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

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Food Security and the Environment
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Stanford University
Deflated U.S Commodity Prices, 1924-2010 (CPI deflator)
Production and Productivity
Relativities and Trends
Global Structure of Production, 2007-2009 average

Composition of Crop Production

Livestock Share

Shares of value of production (1999-2001 PPP prices)
### Spatial Concentration of Production, 2007-09 average

#### World

![World Concentration Graph](image)

<table>
<thead>
<tr>
<th>Country</th>
<th>Cumulative Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>23.4</td>
</tr>
<tr>
<td>USA</td>
<td>34.0</td>
</tr>
<tr>
<td>India</td>
<td>44.4</td>
</tr>
<tr>
<td>FSU</td>
<td>50.0</td>
</tr>
<tr>
<td>Brazil</td>
<td>55.4</td>
</tr>
</tbody>
</table>

#### Sub-Saharan Africa (6% global VOP)

![Sub-Saharan Africa Concentration Graph](image)

<table>
<thead>
<tr>
<th>Country</th>
<th>Cumulative Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nigeria</td>
<td>23.8</td>
</tr>
<tr>
<td>Sth Africa</td>
<td>32.8</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>39.0</td>
</tr>
<tr>
<td>Sudan</td>
<td>44.9</td>
</tr>
<tr>
<td>Uganda</td>
<td>49.6</td>
</tr>
<tr>
<td>Tanzania</td>
<td>54.2</td>
</tr>
<tr>
<td>Kenya</td>
<td>58.7</td>
</tr>
</tbody>
</table>

Source: Pardey (in preparation)
Global Production Quantities, 1961-2009

Cereals 69%/4.7%

Roots and tubers 65.7%/27.8%

Maize 80.7%/6.2%

Rice 85.4%/2.5%

Soybeans 97.2%/0.7%

Wheat 77.7%/10.9%

Note: Percentages are top 10 country share / SSA share

Source: Pardey (in preparation)
Per Capita Production, 1961-2009

Rest of the World

Sub-Saharan Africa

Kg per person

Years

Crop

Corn

Rice

Wheat

Soybeans

Growth Rates, 1961-2009

<table>
<thead>
<tr>
<th></th>
<th>Popln</th>
<th>VOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSA</td>
<td>2.7</td>
<td>2.5</td>
</tr>
<tr>
<td>World</td>
<td>1.7</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Source: Pardey (in preparation)
Global and African Agricultural Productivity Trends -- What Do We (think we) Know?
Global Crop Yields Averages, 1920-2009 (beta)

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>0.27%</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.76%</td>
</tr>
<tr>
<td>Rice</td>
<td>0.27%</td>
</tr>
<tr>
<td>Soybeans</td>
<td>-0.30%</td>
</tr>
<tr>
<td>Barley</td>
<td>0.80%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>2.10%</td>
</tr>
<tr>
<td>Wheat</td>
<td>2.85%</td>
</tr>
<tr>
<td>Rice</td>
<td>2.19%</td>
</tr>
<tr>
<td>Soybeans</td>
<td>1.87%</td>
</tr>
<tr>
<td>Barley</td>
<td>2.21%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>1.78%</td>
</tr>
<tr>
<td>Wheat</td>
<td>1.24%</td>
</tr>
<tr>
<td>Rice</td>
<td>1.13%</td>
</tr>
<tr>
<td>Soybeans</td>
<td>1.02%</td>
</tr>
<tr>
<td>Barley</td>
<td>1.17%</td>
</tr>
</tbody>
</table>

Source: Pardey, Beddow, Xudong and Hurley (forthcoming)

Note: Global growth rates are weighted averages of ln differences
A Century of Global Crop Yield Distributions, 1900-2008 (beta)

Source: Pardey, Beddow, Rao and Hurley (forthcoming)
**Spatial Distribution of Crop Yields, 2000 (SPAM ver 3.0)**

**Panel a: Maize**

**Panel b: Wheat**

**Panel c: Soybean**

**Panel d: Rice**

<table>
<thead>
<tr>
<th></th>
<th>US</th>
<th>Sth Africa</th>
<th>Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maize</strong></td>
<td>32</td>
<td>1.7</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>Wheat</strong></td>
<td>28</td>
<td>1.4</td>
<td>3.6</td>
</tr>
<tr>
<td><strong>Soybean</strong></td>
<td>25</td>
<td>0.5</td>
<td>5.6</td>
</tr>
<tr>
<td><strong>Rice</strong></td>
<td>5.3</td>
<td>0</td>
<td>5.7</td>
</tr>
</tbody>
</table>

