The State of the Global Crop Innovation System

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Key Points

1. High rates of return to agricultural R&D
   - Implies persistent underinvestment—why is it so?

2. Shifting patterns of public support for R&D
   - High-income countries
     - Slowdown in spending growth
     - Diminishing share for on-farm productivity enhancement
     - A different pattern in Brazil, China, and India

3. Shifting productivity patterns
   - Productivity slowdown in high-income countries
   - A different pattern in Brazil, China, and India

4. Implications—institutional reform required?
   - Enhance rates of research investment, restore productivity growth, reduce pressure on natural resource stocks
Rates of return to agricultural R&D

Stylized Representation of Research Benefits and Costs

Gross annual benefits (dollars per year)

Year

R&D Lag

Adoption Process

Research Costs

Research Benefits
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Meta Evidence from Literature Prior to 2000


Key Points from the Meta-Analysis

- **Challenge:**
  - Which research, conducted by whom, and when was responsible for observed productivity growth?

- **Attribution Issues**
  - Long time lags in knowledge creation and adoption
  - Spatial spillovers among states and countries
  - What is the relevant counterfactual alternative?

- **Studies have tended to overstate rates of return as a result of attribution biases . . . but true returns are still very large**
**New Evidence**


J.M. Alston, M.A. Andersen, J.S. James, and P.G. Pardey

*Springer, January 2010*

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### Agricultural Technology Timelines

**Hybrid Corn**

- **1877**: Maize seeds & self-cultivated maize/hybrid vigor
- **1905-1912**: Shell developed correct understanding of interbreeding and cross-breeding
- **1917**: Iowa State Staff on began corn in breeding program
- **1933**: First commercial public hybrid of hybrid maize 933 developed by Iowa State University
- **1936**: Vertically improved in seeds 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 1902 in Germany
- **1986**: Cry1Ac gene sequence published
- **1992**: Yield loss insect protected corn event MON 810 identified by “gene gone”
- **1996**: FDA, USDA & EPA approve for field test
- **1997**: B t corn (corn herbicide) not commercialized in U.S.
- **1998**: Stacked with other traits (e.g. herbicide tolerance)
- **2004**: U.S. patent issued for MON 810
- **2008**: Regulatory approval in 20 countries

*Source: Alston et al. (2010).*
Share of acreage planted to different types of corn varieties—years to reach 80% adoption

Agricultural Technology Timelines

Roundup Ready Soybean

1970
Glyphosate shown to have herbicidal self-activity

1976
Roundup herbicide commercialized in U.S.

1980
Methi-8 cell-to-cell mechanism to infer glyphosate tolerance

Late 1980s
Several genes conferring glyphosate tolerance developed

1987
First soybean transformants on achieved

1990 & 91
Glyphosate-tolerant seeds evaluated

1996
Roundup Ready Soybean commercialized

Golden Rice

1992
Project init. asited by Syngenta

1999
Gm-cfr and transgenic starch introduced to improve rice to express beta-carotene

2001
Rice beta-carotene in agreement with Syngenta

2002
Gm-yab expressed in rice

2004
First Gm-yab trial in Louisiana

2005
Enhanced expression of beta-carotene

2007
Starch viability of rice attached

2012
Anti-crop commercialization of technology

Source: Alston et al. (2010).
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R&D Lags (United States)

Panel a: Varietal Adoption Lags

Panel b: Aggregate R&D-Productivity


The Tyranny of the Red Queen

- Crop varietal innovations masked by
  - Changing location of production => adaptive research
  - Co-evolving pests and diseases => maintenance research
  - The “Red Queen” effect

"Well, in our country," said Alice, still panting a little, "you'd generally get to somewhere else — if you run very fast for a long time, as we've been doing."

"A slow sort of country!" said the Queen. "Now, here, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!"

