Agricultural Productivity and Natural Resource Endowments

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The National Academies workshop
A Sustainability Challenge: Food Security for All, May 2, 2011
Venable LLP Conference Center, Washington D.C.
Critical Questions

• What are the *past and prospective rates* of agricultural productivity growth?
  • Is growth slowing, stagnating, or increasing?
  • Where in the world is this happening (at what scale)?
  • What commodities are performing better than others?

• What is the (past and prospective) *relative rates* of growth of productivity (supply) vs demand
Critical Questions (contd).

• How has, and likely will, the *endowment* of natural resources change over time?
  • within and outside the extent of agriculture

• What is the link between
  • the nature, size, and location of natural resource endowments and the flows of services from those natural resources, and
  • the flow of services and agricultural productivity (*and vice versa*)
Put another way, thanks to the agricultural productivity increases made possible through research and new technology development since 1990, an area greater than all the land in the 26 states east of the Mississippi River, has been spared for other uses.

Imagine the environmental disaster that would have occurred if hundreds of millions of environmentally fragile acres, not suited to farming, had been ploughed up and brought into production. Think of the soil erosion, loss of forests and grasslands, and biodiversity, and extinction of wildlife species that would have ensued!

Norman Borlaug, Foreword

*Persistence Pays* 2001
Critical Indicators

• **What is produced?**
  • Crop and livestock choice (variety and breed)

• **Where is it produced?**
  • Location, location, location

• **How is it produced?**
  • Input composition and intensity
  • “Intensive” vs “extensive”
  • Continuous cropping vs rotation vs intercropped
  • Crop-livestock interactions

  • Land, labor
  • Capital, materials
  • Farm produced (seed, feed, traction)
  • Natural inputs
ECON 101 – Measures of Productivity

TFP (total factor productivity) = \( \frac{Q}{X} \)

MFP (multi-factor productivity) = \( \frac{Q_i}{X_i} \quad i = \text{included outputs and inputs} \)

\( q_e = \frac{Q_e}{Q} \) (excluded outputs as a share of total outputs)

\( x_e = \frac{X_e}{X} \) (excluded inputs as a share of total inputs)

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

Difference between growth in TFP and growth in MFP

\[ d \ln TFP - d \ln MFP = q_e \left( d \ln Q_e - d \ln Q_i \right) - x_e \left( d \ln X_e - d \ln X_i \right) \]
Natural Inputs

• Key to the nexus between productivity and environmental endowments and flows
  • Weather (rainfall, sunlight, day length, wind)
  • Terrain (slope, elevation)
  • Soil (type, depth, organic and nutrient content)
  • Pests and diseases (Exputs)

All these natural inputs vary across time and space
Getting the Temporal Calibration Right

R&D → Technical Change → Productivity Change

(i.e., changes the technical relationship between inputs and outputs)
Aggregate R&D Spending - Productivity Lag

Source: Alston, Pardey and Ruttan (2008) and Alston et al. (2010)
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)
- 1950s: Bt used as a control agent and registered
- 1986: Cry1Ab gene sequence published
- 1986: Cry1Ab cloned into root colonizing 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

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

Source: Beddow (2011 forthcoming)
Some Indications of (Global) Productivity Patterns
Global Crop Yields Averages, 1920-2008 (Beta version)

<table>
<thead>
<tr>
<th>Commodity</th>
<th>1920-1960 Rate</th>
<th>1960-1990 Rate</th>
<th>1990-2008 Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>0.69%</td>
<td>1.73%</td>
<td>1.78%</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.99%</td>
<td>2.57%</td>
<td>0.97%</td>
</tr>
<tr>
<td>Rice</td>
<td>0.49%</td>
<td>2.19%</td>
<td>1.07%</td>
</tr>
</tbody>
</table>

Source: Pardey, Beddow, Xudong and Hurley (forthcoming)
A Century of Global Crop Yield Distributions (Beta version)

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

<table>
<thead>
<tr>
<th>Groupings</th>
<th>Land Productivity</th>
<th></th>
<th>Labor Productivity</th>
<th></th>
</tr>
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<tbody>
<tr>
<td></td>
<td>1961-90</td>
<td>1990-08</td>
<td>Difference</td>
<td>1961-90</td>
</tr>
<tr>
<td>World (simple av.)</td>
<td>1.78</td>
<td>1.55</td>
<td>-0.23</td>
<td>1.74</td>
</tr>
<tr>
<td>World</td>
<td>1.95</td>
<td>2.01</td>
<td>0.06</td>
<td>0.92</td>
</tr>
<tr>
<td>World minus China</td>
<td>1.79</td>
<td>1.53</td>
<td>-0.26</td>
<td>1.09</td>
</tr>
<tr>
<td>80% (N = 22)</td>
<td>1.98</td>
<td>2.21</td>
<td>0.23</td>
<td>0.97</td>
</tr>
<tr>
<td>80% minus China</td>
<td>1.96</td>
<td>1.88</td>
<td>-0.08</td>
<td>2.68</td>
</tr>
<tr>
<td>&lt; 80% (N= 158)</td>
<td>1.82</td>
<td>1.17</td>
<td>-0.64</td>
<td>1.11</td>
</tr>
</tbody>
</table>

**Percent per year**

*Source: Pardey (forthcoming)*
Global Slowdown in Multifactor Productivity Growth?

“I see no evidence of a general slowdown in sector-wide agricultural TFP [growth]. At least through 2006. If anything, the growth rate in agricultural TFP accelerated in recent decades....

