should be interpreted (Beddow et al. 2010). For example, Alston et al. (2010) illustrated that the location of worldwide wheat production has moved markedly, even since the early 1960s. During the three-year period 1961-1963, Russia accounted for 15 percent of the world's wheat production (35.4 million metric tons) and ranked first among wheat producers worldwide. By 2005-2007, Russia had slipped to the world's fourth-ranked wheat producer, accounting for 7.8 percent (47.4 million metric tons) of world wheat production during those years. The massive increases in production by India and, especially, China saw their combined share of world wheat production increase from 11.8 to 28.6 percent over this same period.

Beddow (2012) shows that these spatial movements are not limited to shifts in the balance of production among countries, but are also evident as substantial shifts in the location of production within a country. Using a newly constructed set of county production data he showed that from 1929-2007 the centroid of U.S. corn production—that is, the geographical pivot point of corn production in the United States—moved a total of 748 kilometers, shifting the country's center of gravity in corn production from central Illinois to southeastern Iowa. These changes in location of production imply changes in average productivity (yields) to the extent that different locations have different endowments of soils and climate, different incentives (e.g., relative input and output prices, and, in some instances, agricultural regulations and policies), and different technological opportunities.

The consequences of location in terms of crop yields are graphically illustrated in Figure 5. This map indicates the area extent of global wheat, corn, rice, and soybean production for year 2000 on a 10x10 kilometer pixilated grid for the world. The local yields for each of the four crops is grouped into yield deciles, with light pink indicating the pixels with yields falling in the lowest yielding decile and dark purple representing the highest yielding decile. Each of these four crops has dramatically different global footprints, and, interestingly, the locations of the highest yielding areas for each of the crops are not spatially concordant.

Figure 5. Spatial distribution of crop yields worldwide, 2000



Source: HarvestChoice (2010).

Table 3 indicates the respective U.S., African, and Australian shares of the world's highest yielding pixels.[15] In 2000, the United States accounted for almost one-third of the world's highest-yielding corn acreage, and a quarter or more of the highest-yielding wheat and soybean areas. However, it only accounted for 5.3 percent of the highest yielding rice areas, with Africa home to a larger share of high-yielding rice acres. Although the African share of high-yielding

[15] The area shares reported here are the areas that fall within the top three yielding deciles.

maize, wheat and soybean acreages is much smaller than the corresponding U.S. share, Australia had an even smaller share of the world's higher yielding acreage than Africa.

Table 3. Share of the world's high-yielding area, 2000

	US	Africa	South Africa	Australia
		(percent)		
Maize	32	2.5	1.7	1.6
Wheat	28	3.6	1.4	1.6
Soybean	25	5.6	0.5	2.1
Rice	5.3	5.7	0	1.3

Source: Calculated by author based on data underlying Figure 5.

These crop yield data reinforce the land productivity relativities shown in Figure 4, wherein the average land productivity of sub-Saharan Africa in 2010 exceeded that of Australia. However, Australian and New Zealand agricultural land-to-labor ratios in 2010 of 718 hectares per worker were substantially higher than the African average (7 hectares per worker) such that agricultural output per worker in Australia and New Zealand was $53,811 (2005 prices) compared with just $728.1 per worker for sub-Saharan Africa. Agroecological similarities may account for much of the comparatively low and similar land productivity performances in Africa and Australia (versus the rest-of-the-world), but the two continents have evolved very different agricultural sectors with different technologies and input mixes that manifest in starkly different output per worker outcomes.

Table 4 reveals the patchy and typically limited uptake and use of purchased inputs (including chemical fertilizers, pesticides, improved seed and irrigation) throughout farms in Ethiopia, Ghana, and Kenya, and is likely illustrative of the pattern of agricultural input use throughout a substantial number of other countries in sub-Saharan Africa. Chemical fertilizers are the most widely used off-farm input, but in 2005 only one-third of the farms in Kenya used this input, and the extent of use was even less in Ethiopia and Ghana. This contrasts with Australian agriculture, which likely has factor use uptakes and intensities similar to those in the United States, where material inputs (including energy, purchased seed, chemicals and so forth) accounted for 38 percent of the measured cost of inputs in 2020 (and 52 percent if the cost of capital use was also factored in) (Alston et al. 2010).

