Agricultural R&D, Productivity and Global Food Security

Philip Pardey
Department of Applied Economics, University of Minnesota

Paper presented at the 2011 NZARES Conference

Copyright by author(s). Readers may make copies of this document for non-commercial purposes only, provided that this copyright notice appears on all such copies.
Agricultural R&D, Productivity and Global Food Security

Philip G. Pardey

University of Minnesota and University of Adelaide

NZARES Annual Conference
Tahuna Conference Centre, Nelson
Thursday August 25, 2011
The world is currently in the midst of the greatest demographic upheaval in human history. Dramatic reductions in mortality, followed (but with a lag) by equally marked reductions in fertility, resulted in a doubling of world population between 1960 and 2000. A further increase of 2 to 4.5 billion is projected for the current half-century, with the increase concentrated in the world’s least developed countries. Despite alarmist predictions, historical increases in population have not been economically catastrophic. Moreover, changes in population age structure have opened the door to increased prosperity. Demographic changes have had and will continue to have profound repercussions for human well-being and progress, with some possibilities for mediating those repercussions through policy intervention.
Prices

The parched plains: wheat lands drought cuts crop, may boost prices of bread, food

Foreign Agriculture

Rising food prices curb aid to global poor

Why the high price of food

The Rising Costs of Food

The Economist

Food prices

The end of cheap food rising prices are a threat to many they also present the World with enormous opportunity

Hot Stock Celulas Genetica

Econ Cell Bulletproof technologies, urgent, representation, Street Focus

Food Prices Hit Record High, What's Next?

Food in Mexico

Centéotti’s pricier feast

The tortilla-makers cry wolf

GALLERIES of blood were spilled by the Ants to appease Centéotti, the god of maize. Now someone must have upset two: rising prices could force the price of tortillas up by 50%, the makers of the corn pancakes warned last month. That matters: maize
A Century of Global Production
Global Production, Population & Area Growth, 1908-2008

Source: Pardey (2011)
Global Crop Production (per capita), 1908-2008

Source: Pardey (2011)
Spatial Concentration of Global Agricultural Production, 2006-08 average

World Value of Production

Maize 2008
1 United States 37.2
2 China 20.1
3 Brazil 7.1
4 Mexico 2.9
5 Argentina 2.7
Top 5 total 70.0
Top 10 total 79.2

Wheat 2008
1 China 16.5
2 India 11.5
3 United States 10.0
4 Russia 9.3
5 France 5.7
Top 5 total 52.9
Top 10 total 70.9

Rice 2008
1 China 28.2
2 India 21.6
3 Indonesia 8.8
4 Bangladesh 6.8
5 Viet Nam 5.6
Top 5 total 71.1
Top 10 total 86.0

Source: Pardey (2011)
Global Value of Field Crops Production, 1908-2008

Crops included (15 field crops)
- Barley
- Buckwheat
- Cassava
- Maize
- Millet
- Oats
- Potatoes
- Rice
- Rye
- Sorghum
- Soybean
- Sugarbeet
- Sugarcane
- Sweet potatoes
- Wheat

Source: Pardey (2011)
Global Productivity in the Long Run
Spatial Distribution of Crop Yields, 2000 (SPAM ver 3.0)

Panel a: Maize

Panel b: Wheat

Panel c: Soybean

Panel d: Rice

Share of World’s High-Yielding Area

<table>
<thead>
<tr>
<th></th>
<th>US</th>
<th>Africa</th>
<th>Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>32</td>
<td>2.5</td>
<td>1.6</td>
</tr>
<tr>
<td>Wheat</td>
<td>28</td>
<td>3.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Soybean</td>
<td>25</td>
<td>5.6</td>
<td>2.1</td>
</tr>
<tr>
<td>Rice</td>
<td>5.3</td>
<td>5.7</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Source: HarvestChoice (2010)
A Century of Global Crop Yield Distributions

Source: Pardey, Beddow, Rao and Hurley (forthcoming)
Global Land and Labor Productivity Patterns, 1961-2008
Is Agricultural Productivity Growth Slowing?
Global Crop Yields Averages, 1890-2008

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Commodity</td>
<td>Rate</td>
<td>Commodity</td>
</tr>
<tr>
<td>Maize</td>
<td>0.69%</td>
<td></td>
<td>Maize</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.99%</td>
<td></td>
<td>Wheat</td>
</tr>
<tr>
<td>Rice</td>
<td>0.49%</td>
<td></td>
<td>Rice</td>
</tr>
</tbody>
</table>

Source: Pardey, Beddow, Xudong and Hurley (forthcoming)
### Partial Factor Productivity Growth, 1961-1990 vs 1990-2008

<table>
<thead>
<tr>
<th>Groupings</th>
<th>Land Productivity</th>
<th>Labor Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1961-90</td>
<td>1990-08</td>
</tr>
<tr>
<td>World (simple av.)</td>
<td>1.78</td>
<td>1.55</td>
</tr>
<tr>
<td>World minus China</td>
<td>1.79</td>
<td>1.53</td>
</tr>
<tr>
<td>80% (N = 22)</td>
<td>1.98</td>
<td>2.21</td>
</tr>
<tr>
<td>80% minus China</td>
<td>1.96</td>
<td>1.88</td>
</tr>
<tr>
<td>&lt; 80% (N = 158)</td>
<td>1.82</td>
<td>1.17</td>
</tr>
</tbody>
</table>

*Percent per year*
Views on U.S. Agricultural Productivity Growth Rates

Ball, Wang and Nehring (2010) reported that “... statistical analysis of the [USDA] data does not provide evidence of a longrun productivity slowdown.”