*High Yielding Area Shares*

Source: HarvestChoice (2010)
Global Land and Labor Productivity Patterns, 1961-2009
African Land and Labor Productivity Patterns, 1961-2009

Note: Values of antilog (natural) values shown on axes
Understanding Productivity
Sample of Regional and Global Productivity Studies

<table>
<thead>
<tr>
<th>Authors</th>
<th>Publication year</th>
<th>Data Year(s)</th>
<th>Countries</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antle</td>
<td>1983</td>
<td>1965</td>
<td>45</td>
<td>Econometric</td>
</tr>
<tr>
<td>Craig, Pardey &amp; Roseboom</td>
<td>1997</td>
<td>1961-1990</td>
<td>98</td>
<td>Econometric</td>
</tr>
<tr>
<td>Fuglie</td>
<td>2008</td>
<td>1961-2006</td>
<td>171</td>
<td>Growth accounting</td>
</tr>
<tr>
<td>O’Donnell</td>
<td>2010</td>
<td>1970-2001</td>
<td>88</td>
<td>Hicks–Moorsteen/DEA</td>
</tr>
</tbody>
</table>

Common Denominator – FAO and World Bank Data
FAO and World Bank Data

Land – count of arable, permanently pastured and cropped area

Labor – head count of economically active population in agriculture

Capital – count of tractors in use/on farm
  – percent of irrigated acres

Livestock – weighted head count of buffalo, cattle, pig, sheep, and goat

Materials – fertilizer (nitrogen, phosphate and potash and use in units of active ingredients)
Sources of Measured Productivity Growth

Productivity = \frac{Output}{Input}

1. Technical change (attributable to R&D)

2. Scale effects (gains from specialization and integration)

3. Intermediate or “inside” inputs

4. Mismeasured or omitted inputs (e.g., labor quality, land quality)

5. Natural (typically omitted) inputs
   - Weather (rainfall, temperature, day length, wind, incl. timing)
   - Soil attributes
   - Pests and diseases (“exputs”)
   - Location, location, location!
Changing Structure of US Farm Inputs and Technologies, 1900-2009

Note: Percentages are crop area shares for crop varieties, farm shares for all other entries

Source: Pardey et al. (in preparation)
Intermediate or Inside Inputs

Primary/External Inputs
- Land
- Labor
- Physical capital (machinery, buildings, fencing, etc)
- Biological capital (trees, vines, livestock, seeds)
- Herbicides, fungicides
- Chemical fertilizers
- Electricity
- Other Materials

Intermediate/Inside Inputs
- Farm-produced power
- Green/natural manures
- Feed
- Seeds
- Trees, vines
- Livestock

Marketed/Consumed Outputs
- Grains
- Feed (stover, hay)
- Fruits
- Vegetables, tubers
- Other crop
- Meat
- Milk
- Eggs
- Other Livestock
Intermediate or Inside Inputs – US Farm-produced Power

Land and Labor Shares used to Feed and Maintain Traction Horses and Mules, 1910-1945

Source: Hurley and Pardey (in preparation)

Farm Power, 1867-1970

Change from 1915-1945
1915: 25.7 mil. work animals, 25,000 tractors
1945: 11.9 mil. work animals, 2.4 mil. tractors
Freed up 61 million crop acres (66% reduction)
Freed up 2.3 million hrs labor (63% reduction)
### Structure of African Agricultural Inputs, various years

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>Number of Holders</th>
<th>Area per Holder</th>
<th>Percent of Farm Households Who Use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Improved / purchased</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Natural</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethiopia</td>
<td>2008/9</td>
<td>12.9</td>
<td>0.97</td>
<td>66.8</td>
</tr>
<tr>
<td>Ghana</td>
<td>2005</td>
<td>3.3</td>
<td>3.7</td>
<td>8</td>
</tr>
<tr>
<td>Kenya</td>
<td>2005</td>
<td>4.4</td>
<td>1.2</td>
<td>42</td>
</tr>
</tbody>
</table>

*Source: HarvestChoice (2011)*
Omitted or Mis-measured Inputs

\[ MFP = \frac{Q_i}{X_i} \quad \quad TFP = \frac{Q_i + Q_e}{X_i + X_e} = \frac{Q}{X} \]

where TFP is total factor productivity, MFP is multifactor productivity, \( i \) designates included inputs and outputs, and \( e \) designates excluded quantities.