Table 4. Structure of African agricultural inputs, various years

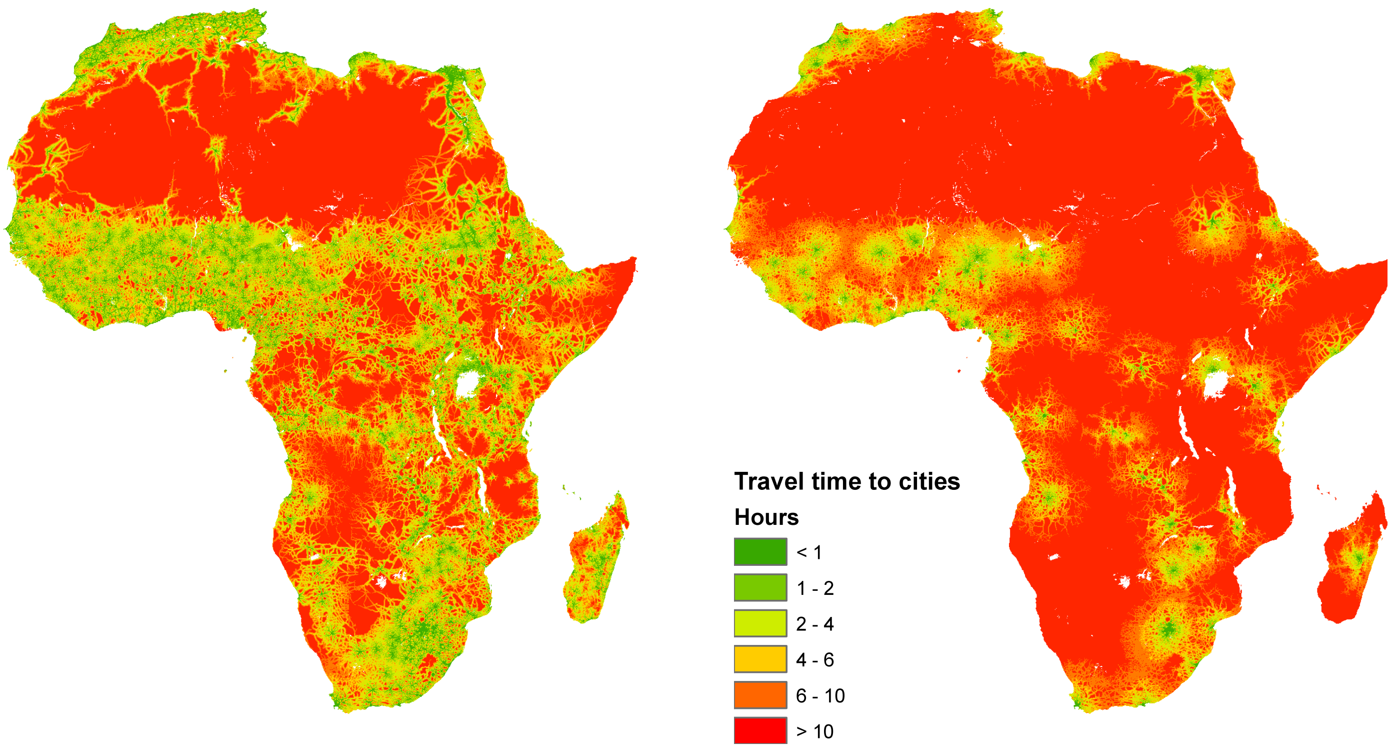
Country	Year	Number of Holders	Area per Holder	Percent of Farm Households Who Use: Fertilizers: Natural	Fertilizers: Chemical	Pesticides	Improved/ purchased Seed	Irrigation
		million	*ha*	*percentage*				
Ethiopia	2008/9	12.9	0.97	66.8	20.7	23.6	11.8	8.5
Ghana	2005	3.3	3.7	8	26	35	31	1
Kenya	2005	4.4	1.2	42	32	15	50	5

Source: Calculated for the author by Melanie Bacou based on farm household surveys from the respective countries for the years indicated in the table.

Pervasive rural poverty and dysfunctional credit markets are likely two key impediments to the use of purchased inputs (Kloeppinger-Todd and Sharma 2010). Another is the farm-level cost of accessing these inputs (and the commensurate costs of delivering any surplus production to sizable markets). Figure 6 plainly illustrates the magnitude of these market access problems. It shows the time-distance to markets (and hence the implied farm-level cost) of purchasing off-farm inputs and delivering marketable surpluses to markets of 25,000 or more people (Panel a) and 100,000 or more people (Panel b). According to these estimates, only 28 percent of African cropland is less than 2 hours away from market centers of 20,000 people or more, and it takes at least 6 hours to reach markets in excess of 500,000 people for around two-thirds of the cropland throughout sub-Saharan Africa. Excessive time distance to markets means it is prohibitively expensive for many African farmers to participate in input (and output) markets of some significance, even if those inputs were physically available and adapted to their local agro-ecologies and other production realities. Most off-farm inputs embody technologies and know-how that take time to develop and adapt to local circumstances. So while investments in transportation and communication infrastructure will be necessary to improve the lot of African farmers (Torero and Chowdhury 2005), so too will the investments in research and development (R&D) required to develop and deploy new on- and off-farm technologies for the diverse and complex production systems that are a hallmark of African agriculture.

