Global and U.S. Trends in Agricultural R&D in a Global Food Security Setting

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Long-run historical perspectives
Long-term World Population – 10,000 BC to 2150

- **10,000 BC**: 1-10 million
- **1880**: 1.5 billion
- **1930**: 2.07 billion
- **1960**: 3.02 billion
- **2010**: 6.8 billion
- **2050**: 8.9 billion
- **2150**: 9.75 billion

Growth Rates of Global Population, Agricultural Land Area, and Value of Agricultural Production, 1908-2008

Source: Pardey (2011)
World Population Projections to 2100
The Supply-Side Challenge

- **Farm Productivity**
  - To increase agricultural productivity fast enough to feed 9-10 billion people within the next 40 years, in the face of
    - competing demands for land and water
    - competing demands for biofuels
    - changing climate
    - co-evolving pests and diseases

- **Agricultural R&D**
  - To conduct enough of the right types of agricultural R&D and get the resulting innovations adopted soon enough to meet the farm productivity challenge
Today’s issues: investing in R&D and productivity
Key Points

1. High rates of return to agricultural R&D
   ➢ Implies persistent underinvestment—why is it so?
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   - 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 and China
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3. Shifting productivity patterns
   - Productivity slowdown in high-income countries
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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
Meta Evidence from Literature Prior to 2000

Mean: 82.1% per annum, real

1,821 observations
292 studies

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
New Evidence


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

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Challenges

– Spillovers
– Long R&D Lags
– Role of maintenance research
Illustrative Technology Development Lags

**Hybrid Corn**
- 1877: Beal conducts first controlled crosses/hybrid vigor
- 1901: Bacillus thuringiensis (Bt) discovered in Japan (and 1911 in Germany)
- 1917: James developed double cross-hybrid
- 1922: Iowa State station began corn in-breeding program
- 1933: First commercial planting of Hybrid Iowa 939 developed by Merle Jenkins
- 1936: First release of a widely popular double-cross hybrid developed at Purdue University
- 1960: Vastly improved in-breds 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)
- 1950s: Bt used as a control agent and registered
- 1986: Cry1Ab gene sequence published
- 1986: Cry1Ab cloned into root colonyizing Pseudomonas bacteria
- 1992: YieldGard insect protected corn event Mon810 produced by “gene gun”
- 1996: FDA, USDA & EPA approvals for YieldGuard
- 1997: Bt corn (corn borer protection) commercialized in U.S.
- 1998: Stacked with other traits (e.g. herbicide tolerance)
- 2004: U.S. patent issued to Monsanto for Mon810
- 2008: Regulatory approval in 20 countries
- 1970: Glyphosate shown to have herbicidal activity
- 1976: Roundup herbicide commercialized in U.S.
- 1980: Identification of 3 mechanisms to infer glyphosphate tolerance
- Late 1980s: Several genes encoding glyphosphate insensitivity isolated
- 1990 & 91: Glyphosphate tolerant seeds evaluated
- 1996: Roundup Ready Soybeans commercialized
- 1990 & 91: Glyphosphate tolerant seeds evaluated
- 1996: Roundup Ready Soybeans commercialized

Source: Alston, Pardey and Ruttan (2008) and Alston et al. (2010)
Share of acreage planted to different types of corn varieties—years to reach 80% adoption

Percentage

100

90

80

70

60

50

40

30

20

10

0


Hybrid corn

GE corn

19 years

13 yrs
Aggregate R&D-Productivity Lag

Source: Alston, Pardey and Ruttan (2008) ; and Alston et al. (2010)
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>
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<tr>
<th>Returns to</th>
<th>Benefit-Cost Ratio (3% real discount rate)</th>
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<td><strong>State R&amp;E</strong></td>
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<td>48-State Average</td>
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**USDA Research** | 17.5

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**Benefit cost ratios seem very big . . .**
## Marginal Returns to U.S. Public Agricultural R&E

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<th>Benefit-Cost Ratio (3% real discount rate)</th>
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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%
- Academic: $51 billion, 13%
- Government: $42 billion, 11%
- Other: $16 billion, 4%

Total Science: $398 billion

By Performer

- Government (USDA): $1.5 billion, 16%
- Academic (SAES): $3.7 billion, 39%
- Business: $4.4 billion, 46%
- Total Science: $398 billion
- Food and Agriculture: $9.6 billion, 2%

Source: Dehmer and Pardey (2011); Pardey and Chan-Kang (2011)

Billions of dollars (2005 prices)

$9.6 billion (nominal dollars)

Source: Dehmer and Pardey (2011)
Agricultural R&D Expenditures, 1950-2007

Billions of dollars (2000 prices)

- Total Ag R&D: 1.6 (1.1) to 4.2
- Public Ag R&D: 1.5 (1.0) to 3.8
- Private Ag R&D: 1.9 (1.4) to 4.7

Average Annual Real Growth (Percentage)
- 1951-1969
- post-1970
- post-1990

Graph shows the growth in agricultural R&D expenditures from 1950 to 2007, with separate lines for total, public, and private expenditures. The graph includes data on average annual real growth for different time periods.

