Evaluating Research & Education Performance in Indian Agricultural Development

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1. Motivation

• India’s targeted commodity- and region-specific agricultural policies have changed little since the 1960s ‘Green Revolution’ development strategy (Shreedhar et al., 2012).

• Prominent in that strategy has been public investment in agricultural research and higher education (Pal and Singh, 1997; Evenson et al., 1999; Fan et al., 1999; Pal and Byerlee, 2003; Chand et al., 2011; Rada and Schimmelpfennig, 2015).

• Between 1960 and 2008, per-state average public spending on Eastern SAUs were 93% of those in the Central region but only 60% of those in the South, 58% of those the North, and 40% of those in the West.
In contrast to a rather status quo policy attitude, India's farm production patterns have been changing dramatically.
1. Motivation

• With this apparent discrepancy between an inflexible policy and a trending output mix in mind, we ask:
  – would Indian agricultural growth have benefitted from more flexible, regionally differentiated education and research public investments?

• Specifically, where have public agricultural research and education brought the greatest rate of return and total factor productivity growth?
Presentation Outline

1. Motivation
2. Descriptive Statistics
3. Model Development
4. Returns to Agricultural Research
5. Data
6. Results
   - Formal technical change, returns to research, efficiency change, TFP growth, policy effects on efficiency
7. Conclusions
What is Total Factor Productivity?

Yield growth
(more crop per hectare)

Input Intensification
(more inputs/ha)

Area growth
(more hectares)

Area growth
(more hectares)

TFP growth

Input-led Growth
- Use more land, labor, capital, fertilizers, irrigation

Science-led Growth
- New technologies
- Better farm management

Price effect

Value growth

Real output growth
### 2. Describing Regional Variations

#### Table 1. Descriptive Statistics of Chain-weighted Tornqvist-Thiel Production Growth Indexes, 1980-2008

<table>
<thead>
<tr>
<th>States</th>
<th>National</th>
<th>North</th>
<th>Central</th>
<th>West</th>
<th>East</th>
<th>South</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
</tr>
<tr>
<td>Growth Indexes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>metric tons</td>
<td>1.808</td>
<td>1.941</td>
<td>2.391</td>
<td>1.808</td>
<td>1.777</td>
</tr>
<tr>
<td>Land</td>
<td>rain-fed equivalent hectares</td>
<td>1.122</td>
<td>1.122</td>
<td>1.158</td>
<td>1.131</td>
<td>1.184</td>
</tr>
<tr>
<td>Labor</td>
<td>male &amp; female labor days</td>
<td>1.065</td>
<td>1.110</td>
<td>1.195</td>
<td>1.067</td>
<td>1.070</td>
</tr>
<tr>
<td>Animal Capital</td>
<td>cattle-equivalent stocks</td>
<td>1.123</td>
<td>1.130</td>
<td>1.124</td>
<td>1.092</td>
<td>1.366</td>
</tr>
<tr>
<td>Machinery Capital</td>
<td>tractor counts</td>
<td>5.622</td>
<td>6.726</td>
<td>7.557</td>
<td>7.443</td>
<td>3.688</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>Kg of active N,P,K ingredients</td>
<td>2.570</td>
<td>2.311</td>
<td>3.738</td>
<td>2.606</td>
<td>2.976</td>
</tr>
<tr>
<td>Energy</td>
<td>KwH</td>
<td>5.574</td>
<td>4.586</td>
<td>10.322</td>
<td>3.559</td>
<td>5.280</td>
</tr>
</tbody>
</table>

- **High output growth; high input growth**
- **Low output growth; low input growth**
2. Describing Regional Variations

Table 1. Descriptive Statistics of Conditioning & Policy Variables, 1980-2008

<table>
<thead>
<tr>
<th>States</th>
<th>National</th>
<th>North</th>
<th>Central</th>
<th>West</th>
<th>East</th>
<th>South</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Haryana, Punjab, Himachal</td>
<td>Old MP</td>
<td>Gujarat, Maharashtra, Old Bihar,</td>
<td>West Bengal,</td>
<td>Andhra Pradesh, Karnataka, Kerala, Tamil Nadu</td>
<td></td>
</tr>
<tr>
<td>Levels</td>
<td>Description</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
</tr>
<tr>
<td>Rain</td>
<td>annual average (a.a.) in mm</td>
<td>1,220</td>
<td>818</td>
<td>2,093</td>
<td>615</td>
<td>1,790</td>
</tr>
<tr>
<td>Roads</td>
<td>a.a. state density of roads</td>
<td>810</td>
<td>549</td>
<td>192</td>
<td>494</td>
<td>712</td>
</tr>
<tr>
<td>State Avg SAU Expenditures, 1960-2008</td>
<td>a.a. millions of 2004 constant Rupees</td>
<td>7,587</td>
<td>517</td>
<td>325</td>
<td>759</td>
<td>301</td>
</tr>
<tr>
<td>Canal Irrigation</td>
<td>hectares</td>
<td>1,068</td>
<td>1,416</td>
<td>1,589</td>
<td>859</td>
<td>927</td>
</tr>
<tr>
<td>Well Irrigation</td>
<td>hectares</td>
<td>1,912</td>
<td>3,012</td>
<td>2,700</td>
<td>2,303</td>
<td>1,083</td>
</tr>
<tr>
<td>Schooling</td>
<td>years</td>
<td>3.391</td>
<td>3.538</td>
<td>2.485</td>
<td>3.182</td>
<td>2.952</td>
</tr>
</tbody>
</table>

Substantial variations across regions in annual rainfall and infrastructure…. and Research and Education too!
3. Model Development

• Our purpose is to regionally evaluate India’s public agricultural research and education investments.