Figure 6. African time distance to markets

Panel a: Population > 20,000 Panel b: Population > 500,000



Source: Calculated for author by Joe Guo based on data from HarvestChoice and Joint Research Centre of the European Commission. See www.HarvestChoice.org for details of these estimates.

Agricultural R&D

There is ample evidence that the productivity enhancing effects of the new knowledge and innovations arising from spending on agricultural R&D can be profound (e.g. Alston et al. 2000). Innovation in agriculture has many features in common with innovation more generally, but also some important differences. In many ways the study of innovation is a study of market failure and the individual and collective actions–notably investing in agricultural R&D–taken to deal with it. Like other parts of the economy, agriculture is characterized by market failures associated with incomplete property rights over inventions. The atomistic structure of much of agriculture means that the attenuation of incentives to innovate is more pronounced (and particularly so in many of the poorest parts of Africa where the average farm size is small, and getting smaller) than in other industries that are more concentrated in their industrial structure. On the other hand, unlike most innovations in manufacturing, food processing, or transportation, agricultural technology has a degree of site specificity because of the biological nature of agricultural production, in which appropriate technologies vary with changes in climate, soil types, topography, latitude, altitude, and distance from markets. The site-specific aspects circumscribe, but by no means remove, the potential for knowledge spillovers and the associated market failures that are exacerbated by the small-scale, competitive, atomistic industrial structure of agriculture.

Distinctive attributes of African agricultural R&D[16]

1. *Agricultural R&D benefits are difficult to appropriate*. The partial public-good nature of much of the knowledge produced by research means that research benefits are not fully privately appropriable. Indeed, the main reason for private-sector underinvestment in agricultural R&D is inappropriability of some research benefits: the firm responsible for developing a technology may not be able to capture (i.e., appropriate) all of the benefits accruing to the innovation, often because fully effective patenting or secrecy is not possible or because some research benefits (or costs) accrue to people other than those who use the results. Consequently, those who invest in R&D cannot capture all of the benefits—others can "free-ride" on an investment in research, using the results and sharing in the benefits without sharing in the costs.[17] In such cases, private benefits to an investor (or group of investors) are less than the social benefits of the investment and some socially profitable investment opportunities remain unexploited. The upshot is that, in the absence of government intervention, investment in agricultural research is likely to be too little.

   The types of technology often suited to African agriculture have hitherto been of the sort for which appropriability problems are more pronounced—types that have been comparatively neglected by the private sector even in the richest countries. In particular, until recently, private research has tended to emphasize mechanical and chemical technologies, which are comparatively well protected by patents, trade secrecy, and other intellectual property rights; and the private sector has generally neglected varietal technologies except where the returns are appropriable, as for hybrid seed. In less-developed countries, the emphasis in innovation has often been on self-pollinating crop varieties and disembodied farm management practices, which are the least appropriable of all. The recent innovations in rich-country institutions mean that private firms are now finding it more profitable to invest in plant varieties; the same may be true in some less-developed countries, but not all countries have made comparable institutional changes.

2. *Agricultural R&D lags are especially long*. The lags between investing in R&D and realizing a return from that investment are long, often spanning decades, not months or years. The dynamic structure linking research spending and productivity involves a confluence of processes—including the creation and destruction of knowledge stocks and the adoption and disadoption of innovations over space and time—each of which has its

[16] This section draws from Pardey and Alston (2010).
[17] For instance, an agronomist or farmer who developed an improved wheat variety would have difficulty appropriating the benefits because open-pollinated crops like wheat reproduce themselves, unlike hybrid crops, which do not. The inventor could not realize all of the *potential* social benefits simply by using the new variety himself; but if he sold the (fertile) seed in one year the buyers could keep some of the grain produced from that seed for subsequent use as seed. Hence the inventor is not able to reap the returns to his innovation.

own complex dynamics. That science is a cumulative process, in which today's new ideas are derived from the accumulated stock of past ideas, influences the nature of the research-productivity relationship as well. It makes the creation of knowledge unlike other production processes. The evidence for these long lags is compelling. One form of evidence is the result of statistical efforts to establish the relationship between current and past R&D spending and agricultural productivity. The dozens of studies done to date indicate that the productivity consequences of public agricultural R&D are distributed over many decades, with a lag of 15-25 years before peak impacts are reached and continuing effects for decades afterwards.[18]

3. *Agricultural R&D spills over, but not equally everywhere*. As will be evident from the evidence presented in the next section, underfunding of African agricultural R&D is clearly problematic, and the stage is set for the problem to worsen. In addition to the distinctive features of most African (and other developing countries) described above, the inadequacy of agricultural knowledge stocks may be exacerbated by changes occurring in developed countries. While the most immediate and tangible effect of the new technologies and ideas stemming from research done in one country is to foster productivity growth in that country, the new technologies and ideas often spill over and spur sizable productivity gains elsewhere in the world. In the past, developing countries, including many throughout Africa, benefited considerably from technological spillovers from developed countries, in part because the bulk of the world's agricultural science and innovation occurred in rich countries.[19] Increasingly, spillovers from developed countries may not be available to developing countries in the same ways or to the same extent.[20]