Despite this generally optimistic conclusion, it is also clear that agricultural productivity growth has been very uneven... TFP growth may in fact be slowing in developed countries while accelerating in developing countries.”

Fuglie (2008, p. 440)
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>
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</thead>
<tbody>
<tr>
<td>Antle</td>
<td>1983</td>
<td>1965</td>
<td>45</td>
<td>Econometric</td>
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<tr>
<td>Block</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Craig, Pardey &amp; Roseboom</td>
<td>1997</td>
<td>1981-1990</td>
<td>98</td>
<td>Econometric</td>
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<td>Fuglie</td>
<td>2008</td>
<td>1961-2006</td>
<td>171</td>
<td>Growth accounting</td>
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<td>O’Donnell</td>
<td>2010</td>
<td>1970-2001</td>
<td>88</td>
<td>Hicks–Moorsteen/DEA</td>
</tr>
</tbody>
</table>
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)

### Fuglie Factor Weights

<table>
<thead>
<tr>
<th></th>
<th>Developing</th>
<th>World</th>
<th>U.S.</th>
<th>InSTePP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agg. Input</strong></td>
<td>-0.22</td>
<td>0.07</td>
<td>0.54</td>
<td>-0.07</td>
</tr>
<tr>
<td><strong>MFP</strong></td>
<td>1.94</td>
<td>1.65</td>
<td>1.18</td>
<td>1.73</td>
</tr>
</tbody>
</table>

*(percent per year)*

Source: Pardey (forthcoming)
U.S. Multifactor Productivity, 1949-2007

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
Some Big (Largely) Unknowns

• The Location of Production

• The Spatial Dynamics of Agriculture

• The Prevalence (and consequences) of Pests and Diseases
Spatial Distribution of Crop Yields, 2000 (SPAM ver 3.0)

Panel a: Maize

Panel d: Rice

Panel c: Soybean

Panel b: Wheat

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

Share of World’s High-Yielding Area

Yield (decile)

Source: HarvestChoice (2010)
Which cropland extent?
Global Value of Field Crops Production, 1908-2008 (beta)

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

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

World Value of Production

<table>
<thead>
<tr>
<th>Country</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>22.5</td>
</tr>
<tr>
<td>USA</td>
<td>33.3</td>
</tr>
<tr>
<td>India</td>
<td>43.8</td>
</tr>
<tr>
<td>FSU</td>
<td>49.4</td>
</tr>
<tr>
<td>Brazil</td>
<td>54.9</td>
</tr>
</tbody>
</table>

Cumulative

Maize 2008

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>United States</td>
<td>37.2</td>
</tr>
<tr>
<td>2</td>
<td>China</td>
<td>20.1</td>
</tr>
<tr>
<td>3</td>
<td>Brazil</td>
<td>7.1</td>
</tr>
<tr>
<td>4</td>
<td>Mexico</td>
<td>2.9</td>
</tr>
<tr>
<td>5</td>
<td>Argentina</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Top 5 total 70.0

Wheat 2008

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>China</td>
<td>16.5</td>
</tr>
<tr>
<td>2</td>
<td>India</td>
<td>11.5</td>
</tr>
<tr>
<td>3</td>
<td>United States</td>
<td>10.0</td>
</tr>
<tr>
<td>4</td>
<td>Russia</td>
<td>9.3</td>
</tr>
<tr>
<td>5</td>
<td>France</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Top 5 total 52.9

dir

Rice 2008

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>Share (%)</th>
</tr>
</thead>
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<td>1</td>
<td>China</td>
<td>28.2</td>
</tr>
<tr>
<td>2</td>
<td>India</td>
<td>21.6</td>
</tr>
<tr>
<td>3</td>
<td>Indonesia</td>
<td>8.8</td>
</tr>
<tr>
<td>4</td>
<td>Bangladesh</td>
<td>6.8</td>
</tr>
<tr>
<td>5</td>
<td>Viet Nam</td>
<td>5.6</td>
</tr>
</tbody>
</table>

Top 5 total 71.1

dir

dir

dir

Source: Pardey (forthcoming)
Spatial Variation in Abiotic Productivity Constraints

- Steeplands
- Drylands
- Poorly drained Soils
- Low Nutrient Capital Soils

Global Probability of Occurrence of Wheat Rust (pre-release version)

*Puccinia striiformis* (Stripe Rust)

*Puccinia triticina* (Leaf Rust)

*Puccinia graminis* (Stem Rust)

Source: Pardey et al. (2011 forthcoming)
Crop Disease – Stem Rust Example

Fig. 4.1. Percentage loss in wheat yield caused by stem rust from 1918 to 1997 in northern, central, and southern regions of the Great Plains of the United States (2,10).

KS& ND  20.4 MMT ~ 100% Oz output
Final Thoughts

“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.”

Abbrevovitz (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)
Final Thoughts

Agricultural economists and other social scientists tend to take data as facts. The problem is the data are not facts. Facts are what is really there. Data are quantitative representation of facts, which statistical workers and economists concoct.

I call the study of how primary statistical information is made into economic data “factology.” The neglect of factology risks scientific ruin.

The bottom line is, for data producers, that full disclosure of procedures and labeling of data series are essential; and, for data users, be careful and investigate the data before using them.

Bruce Gardner (1992, AAEA Waugh Lecture)
Thanks!

Selected Sources