Alston, Anderson, James and Pardey (2010a, pp. 120–121) concluded “There can be little doubt that the InSTePP MFP data exhibit evidence of a slowdown in multifactor productivity growth in the period 1990–2002 compared with the previous [1949–1990] period.”
U.S. Multifactor Productivity, 1910-2007

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

State MFP Growth Distributions

1949-1990
- US = 2.02%pa

1990-2007
- US = 1.18%pa
U.S. Multifactor Productivity, 1910-2007

State MFP Growth Distributions

1949-1990

US = 2.02%pa

1990-2007

US = 1.18%pa

US MFP Trend Rolling Regression Results (15 year interval)

Source: Alston, Anderson, James and Pardey (2011 forthcoming)

Source: Nossal et al. (2009)
On the Desirability of Zero Productivity Growth!

“Since we know little about the causes of productivity increase, the indicated importance of this element may be taken to be some sort of measure of our ignorance about the causes of economic growth in the United States.”

Abramovitz (AER 1956, pp. 5-23)

In an idea he attributed to Zvi Griliches, Schultz argued that the economically ideal output-to-input ratio would stay at or close to one, the notion being that “… the closer we come to a one-to-one relationship in our formulation, the more complete would be our (economic) explanation [of the sources of output growth].”

Schultz (1956, p.758)
“Sources” of Measured Productivity Growth

Productivity = \frac{\text{Output}}{\text{Input}}

- Technical change (attributable to R&D)
- Scale effects (gains from specialization and integration)
- Mismeasured input growth (e.g., labor quality, land quality)
- Omitted input
  - Biological inputs
  - Energy, chemicals etc. in LDCs
- Natural inputs
  - Weather (rainfall, temperature, day length, wind, incl. timing)
  - Soil attributes
  - Pests and diseases (exputs)
Changing Location of Agriculture

Panel a: Cropland Extent, 1700

Panel b: Cropland Extent, 2000

Panel c: Movement of Regional Cropland Centroids, 1700 – 2000

Source: Beddow, Pardey, Koo and Wood (2010)
U.S. Maize Production, 1880 and 2007

Source: Beddow (2011 forthcoming)
R&D-Productivity Relationships
Illustrative Technology Development Lags

Source: Alston, Pardey and Ruttan (2008) and Alston et al. (2010)
U.S. Maize Technology Adoption Lags

Source: Beddow (2011 forthcoming)
Aggregate R&D-Productivity Lag

![Graph showing the relationship between R&D and productivity with a lag of 5 years. The graph includes two curves labeled 'Trapezoidal' and 'Gamma'. The lag weight is shown on the y-axis, ranging from 0.00 to 0.10, and the year is shown on the x-axis, ranging from 0 to 50.]  

Source: Alston, Pardey and Ruttan (2008) and Alston et al. (2010)
What’s Been Happening to Food and Agricultural R&D Investments Globally?
Global Science Spending Landscape, 2000

**Total Science**

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

**Food & Agricultural R&D**

- U.S. public, 11%
- U.S. private, 9%
- Low+middle income public (excl. U.S.), 27%
- Low+middle income private, 2%
- Other High income public (excl. U.S.), 24%
- Other High income private (excl. U.S.), 2%

2007 OECD Total = $30.7 billion

New Zealand share

- Public: 1.4%
- Private: 0.7%
- Total: 1.1%

$782.7 billion

$37.8 billion

Note: Spending in 2005 prices

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

“Global” Public Spending

OECD Countries

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

**Slowing Growth in Spending**

- **Percent per year**
  - 1950s – 1960s: 3.6 %py
  - 1970s – 1980s: 1.8 %py
  - 1990s – 2000s: 0.9 %py

**Declining Emphasis on Farm Productivity**

- **Percent**
Food and Agricultural Research Intensity Ratios

Panel a: Public

Panel b: Public and Private

Source: Pardey and Chan-Kang (2011, beta version)
R&D Shares, 1973-2007 (high-income countries)

Source: Pardey and Chan-Kang (2011, beta version)
New Evidence on the Payoffs to Investing in Agricultural R&D

What are the estimated rates?