   Second, technologies that are applicable may not be as readily accessible because of increasing intellectual property protection of privately owned technologies (Wright and Pardey 2006) and, perhaps, more importantly, the expanding scope and enforcement of biosafety regulations. Third, those technologies that are applicable and available are likely to require more substantial local development and adaptation, calling for more sophisticated and more extensive forms of scientific R&D than in the past. The requirement for local adaptive research is also likely to be exacerbated as changes in global and local climate regimes add further to the need for adaptive responses to those changed agricultural production environments. Large areas in African agriculture seem

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[18] Alston et al. (2010) reviewed the prior literature. They also developed their own estimates using newly constructed U.S. state-level productivity over 1949-2002 and U.S. federal and state spending on agricultural R&D and extension over 1890-2002. Their preferred model had a peak lagged research impact at year 24 and a total lag length of 50 years.

[19] Developed countries have also benefited substantially from spillins of R&D done in or directed toward the developing world. Alston (2002) reviewed work by economists in quantifying these benefits.

[20] Decreasing spillover potential is caused by several related market and policy trends in developed countries. First, the types of technologies being developed may no longer be as readily applicable to developing countries as they were in the past. As previously noted, developed country R&D agendas have been reoriented away from productivity gains in food staples toward other aspects of agricultural production, such as environmental effects, food quality, and the medical, energy, and industrial uses of agricultural commodities. This growing divergence between developed-country research agendas and the priorities of developing countries implies fewer applicable technologies that would be candidates for adaptation to developing countries.

especially susceptible to the consequences of climate change (Lobell et al. 2008; FAO 2009; Müllera et al. 2011).[21]

4. *Economies of size, scale, and scope in agricultural R&D*. In evaluating the extent of underinvestment in agricultural R&D and potential means of increasing investment, it is important to consider the economies of size, scale, and scope in knowledge accumulation and dissemination. For instance, if technological spillovers continue to be fairly available and accessible, as they have been in the past, it might not make sense for small, poor, agrarian nations to spend their scarce intellectual and other capital resources in agricultural science. However, if spillins from developed countries decrease, developing countries will need to conduct more of their own research; but many nations may be too small to achieve an efficient scale in many, if any, of their R&D priority areas (e.g., Byerlee and Traxler 2001). In 2000, for example, 40 percent of the agricultural research agencies in sub-Saharan Africa employed fewer than five full-time-equivalent (fte) researchers in 2000; 93 percent of the region's agricultural R&D agencies employed fewer than 50 researchers (James, Pardey and Alston 2008).[22] Creative institutional innovations to collectively fund and efficiently conduct the research in ways that realize these scale and scope economies will be crucial.

R&D trends[23]

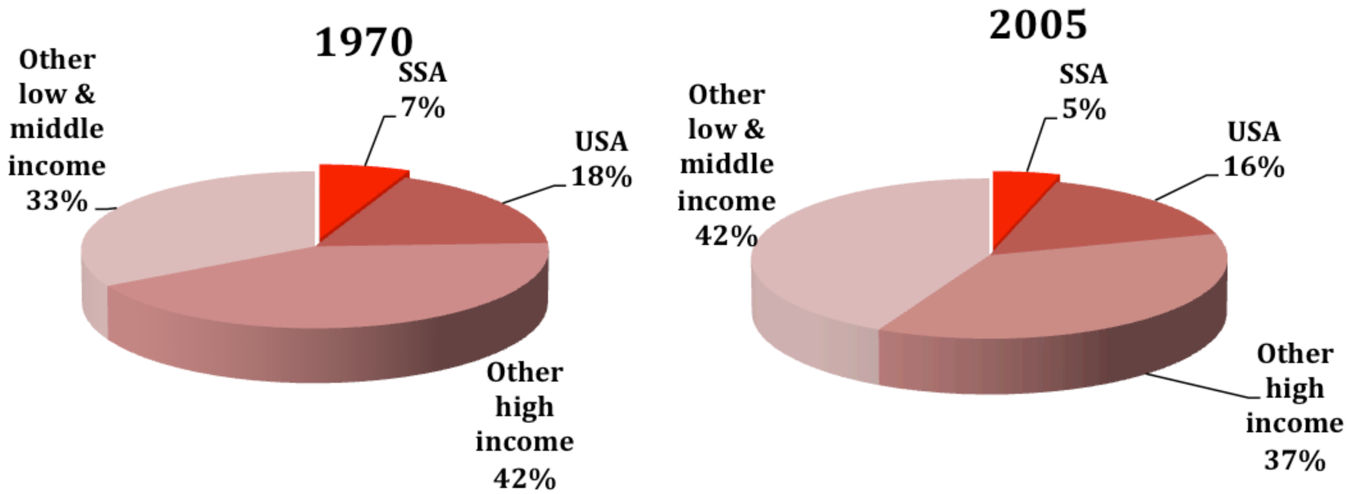
In light of the complex relationship linking agricultural R&D spending to productivity changes, an assessment of the state of, and potential for, innovation in African agriculture requires at least a long-run look (to deal with the reality of long lags) and a multi-country cum multi-continent look (to develop a sense of the spillover potentials). Figure 7 provides preliminary, new estimates of public agricultural R&D spending worldwide spanning a thirty-five year period and measured in 2005 international dollars. Pardey and Chan-Kang (2012) estimate that in 1970 the world spent $11.4 billion dollars on public agricultural R&D, which more than doubled to $28.7 billion by 2005. There was a substantial spatial shift in where this research was performed. In 1970, the high-income countries as a group (including the United States) accounted for 60 percent of the world's total. By 2005 that share had slipped to 53 percent. Although the low- and middle-income countries as a group gained market share, notably, sub-Saharan Africa lost ground. The region accounted for a smaller share of the world's spending in 2005 (4.8 percent) than it did in 1970 (6.6 percent). If spending by South Africa and Nigeria—the two largest agricultural economies in the region—were set aside, the rest-of-Africa accounted for just 2.8 percent of the world's agricultural R&D spending in 2005.