• Federal funding to a given SAU depends on its connection to national agricultural priorities.

• Since 1960 SAU funding has been much deeper in the North, West, and South than in the East or Central regions.

• By the late 1990s the majority of public agricultural research institutes were located in the North and South, largely due to political influences (Singh and Pal, 1997).
There were 26 SAUs in 1986, rising to 31 in 2005, 55 in 2012 and 63 in 2015 (Evenson et al., 1999; Pal and Byerlee, 2006; Pal et al., 2012; Pal, 2017).

This proliferation primarily reflects administrative reorganization to boost the research profile of such areas as animal science, horticulture, and fisheries.

However there has been no commensurate increase in the number of full-time equivalent (FTE) scientists. Scientist FTE in the SAU system fell by 26% in 2000-2009 (Pal et al., 2012).
Let’s consider a production function in which output ($Y_{it}$) is a function of production inputs ($X_{it}$), policy & precipitation variables ($Z_{it}$), and error ($E_{it}$):

$$\ln y_{it} = f (\ln x_{kit}, \ln z_{jit}; \beta) + \varepsilon_{it}$$

One-sided inefficiency error capturing relative productivity:
$$u_{it} \sim N^+ (0, \sigma_{u,it}^2)$$

Two-sided idiosyncratic error capturing unaccounted-for heterogeneity:
$$v_{it} \sim N (0, \sigma_{v,it}^2)$$
3. Model Development

This model will be estimated by log-likelihood function (Kumbhakar and Lovell, 2000):

\[
\ln LL = \text{constant} - \frac{1}{2} \sum_{s=1}^{S} \sum_{i=1}^{I} \left[ \ln \left( \sigma_{u,it}^2 + \sigma_{v,it}^2 \right) \right] + \sum_{s=1}^{S} \sum_{i=1}^{I} \ln \Phi \left( -\frac{\varepsilon_{it} \lambda_{it}}{\sigma_{it}} \right) \\
- \frac{1}{2} \sum_{s=1}^{S} \sum_{i=1}^{I} \left( \frac{\varepsilon_{it}^2}{\sigma_{it}^2} \right),
\]

Note how the function relies on the variance of the idiosyncratic and inefficiency error. Stata assumes homoscedastic errors, which will result in biased inefficiency and technology parameters (Hadri, 1999; Hadri, et al. 2003; Kumbhakar and Lovell, 2000).
3. Model Development

We introduce heteroscedasticity by scaling the variance of each error:

\[
\ln y_{it} = f(\ln x_{kit}, \ln z_{jit}; \beta) + \nu_{it} - u_{it}
\]

\[
\ln y_{it} = f(\ln x_{kit}, \ln z_{jit}; \beta) + \exp\{g(\ln q_{it}, \pi)\} - \exp\{h(\ln w_{lit})\}
\]

Technical efficiency is estimated as:

\[
f(\ln x_{kit}, \ln z_{jit}; \beta) = \beta_0 + \sum_{j} \beta_j \ln x_{kjt} + \beta_{\text{Rain}_{it}} \text{Rain}_{it} + \beta_{\text{Roads}_{it}} \text{Roads}_{it} + \beta_{\text{ARE}_{it}} \text{ARE}_{it}
\]

\[
h(\ln w_{it}) = \ln \sigma^2 \text{Well}_it + \ln \sigma^2 \text{Irrig}_it + \ln \sigma^2 \text{Canal}_it + \ln \sigma^2 \text{School}_it
\]

\[
TE_{it} = E[e^{(-u_{it}\mid\varepsilon_{it})} \left(\omega_{R_{it}} \exp(\text{School}_{it}) + \text{ARE}_{it}\right) \delta_{it}] \sim N(0, \sigma^2_{u,it})
\]

\[
\frac{\partial \ln E(TE)}{\partial \ln w_i} = -e^{h(\ln w)} \omega_i
\]

\[
\ln \sigma^2_{u,it} = 2h(\ln w) = 2(\omega + \omega_{\text{Well}_it} + \omega_{\text{Irrig}_it} + \omega_{\text{Canal}_it} + \omega_{\text{School}_it} + \delta_{it})
\]
5. Results: Frontier specification tests

• 1. Distribution of inefficiency error – exponential, half-normal, or truncated normal?