“Gilding the Lily” – Are they believable?
Meta Evidence on the Returns to Agricultural Research

Prior to 2000 (1,819 obs)
Post 2000 (410 obs)

Aggregate

1958-2010 (2,229 obs)

US Evidence on Rates of Return to Research

“Focusing on the contribution of productivity-oriented agricultural research undertaken by the main U.S. public agricultural research institutions—SAESs, VMCs, ARS, and ERS—to agricultural productivity in the 48 contiguous states, including spillover effects to other states in the same geoclimatic region, during 1970–2004, the marginal real rate of return is approximately 50% (Huffman 2010: Huffman and Evenson 2006a,b).”

Huffman, Norton and Tweeten (March 2011)
If 50% per Year Was the Right Answer

Terminal value of a dollar invested for

- 35 years is $1.5 billion
- 50 years is $637.6 billion

Terminal value of $4 billion invested in 2005

- 35 years (year 2040) is $5,824 trillion

>100 times the projected size of the US economy ($42 trillion)*
>10 times projected global GDP ($307 trillion)*

* Fogel (2007)
## Benefit-Cost vs Real Internal Rates of Return, New Evidence

<table>
<thead>
<tr>
<th>Returns to</th>
<th>Benefit-Cost Ratio (3% real discount rate)</th>
<th>Conventional Real Internal Rate of Return</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Own-State</td>
<td>National</td>
</tr>
<tr>
<td><strong>State R&amp;E</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>48-State Average</td>
<td>21</td>
<td>32.1</td>
</tr>
<tr>
<td>48-State Minimum</td>
<td>2.4</td>
<td>9.9</td>
</tr>
<tr>
<td>48-State Maximum</td>
<td>57.8</td>
<td>69.2</td>
</tr>
<tr>
<td><strong>USDA Research</strong></td>
<td>17.5</td>
<td></td>
</tr>
</tbody>
</table>

Benefit cost ratios seem very big . . . but the implied IRRs are comparatively modest compared with prior estimates, reflecting the very long lags and other modeling details (improvements).
Recalibrating the Rates of Return

- Conventional internal rates of return implicitly assume that the flow of benefits can be reinvested by the beneficiaries (say farmers or food consumers) at the same rate as the investment being evaluated.

- A modified internal rate of return assumes the stream of benefits is reinvested by the beneficiaries at some external rate of return, $r$, which could be different from the rate for the project being evaluated.

<table>
<thead>
<tr>
<th></th>
<th>Internal Rate of Return</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
</tr>
<tr>
<td></td>
<td>percent per year</td>
</tr>
<tr>
<td>State Average</td>
<td>18.9</td>
</tr>
<tr>
<td>National</td>
<td>22.7</td>
</tr>
</tbody>
</table>
Key Points from Meta-Analyses and Other Recent Work

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 within and among countries
- What is the relevant counterfactual alternative?

Estimation Issues

- Errors in (implicit) assumptions about reinvestment rates

Bottom Line

Studies have tended to overstate rates of return as a result of attribution biases and estimation problems . . . but true returns are still very large
The Tyranny of the Red Queen

- Productivity effects of (many) agricultural innovations confounded by
  - Changing location of production => adaptive research
  - Co-evolving pests and diseases and climate change effects => 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
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

Projected

Year 2000
$407

$316

$240

Projected
Thanks!

Selected Sources


www.instepp.umn.edu

www.harvestchoice.org
Food and Agricultural Research Intensity Ratios, 1970-2007

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

1. High rates of return to agricultural R&D
   • Implies persistent underinvestment

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 China, for example

3. Shifting productivity patterns
   • Productivity slowdown in high-income countries
   • A different pattern in China

4. Implications—institutional reform required?
   • Enhance rates of research investment, restore productivity growth, reduce pressure on natural resource stocks
Global Crop Production (per capita), 1908-2008

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Rate</th>
<th>Commodity</th>
<th>Rate</th>
<th>Commodity</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>0.07</td>
<td>Maize</td>
<td>0.48</td>
<td>Maize</td>
<td>1.22</td>
</tr>
<tr>
<td>Wheat</td>
<td>1.21</td>
<td>Wheat</td>
<td>0.56</td>
<td>Wheat</td>
<td>0.72</td>
</tr>
<tr>
<td>Rice</td>
<td>1.91</td>
<td>Rice</td>
<td>0.47</td>
<td>Rice</td>
<td>0.83</td>
</tr>
<tr>
<td>Soybeans</td>
<td>n.a.</td>
<td>Soybeans</td>
<td>4.07</td>
<td>Soybeans</td>
<td>3.12</td>
</tr>
</tbody>
</table>

Source: Pardey (2011)
Agricultural R&D Intensities vs Agricultural Area Extent, 2007

The graph illustrates the comparison between total agricultural R&D (AgR&D) intensities and agricultural area extent across different countries in 2007. The y-axis represents the total AgR&D per 100$ of total AgGDP, while the x-axis shows the agricultural land per 100$ of total AgR&D spending. The data points are grouped by countries, each with distinct markers and lines to connect them. Key countries highlighted include Belgium, Denmark, Switzerland, UK, Japan, Norway, USA, and Australia.
Food and Agricultural R&D Share in Total R&D

Note: Low and middle income group excludes Eastern Europe and countries that were part of the former USSR

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