[21] An important caveat is that farmers can (and have) responded to all sorts of changes in the past, including what crops to grow where, and when. For example, Beddow (2012) graphically illustrated the capacity of corn producers in the United States to change both the location and timing of production in ways that have more than offset any overall climate warming effects over the past century or more.

[22] In fact, in 2000, one third of the public agencies in India and almost all the public agencies in the United States employed more than 100 fte researchers.

[23] The research and development estimates reported here draw in part from estimates made by Pardey and Chan-Kang (2012) are preliminary and subject to revision. The estimates exclude the Former Soviet Union and Eastern European countries due to lack of data.

Figure 7. Global public agricultural R&D spending, 1970 and 2005



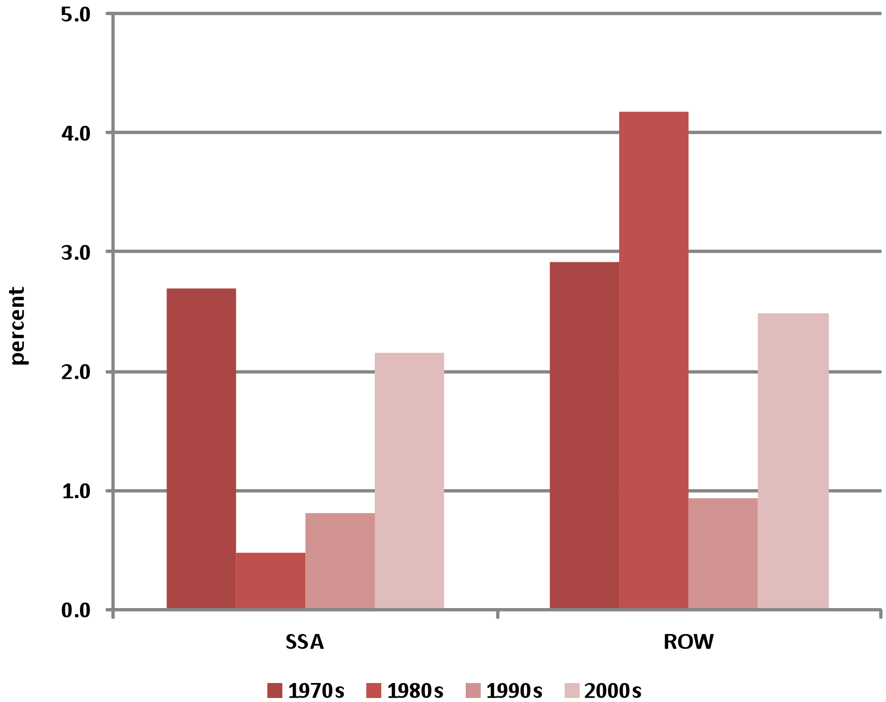
11.4 billion of 2005 PPP$** **28.7 billion of 2005 PPP$

Source: Pardey and Chan-King (2012, beta version)

Looking more carefully at the growth in constant-priced public R&D spending, Africa grew by 1.2 percent per year from 1970-2005 compared with 2.7 percent per year for the rest-of-the-world total. During the 1970s, African spending on public agricultural R&D grew by 2.7 percent per year, slowed substantially to 0.5 percent per year during the 1980s, and increased slightly to 0.8 percent per year during the 1990s (Figure 8). Spending growth rebounded during the first half of the 2000s to average 2.1 percent per year, but the recovery appears fragile and was not widespread. Over half of the increase in spending from 2000-2005 came from just two countries, Nigeria and Ethiopia (see also Beintema and Stads 2011).[24]

[24] Notably, 13 of the 33 African countries (i.e., 39 percent) increased their spending by less than 0.6 percent per year during the period 2000-2005. Thus a substantial share of the countries in the region saw virtually no growth in spending (including the regionally important South African system), and, after accounting for inflation, 17 countries spent less during the 2000s than in the 1990s.