Source: Dehmer and Pardey (2011)
USDA Role in Funding SAES Research

Source: Pardey et al. (2011) with data from USDA, CRIS (various years)
Farm Productivity Share of SAES Research

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

Total Science

- Agricultural R&D, 5%
- Other R&D, 95%

$782.7 billion

Food & Agricultural R&D

- Low+middle income public, 27%
- Other High income public (excl. U.S.), 11%
- Other High income public (excl. U.S.), 9%
- U.S. public, 2%
- U.S. private, 2%
- Low+middle income private, 2%

$37.5 billion

Note: Spending in 2005 prices
Source: Dehmer and Pardey (2011); Pardey and Chan-Kang (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

Average Annual Growth Rate

Source: Pardey and Pingali (2010).
Farm 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
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

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<td>2.95</td>
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*(percent per year)*

Source: Alston, Beddow and Pardey (2010).
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<td>1.48</td>
<td>2.47</td>
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<td>1.07</td>
<td>0.54</td>
<td>1.14</td>
<td>0.02</td>
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*Source: Alston, Beddow and Pardey (2010).*
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<td>0.54</td>
<td>1.14</td>
<td>0.02</td>
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<tr>
<td>Middle Income</td>
<td>2.41</td>
<td>2.12</td>
<td>3.23</td>
<td>0.85</td>
<td>2.54</td>
<td>0.81</td>
<td>3.21</td>
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<tr>
<td>Low Income</td>
<td>1.07</td>
<td>0.65</td>
<td>1.32</td>
<td>2.15</td>
<td>1.46</td>
<td>2.16</td>
<td>2.63</td>
<td>0.00</td>
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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></th>
<th>Labor Productivity</th>
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<tr>
<td>World</td>
<td>2.03</td>
<td>1.82</td>
<td>1.12</td>
<td>1.36</td>
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<tr>
<td>excl. China</td>
<td>1.90</td>
<td>1.19</td>
<td>1.21</td>
<td>0.42</td>
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<tr>
<td>excl. China &amp; USSR</td>
<td>1.91</td>
<td>1.57</td>
<td>1.13</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Source: Alston, Beddow and Pardey (2010).
U.S. agricultural productivity data

- Long-term project led by Phil Pardey
  - detailed state-specific data on
    - 74 categories of outputs
    - 58 categories of inputs
  - 48 contiguous states
  - long series (1949-2002)
  - soon to be released

- Currently updating to 2007

- MFP = Total Output / Total Input
U.S. Agricultural Productivity, 1949-2002

Index (1949=100)

Output Index


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

1990-2002

Legend:
- < 1.25
- 1.25 to 1.50
- 1.50 to 1.75
- 1.75 to 2.00
- > 2.00
U.S. Multifactor Productivity, 1910-2007

State MFP Growth Distributions

1949-1990

US = 2.02%pa

1990-2007

US = 1.18%pa

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

Index = 100 in 1924

Growth Rates, Percent per Year

<table>
<thead>
<tr>
<th>Period</th>
<th>Commodity</th>
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<tbody>
<tr>
<td></td>
<td>Maize</td>
</tr>
<tr>
<td>1924-2005</td>
<td>-1.08</td>
</tr>
<tr>
<td>1950-2005</td>
<td>-2.61</td>
</tr>
<tr>
<td>1975-1990</td>
<td>-4.45</td>
</tr>
<tr>
<td>1990-2005</td>
<td>-3.22</td>
</tr>
<tr>
<td>2000-2005</td>
<td>-2.04</td>
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</table>

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?

Policy Options

- **Do nothing**
  - Wasted opportunity (high rates of return)
  - Declining competitiveness (for most developed countries)
  - Worsening world food supply and demand balance
    - from the perspective of the world’s poor
    - in terms of implications for natural resource stocks

- **Reinvigorate public investments in agricultural R&D**
  - Enhance government commitment to agriculture
  - Shift priorities within the agriculture budget (e.g., R&D vs subsidies)

- **Encourage private investments in agricultural R&D**
  - Enhance IPRs (e.g., end-point royalties)
  - Strengthen co-financing arrangements and institutions (e.g., RDCs)
Selected Sources


Thank You!

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