— Through the Looking Glass
### Marginal Returns to U.S. Public Agricultural R&E

<table>
<thead>
<tr>
<th>Returns to</th>
<th>Benefit Cost Ratio (3% real discount rate)</th>
<th>Real Internal Rate of Return</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Own-State</td>
<td>National</td>
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<tr>
<td><strong>State R&amp;E</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>48-State Average</td>
<td>21.0</td>
<td>32.1</td>
</tr>
<tr>
<td>48-State Minimum</td>
<td>2.4</td>
<td>9.9</td>
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<tr>
<td>48-State Maximum</td>
<td>57.8</td>
<td>69.2</td>
</tr>
<tr>
<td>USDA Research</td>
<td>17.5</td>
<td></td>
</tr>
</tbody>
</table>

*Benefit cost ratios seem very big... but the implied IRRs are comparatively modest reflecting the very long lags and other modeling details (improvements)*
U.S. science spending

U.S. Science Spending, 2008

Total Science

- Food and Agriculture: $9.6 billion, 2%
- Business: $289 billion, 73%
- Other: $16 billion, 4%

By Performer

- Government (USDA): $42 billion, 11%
- Academic (SAES): $37 billion, 13%
- Business: $18 billion, 46%
- Other: $16 billion, 4%

Source: NSB (2010), USDA, CRIS (various years), and Dehmer and Pardey (2011)

Billions of dollars (2005 prices)

Total

Private

Public

$9.6 billion (nominal dollars)

Percentage

Food processing share of private

59%

Private share of total agricultural R&D

46%

Source: Dehmer and Pardey (2011)


Average Annual Growth Rate

% per year

0.0

1.0

1.5

2.0

2.5

3.0

3.5

4.0

1950s & 1960s

1970s & 1980s

1990s & 2000s

Source: Pardey et al. (2011) with data from USDA, CRIS (various years)
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USDA Role in Funding SAES Research, 1970–2009

Federal share of SAES
NIFA cum CSREES share of SAES
NIFA cum CSREES share of total federal
USDA share of total federal

Source: Pardey et al. (2011) with data from USDA, CRIS (various years)

Farm Productivity Share of SAES Research, 1976-2009

percentage

Source: Pardey et al. (2011) with data from USDA, CRIS (various years)
Global science spending

Source: Pardey et al. (2011) with data from USDA, CRIS (various years)
Global Science Spending Landscape, 2000

Total Science

Food & Agricultural R&D

$782.7 billion

$37.5 billion

Note: Spending in 2005 prices
Source: NSB (2010), USDA, CRIS (various years), and Dehmer and Pardey (2011)

Food and Agricultural Research Intensity Ratios

Panel a: Public

Panel b: Public and Private

Source: Pardey and Pingali (2010).
Public Food and Agricultural Research Expenditures

Source: Pardey and Pingali (2010).

Productivity patterns
Sources . . .

The Shifting Patterns of Agricultural Production and Productivity Worldwide
March 2010 (CARD, Iowa State University, MATRIC e-book)
Julian Alston, Bruce Babcock, and Philip Pardey (editors)
- 23 authors, 15 chapters
- 5 chapters => global overview, general issues
- 10 country-specific chapters
  - Argentina
  - Australia and New Zealand
  - Canada
  - China
  - India
  - Indonesia
  - Former Soviet Union and Eastern Europe
  - South Africa
  - United Kingdom
  - United States

Sources . . .

Diverging Agricultural Productivity Paths—International Competitiveness and Food Security in the Long Run
(theme in Choices, Fall 2009)
Julian Alston and Philip Pardey (theme editors)
Six articles:
  - Theme overview
  - Global patterns
  - Canada
  - China
  - Former Soviet Union and Eastern Europe
  - United States
Main points

- Evidence of a significant pervasive slowdown in agricultural productivity growth since 1990 or thereabouts
- China is an important exception with faster growth reflecting institutional change and other factors
- The converse applies for FSU and Central European countries
- Similar patterns emerge using various measures
  - Commodity prices
  - Crop yields
  - Production per unit of land or labor
  - Multifactor productivity measures where available
    - Australia, Canada, United States, United Kingdom

Global Crop Yield Growth Rates, 1961-2007

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>World</td>
<td>2.20</td>
<td>2.95</td>
<td>2.19</td>
<td>1.79</td>
</tr>
<tr>
<td></td>
<td>1.77</td>
<td>0.52</td>
<td>0.96</td>
<td>1.08</td>
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<tr>
<td>High Income</td>
<td>2.34</td>
<td>2.47</td>
<td>1.07</td>
<td>1.14</td>
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<tr>
<td></td>
<td>1.48</td>
<td>0.06</td>
<td>0.54</td>
<td>0.02</td>
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<tr>
<td>Middle Income</td>
<td>2.41</td>
<td>3.23</td>
<td>2.54</td>
<td>3.21</td>
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<tr>
<td></td>
<td>2.12</td>
<td>0.85</td>
<td>0.81</td>
<td>2.08</td>
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<tr>
<td>Low Income</td>
<td>1.07</td>
<td>1.32</td>
<td>1.46</td>
<td>2.63</td>
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<tr>
<td></td>
<td>0.65</td>
<td>2.15</td>
<td>2.16</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Source: Alston, Beddow and Pardey (2010).
### Growth in Agricultural Land and Labor Productivity, 1961-2005