Difference between growth in TFP and growth in MFP is

\[ d \ln TFP - d \ln MFP = q (d \ln Q - d \ln Q) - \chi (d \ln X_e - d \ln X_i) \]

Relative rates of growth of total and excluded outputs as a share of total outputs

excluded outputs as a share of total outputs

excluded inputs as a share of total inputs

Rate of growth of excluded minus included quantities
Mismeasured Land/Soil Services -- Effects on Maize Yields of Changes in Soil Fertility

Source: Koo (2011 forthcoming)
Exports -- U.S. Wheat Production Losses to Stem Rust, 1918-2010

<table>
<thead>
<tr>
<th>Period</th>
<th>Quantity</th>
<th>Share of Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>1918-1970</td>
<td>890,826</td>
<td>1.82</td>
</tr>
<tr>
<td>1970-2010</td>
<td>55,337</td>
<td>0.06</td>
</tr>
<tr>
<td>1918-2010</td>
<td>946,153</td>
<td>0.70</td>
</tr>
</tbody>
</table>
Spatial Dynamics of Agriculture -- U.S. Maize Production, 1880 and 2007

Source: Beddow (2011 forthcoming)
Productivity Slowdown?
### Global Crop Yield Growth Rates, 1961-2009

<table>
<thead>
<tr>
<th>Group</th>
<th>Maize 61-90</th>
<th>90-09</th>
<th>Wheat 61-90</th>
<th>90-09</th>
<th>Rice 61-90</th>
<th>90-09</th>
<th>Soybeans 61-90</th>
<th>90-09</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>1.34</td>
<td>1.71</td>
<td>2.41</td>
<td>0.91</td>
<td>1.31</td>
<td>1.03</td>
<td>1.46</td>
<td>0.74</td>
</tr>
<tr>
<td>Sub-saharan Africa</td>
<td>0.75</td>
<td>0.87</td>
<td>1.65</td>
<td>0.67</td>
<td>1.59</td>
<td>0.31</td>
<td>1.42</td>
<td>-0.32</td>
</tr>
<tr>
<td>Top 20 producers</td>
<td>2.22</td>
<td>2.05</td>
<td>2.65</td>
<td>1.06</td>
<td>1.72</td>
<td>1.59</td>
<td>1.92</td>
<td>1.21</td>
</tr>
<tr>
<td>Other Producers</td>
<td>1.20</td>
<td>1.65</td>
<td>2.36</td>
<td>0.87</td>
<td>1.22</td>
<td>0.91</td>
<td>1.32</td>
<td>0.59</td>
</tr>
</tbody>
</table>

Note: Growth rates are simple averages of year to year log differences.
# Share of Countries with Slower Yield Growth since 1990

<table>
<thead>
<tr>
<th>Grouping</th>
<th>Maize</th>
<th>Wheat</th>
<th>Rice</th>
<th>Soybeans</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All Countries</strong></td>
<td>49</td>
<td>73</td>
<td>57</td>
<td>59</td>
</tr>
<tr>
<td><strong>Top 10 Producers</strong></td>
<td>50</td>
<td>100</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td><strong>High Income</strong></td>
<td>61</td>
<td>88</td>
<td>71</td>
<td>67</td>
</tr>
<tr>
<td><strong>Sub-Saharan Africa</strong></td>
<td>44</td>
<td>65</td>
<td>58</td>
<td>65</td>
</tr>
</tbody>
</table>

*(percent)*

Note: Annual average growth during 1961-1990 vs 1990-2009
**Share of Countries with Slower Productivity Growth since 1990**

<table>
<thead>
<tr>
<th>Grouping</th>
<th>1990-2009+</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Land</strong></td>
</tr>
<tr>
<td>All Countries</td>
<td>53</td>
</tr>
<tr>
<td>SSA countries with growth rates &lt; world average</td>
<td>70</td>
</tr>
<tr>
<td>High Income</td>
<td>64</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>53</td>
</tr>
</tbody>
</table>

* Annual average growth during 1961-1990 vs 1990-2009

<table>
<thead>
<tr>
<th>Productivity Growth*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Land</strong></td>
</tr>
<tr>
<td>World</td>
</tr>
<tr>
<td>SSA countries with growth rates &lt; world average</td>
</tr>
</tbody>
</table>