Figure 8. Growth in public food and agricultural R&D spending, 1970-2005



Source: Pardey and Chan-Kang (2012, beta version). Annual growth rates are calculated using the least-squares regression method. 2000s represent 2000-2005.

It is the pattern of spending over the long haul that is critical for agricultural R&D, especially given the long gestation period for new crop varieties and livestock breeds, and the desirability of long-term employment assurances for scientists and other staff. Variability encourages an over-emphasis on short-term projects or on projects with short lags between investment and outcomes, and adoption. It also discourages specialization of scientists and other resources in areas of work where sustained funding may be uncertain, even when these areas have high pay-off potentials. Pardey, Roseboom and Beintema (1997) identified fluctuating and uncertain spending trends as being a major constraint for African agricultural research.[25] Using more recent data, (Beintema and Stads 2011, p. 27) reaffirmed that this problem still bedevils many of the agricultural research agencies in the region, particularly those that remain heavily reliant on fickle external (donor) sources of funding.

Another disturbing feature of the data is the dramatic slowdown in the growth of funding for the rest-of-world group (Figure 8). If China and India are set aside, Pardey and Chan-Kang (2012) estimate that rest-of-world grew by just 1.0 percent per year during the period 1990-2005. Moreover, spending in the high-income group slowed after the 1990s, and grew by only 1.7 percent per year the first half of the 2000s (versus 2.6 percent per year from 1970-2005). The productivity performance of the rich countries will bear the brunt of this slower growth in spending, but knowledge and innovation spillovers to Africa and the rest of the developing world

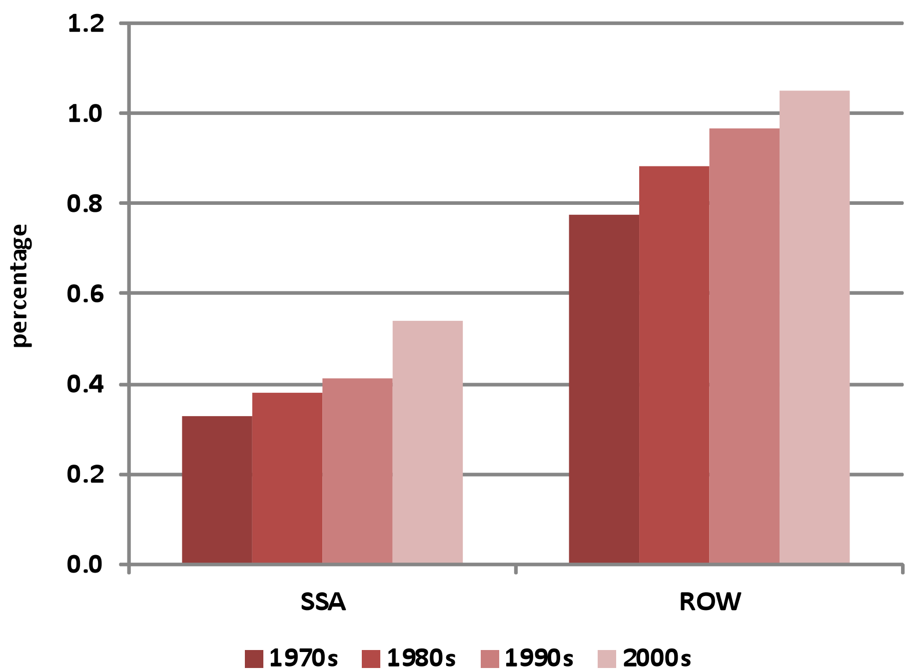
[25] See also Lipton (1989).

are also likely to be compromised, not least because rich countries still collectively conduct more than half the entire world's public agricultural R&D (and substantially more than half the world's private food and agricultural R&D).

Intensity of agricultural research

Countries with larger (smaller) agricultural economies are likely to invest more (less) in agricultural R&D simply due to a congruence effect (Pardey, Kang and Elliott 1989). For this reason, normalizing agricultural research expenditures with respect to the size of the agricultural economies they serve provides an indication of the intensity (distinct from amount) of research spending. The research intensity ratios summarized in Figure 9 show (weighted) averages by decades of the amount of public agricultural R&D spending relative to the corresponding agricultural GDPs (agGDP).

Figure 9. Intensity of public agricultural research spending, 1970-2005



Source: Pardey and Chan-Kang (2012, beta version). Data represent weighted average of country intensity ratios within each region. 2000s represent 2000-2005.