<table>
<thead>
<tr>
<th>Group</th>
<th>Land Productivity</th>
<th>Labor Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>World</strong></td>
<td>2.03</td>
<td>1.82</td>
</tr>
<tr>
<td>excl. China</td>
<td>1.90</td>
<td>1.19</td>
</tr>
<tr>
<td>excl. China &amp; USSR</td>
<td>1.91</td>
<td>1.57</td>
</tr>
<tr>
<td><strong>Latin America</strong></td>
<td>2.17</td>
<td>2.83</td>
</tr>
<tr>
<td>excl. China</td>
<td>2.56</td>
<td>3.01</td>
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<tr>
<td><strong>Asia</strong></td>
<td>2.45</td>
<td>1.83</td>
</tr>
<tr>
<td>excl. China</td>
<td>2.81</td>
<td>4.50</td>
</tr>
<tr>
<td><strong>Africa</strong></td>
<td>2.18</td>
<td>2.21</td>
</tr>
<tr>
<td><strong>Low Income Countries</strong></td>
<td>2.00</td>
<td>2.39</td>
</tr>
<tr>
<td><strong>Middle Income Countries</strong></td>
<td>2.35</td>
<td>2.30</td>
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<tr>
<td>excl. China</td>
<td>2.18</td>
<td>1.37</td>
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<tr>
<td><strong>High Income Countries</strong></td>
<td>1.61</td>
<td>0.72</td>
</tr>
<tr>
<td><strong>Top 20 Producers</strong></td>
<td>2.11</td>
<td>2.16</td>
</tr>
<tr>
<td>excl. China</td>
<td>1.98</td>
<td>1.38</td>
</tr>
<tr>
<td><strong>Other Producers</strong></td>
<td>1.74</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Source: Alston, Beddow and Pardey (2010).

1949-2002
Pre-1990
2.02% per year
Post-1990
0.97% per year

Real U.S. Commodity Prices, 1924-2008 (Deflator = CPI-U)

Index = 100 in 1924

Period | Commodity | Growth Rates, Percent per Year
---|---|---
1924-2005 | Maize | -1.08
1924-2005 | Wheat | -0.73
1924-2005 | Rice | -1.53
1924-2005 | Soybean | -1.17
1950-2005 | Maize | -2.61
1950-2005 | Wheat | -2.16
1950-2005 | Rice | -2.51
1950-2005 | Soybean | -1.56
1975-2005 | Maize | -3.93
1975-2005 | Wheat | -3.30
1975-2005 | Rice | -3.68
1975-2005 | Soybean | -2.59
1975-1990 | Maize | -4.45
1975-1990 | Wheat | -3.59
1975-1990 | Rice | -4.84
1975-1990 | Soybean | -2.89
1990-2005 | Maize | -3.22
1990-2005 | Wheat | -0.63
1990-2005 | Rice | -1.96
1990-2005 | Soybean | -2.28
2000-2005 | Maize | -2.04
2000-2005 | Wheat | 1.59
2000-2005 | Rice | 1.10
2000-2005 | Soybean | 1.31

60 percent decline since mid 1970s!
What will commodity prices do over the next 40 years?
A return to the rapid real declines of the 1970s and 1980s?
A continuation of the recent pattern?
What are the key determinants?

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U.S. Policy Options

- Reinvesting in agricultural R&D
  - Redirecting federal tax revenue to agricultural R&D
    - Priorities within the agricultural budget
      - nutrition vs farm subsidies vs R&D
  - Priorities within the agricultural budget
- Co-financing arrangements
  - Research levy with a public match
    - Farmers, input suppliers, post-farm processors, bio-energy and other industries that benefit from R&D
- Similar ideas may be relevant for Canada

Selected Sources


Thank You!

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