* Annual average, 1961-2009
U.S. Multifactor Productivity, 1949-2007

InStePP Production Accounts

**Outputs**
- Crops 61
- Livestock (9)
- Miscellaneous (4)

**Inputs**
- Land (3)
  - Cropland, irrigated cropland, pasture and grassland
- Labor (32)
  - Family labor
  - Hired labor
- Operator labor (30)
  - Education: 0–7 years, 8 years, 1–3 years of high school, 4 years of high school, 1–3 years of college, 4 years or more of college
  - Age: 25–34, 35–44, 45–54, 55–64, or 65 or more years of age
- Capital (12)
  - Machinery (6)
    - Automobiles, combines, mowers and conditioners, pickers and balers, tractors, trucks
  - Biological capital (5)
    - Breeding cows, chickens, ewes, milking cows, sows
- Buildings
- Materials (11)
  - Electricity, purchased feed, fuel, hired machines, pesticides, nitrogen, phosphorous, potash, repairs, seeds, miscellaneous purchases
South African MFP Growth

Index, 1947-48 = 100

Source: Liebenberg and Pardey (2010)
Productivity and R&D
Illustrative Technology Development Lags

Hybrid Corn
- 1877: Best conducts first controlled crosses/hybrid vigor
- 1901: 59 years
- 1936: Vastly improved in-breeds led to shift to single-cross hybrids
- 1960: 95 percent of U.S. corn acreage in hybrids

Bt Corn
- 1901: Bacillus thuringiensis (BT) discovered in Japan (and 1911 in Germany)
- 1970: 96 years
- 1976: BT corn (corn borer protection) commercialized in U.S.
- 1980: Stacked with other traits (e.g., herbicide tolerance)
- 1996: U.S. patent issued to Monsanto for Mon810
- 2004: Regulatory approval in 20 countries

Roundup Ready Soybean
- 1970: Glyphosate shown to have herbicidal activity
- 1980: Early 1980s
- 1990 & 91: 26 years
- 1996: Roundup Ready Soybeans commercialized

Source: Pardey, Alston and Ruttan (2008) and Alston et al. (2010)
Global Public Agricultural R&D Trends, 1960-2005 (beta)

Source: Pardey and Chan-Kang (2011, beta version)
Public Food and Agricultural R&D Spending, 2005 (beta)

- **United States**: 15.8%
- **High-income (minus US)**: 36.8%
- **LAC**: 11.2%
- **Asia and Pacific (minus China & India)**: 6.5%
- **Sub-Saharan Africa**: 4.8%
- **India**: 5.3%
- **China**: 11.5%
- **Other**: 8.2%

**2005 total $28.7 billion (2005, PPP dollars)**

Source: Pardey and Chan-Kang (2011, beta version)
Growth in Food and Agricultural R&D Expenditures, 1960-2005 (beta)

“Global” Public Spending

OECD Countries

Source: Pardey and Chan-Kang (2011, beta version)

Note: Data represent simple average of country growth rates within each region. 2000s represent 2000-2005.

Slowing Growth in Spending

Declining Emphasis on Farm Productivity

Source: Pardey and Chan-Kang (2011)
Agricultural Research Intensity Ratios, 1970-2005 (beta)

Panel a: Public

Panel b: Public and Private

Source: Pardey and Chan-Kang (2011, beta version)

Note: Data represent weighted average of country intensity rations within each region. 2000s represent 2000-2005.
South African R&D and MFP Growth

Index, 1947-48 = 100

Source: Liebenberg and Pardey (2010 and 2011)
In Closing

- Large and persistent spatial differences in agricultural productivity
  - Levels
  - Paths (factor intensities)
  - Rates of growth
- African productivity levels generally lag ROW
- Large variation in productivity performance within Africa
- Compelling evidence of a slowdown in the rate of global agricultural productivity growth (substantial in some important instances)
- Slowdown especially evident in world’s richest countries, but fairly widespread in ROW
- Evidence mounting that a significant culprit for the slowdown is a reduction in the rate of growth of productivity-oriented R&D spending
- Agricultural transformation processes take considerable time, but have profound consequences
Per Capita Agricultural Output—Past, Present and Future?

Year 1900
$134 per capita

Year 2000
$241 per capita

U.S. MFP Growth Rates
1949-2007 1.78 ppy
1990-2007 1.18 ppy
Projected 0.52 ppy

Source: Pardey (in preparation)
Thanks!

Selected Sources


www.instepp.umn.edu

www.harvestchoice.org