According to these estimates, during the 1970s African agriculture spent just 33 cents on public agricultural R&D for every $100 of agricultural output. Over the following decades this ratio rose modestly, so that 54 cents was spent on research for every $100 of agGDP in the 2000s (a research intensity ratio of 0.54). Notwithstanding this increase, the intensity of investment in African agricultural R&D remains substantially below the corresponding rest-of-world ratio (0.78 in the 1970s and 1.05 in the 2000s). As one might expect, it is also substantially below the rich-country average (2.7 in the 2000s), although above the intensity of investment in Asian agriculture which averaged 0.42 in the 2000s. Factoring in the private sector widens the Africa versus rest-of-world gap quite considerably. Beintema and Stads (2006, p. 26) estimated that in

2000, privately performed research represented just over 2 percent of the total (public and private) agricultural research conducted throughout sub-Saharan Africa (and two-thirds of that private research was performed in South Africa alone). Adding in private food and agricultural R&D raises the rich-country overall research intensity ratio for the 2000s to 5.5, almost 10 times the corresponding African ratio (Pardey and Chan-Kang 2012).[26]

African agricultural R&D (or perhaps more precisely, some countries within the region) has made some progress, but that progress is erratic and there remain persistent (and wide) investment gaps between Africa and the rest-of-the-world. These measures suggest the immensity of the challenge of playing catch-up in sub-Saharan Africa. The measures also underscore the need to transmit knowledge across borders and continents and to raise current amounts of funding for agricultural R&D while also developing the policy and infrastructure needed to accelerate the rate of knowledge creation and accumulation in Africa over the long haul. Developing local capacity to carry forward findings will yield a double dividend: increasing local innovative capacities while also enhancing the ability of local research agencies to tap discoveries made elsewhere.

Conclusion

The imperatives of African agricultural development, and the sheer scope, rural concentration, and dire outcomes of poverty and hunger in many African countries gives a sense of urgency to improving the production and poverty alleviating performance of the region's agriculture sector. A key to ramping up productivity growth in African agriculture will be increased, sustained, and, possibly, refocused investments in agricultural R&D and the rural infrastructure that is essential to economically link farmers to markets. The conundrum is that agricultural R&D, and the productivity gains that flow from those investments, typically take considerable time to realize their full effects. The politically expedient option seems to be to defer investments in agricultural innovation and rural infrastructure (in favor of other spending, including fertilizer and other subsidies) or skew those investments to politically more vocal urban constituents.

The legacies of such choices made in earlier decades—most notably almost two lost decades of agricultural R&D spending growth in the 1980s and 1990s—are now evident. While overall agricultural output growth in Africa during the past decade has been comparatively strong, the growth is from a low base and the evidence presented here suggests that this output growth has not been accompanied by a pervasive increase in agricultural productivity.[27] Absent broad-based growth in agricultural productivity it will be hard to generate and sustain increases in per capita production and per capita incomes, both of which will be required to efficiently support the increasingly urbanized economies throughout the region. While more and, especially, sustained funding for agricultural R&D is likely to yield sizable social payoffs, the more systematic use of evidenced-based approaches to retargeting the region's innovative effort could also maximize the development potential of these scarce research dollars.

[26] This is assuming the 2 percent private share reported by Beintema and Stads (2006) for 2000 is indicative of the private share for the first half of the 2000s.
[27] Notably, less than half the countries in sub-Saharan Africa had faster agricultural output growth in the 2000s compared with the previous decade.

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Core Literature on Agricultural Productivity and R&D

Alston, J.M.. 2002. Spillovers. *Australian Journal of Agricultural and Resource Economics* 46(3): 315–346

Presents and critically reviews the available evidence on interstate and international agricultural R&D spillovers. In studies of aggregate state or national agricultural productivity, interstate or international R&D spillovers might account for half or more of the total measured productivity growth. Similarly, results from studies of particular crop technologies indicate that international technology spillovers, and multinational impacts of technologies from international centers, were important elements in the total picture of agricultural development in the 20^{th} Century.

Alston, J.M., B.A. Babcock and P.G. Pardey, eds.. 2010. *The shifting patterns of agricultural production and productivity worldwide,* CARD-MATRIC on-line volume. Ames: Iowa State University.

This book reports a range of contemporary evidence regarding recent trends in agricultural productivity around the world. The fundamental purpose of the volume is to better understand the nature of the long-term growth in the supply of food and its principal determinants. The evidence is presented from two perspectives. One is from a general interest in the world food situation in the long run. The other is from an interest in the implications of U.S. and global productivity patterns for U.S. agriculture.

Alston, J.M., M.A. Andersen, J.S. James, and P.G. Pardey. 2010. *Persistence pays: U.S. agricultural productivity growth and the benefits from public R&D spending.* New York: Springer, 2010.

In this book the authors document and assess the evolving path of U.S. agriculture in the 20th century and the role of public R&D in that evolution. They provide a detailed quantitative assessment of the shifting patterns of production among the states and over time and of the public institutions and investments in agricultural R&D. Then, based on newly constructed sets of panel data, some of which span the entire 20th century and more, the authors present new econometric evidence linking state-specific agricultural productivity measures to federal and state government investments in agricultural research and extension. The results show that although the benefits from past public investments in agricultural research have been worth many times more than the costs, the time lags between R&D spending and its effects on productivity are longer than commonly found or assumed in the prior published work. Also, the spillover effects of R&D among states are important, such that the national net benefits from a state's agricultural research investments are much greater than own-state net benefits.

Alston, J.M., M. C. Marra, P.G. Pardey, and T.J. Wyatt. 2000. *A meta analysis of rates of return to agricultural R&D: Ex pede herculem?* Washington D.C.: IFPRI Research Report No 113.

This report provides a comprehensive (statistical) assessment of the entire body of published evidence from 1953-2000 on the returns to agricultural R&D. In doing so, it attempts to answer five key questions of interest to both researchers and policymakers, specifically: 1) Has the rate of return to agricultural R&D declined over time? 2) Do the returns to agricultural R&D differ internationally among regions of the world, or between national agricultural research systems and international centers? 3) Does the return to research vary according to its problematic focus, and how does the rate of return to environmental or natural resource research compare with more traditional agricultural production R&D? 4) Does the rate of return vary between basic and more applied research, or between research and extension? and 5) Is systematic bias built into the estimates from particular evaluation techniques and estimation details from other aspects of the analysis, or according to who does it?

Alston, J.M., G.W. Norton, and P.G. Pardey. 1995. *Science under scarcity: Principles and practice for agricultural research evaluation and priority setting*. Ithaca, NY: Cornell University Press (republished by CAB International 1998).

This book reviews, synthesizes and extends the economic methods used to evaluate and prioritize investments in agricultural research. In doing so it covers such methods as productivity measurement, economic surplus analysis, econometric techniques, mathematical programming procedures and scoring models. It discusses these practices in the context of scientific policy, describes their conceptual foundation, and explains how to do them.

Beintema, N. and G-J Stads. 2011. *African agricultural R&D in the new millennium: Progress for some, challenges for many*. IFPRI Food Policy Report. Washington, D.C.: International Food Policy Research Institute.

This report provides the most up-to-date data concerning investments in and staffing of agricultural R&D agencies throughout sub-Saharan Africa. It describes some of the key institutional realties of African agricultural R&D and the important challenges to improving innovation effort in the region. Additional agricultural R&D data for Africa and elsewhere in the world can be obtained on line at http://www.asti.cgiar.org/.

Hayami, Y. and V.W. Ruttan. 1971. *Agricultural development: An international perspective.* Baltimore: Johns Hopkins University Press (reprinted 1985).

This volume develops the analytical and empirical basis for the induced innovation hypothesis within the context of agriculture. The authors describe how differences in factor scarcity induce technical changes that are consistent with country’s resource endowments. The authors also extend the theory of induced technical change to encompass associated processes of induced institutional change.

Nin-Pratt, A. and B. Yu. 2008. *An updated look at the recovery of agricultural productivity in sub-Saharan Africa.* IFPRI Discussion Paper No. 00787, Washington D.C.: International Food Policy Research Institute.

This paper gives an overview of the existing evidence on African agricultural productivity growth and presents new evidence on the evolution of sub-Saharan Africa’s agricultural total factor productivity (TFP) over the past 40 years using a nonparametric Malmquist index. The authors identify a recovery in the performance of sub-Saharan Africa’s agriculture during the 1984–2003 period after a long period of poor performance and decline and discuss possible factors that gave rise to this apparent rebound in productivity growth.

Wood, S., K. Sebastian, and S.J. Scherr. 2000. *Pilot analysis of global ecosystems: Agroecosystems*. Washington, D.C.: World Resources Institute.

Agricultural production and productivity is heavily reliant on, and in turn has major implications for, ecosystem services. This report assembles and compares information already available on a global scale to show how human action has profoundly changed the extent, condition, and capacity of agroecosystems. Agriculture has expanded at the expense of grasslands and forests, engineering projects have altered the hydrological regime of most of the world's major rivers, settlement and other forms of development have converted habitats around the world's coastlines. Human activities have adversely altered the earth's most important biogeochemical cycles—the water, carbon, and nitrogen cycles—on which all life forms depend. While intensive management regimes and infrastructure development have contributed positively to providing some goods and services, such as food and fiber from forest plantations, the authors argue that they have also led to habitat fragmentation, pollution, and increased ecosystem vulnerability to pest attack, fires, and invasion by nonnative species. Information is often incomplete and the picture confused, but there are signs that the overall capacity of ecosystems to continue to produce many of the goods and services on which humanity depend is declining.