• 2. Are the inefficiency and idiosyncratic errors heteroskedastic or homoscedastic?
Table 2. Inefficiency \( u \) and idiosyncratic error \( v \) variance specification tests

**Likelihood ratio tests**

<table>
<thead>
<tr>
<th>Ho: homoscedasticity</th>
<th>Ha: heteroscedasticity</th>
<th>Chi-squared test statistics</th>
<th>Model Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma^2_{u,t} = \exp(\gamma_u) ), ( \gamma_u ) is a constant.</td>
<td>( \sigma^2_{u,t} = \exp{h(\ln w_{it}, \omega)} )</td>
<td>( \chi^2(7) = 70.52 ) Prob &gt; ( \chi^2 = 0.00 ) Heteroscedastic</td>
<td></td>
</tr>
<tr>
<td>( \sigma^2_{v,t} = \exp(\gamma_v) ), ( \gamma_v ) is a constant.</td>
<td>( \sigma^2_{v,t} = \exp{g(\ln q_{it}, \pi)} )</td>
<td>( \chi^2(5) = 87.28 ) Prob &gt; ( \chi^2 = 0.00 ) Heteroscedastic</td>
<td></td>
</tr>
<tr>
<td>( \sigma^2_{u,t} = \exp(\gamma_u) ) and ( \sigma^2_{v,t} = \exp{g(\ln q_{it}, \pi)} )</td>
<td>( \chi^2(8) = 90.39 ) Prob &gt; ( \chi^2 = 0.00 ) Heteroscedastic</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Parameter tests**

<table>
<thead>
<tr>
<th>Ho: homoscedasticity</th>
<th>Ha: heteroscedasticity</th>
<th>Chi-squared test statistics</th>
<th>Model Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sum_{l=1}^{7} \omega_l = 0 )</td>
<td>( \sum_{l=1}^{7} \omega_l \neq 0 )</td>
<td>( \chi^2(8) = 617.02 ) Prob &gt; ( \chi^2 = 0.00 ) Heteroscedastic</td>
<td></td>
</tr>
<tr>
<td>( \pi = 0 )</td>
<td>( \pi \neq 0 )</td>
<td>( \chi^2(2) = 1555.40 ) Prob &gt; ( \chi^2 = 0.00 ) Heteroscedastic</td>
<td></td>
</tr>
<tr>
<td>( \sum_{l=1}^{7} \omega_l = \pi = 0 )</td>
<td>( \omega_l \neq \pi \neq 0 )</td>
<td>( \chi^2(10) = 5267.52 ) Prob &gt; ( \chi^2 = 0.00 ) Heteroscedastic</td>
<td></td>
</tr>
</tbody>
</table>
5. Results: Formal technical change

Table 3. Regional per-annum rates of agricultural formal technical change, efficiency change, and total factor productivity growth, India, 1980-2008

<table>
<thead>
<tr>
<th>Region</th>
<th>Formal Technical Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>0.263%</td>
</tr>
<tr>
<td>Central</td>
<td>0.152%</td>
</tr>
<tr>
<td>East</td>
<td>0.085%</td>
</tr>
<tr>
<td>South</td>
<td>0.208%</td>
</tr>
<tr>
<td>West</td>
<td>0.263%</td>
</tr>
</tbody>
</table>

Note: The West regional slope parameter estimate in Table A.1 is not statistically different from the North’s (omitted region) and thus assumes the North’s value here. Mean TE Change is estimated by an exponential trend function which includes an error term.
Table 4. Agricultural research rates of return by Indian region

<table>
<thead>
<tr>
<th>Region</th>
<th>Ratio of Total Ag Revenue (Y/ARE)</th>
<th>Internal Rate of Return (irr)</th>
<th>Modified Internal Rate of Return (mirr)</th>
<th>Benefit-Cost Ratio (bc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>48.903</td>
<td>41.633</td>
<td>21.014</td>
<td>5.065</td>
</tr>
<tr>
<td>West</td>
<td>39.346</td>
<td>36.413</td>
<td>19.561</td>
<td>4.075</td>
</tr>
<tr>
<td>Central</td>
<td>52.227</td>
<td>30.563</td>
<td>17.79</td>
<td>3.116</td>
</tr>
<tr>
<td>East</td>
<td>41.782</td>
<td>16.128</td>
<td>12.626</td>
<td>1.390</td>
</tr>
<tr>
<td>South</td>
<td>40.709</td>
<td>31.954</td>
<td>18.227</td>
<td>3.330</td>
</tr>
</tbody>
</table>

Attribution Scenario 1: ICAR expenditures allocated by State

<table>
<thead>
<tr>
<th>Region</th>
<th>Ratio of Total Ag Revenue (Y/ARE)</th>
<th>Internal Rate of Return (irr)</th>
<th>Modified Internal Rate of Return (mirr)</th>
<th>Benefit-Cost Ratio (bc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>160.293</td>
<td>80.509</td>
<td>29.265</td>
<td>16.603</td>
</tr>
<tr>
<td>West</td>
<td>97.392</td>
<td>61.693</td>
<td>25.736</td>
<td>10.088</td>
</tr>
<tr>
<td>Central</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>East</td>
<td>114.883</td>
<td>34.958</td>
<td>19.136</td>
<td>3.822</td>
</tr>
<tr>
<td>South</td>
<td>134.433</td>
<td>64.656</td>
<td>26.340</td>
<td>10.997</td>
</tr>
</tbody>
</table>

Attribution Scenario 2: ICAR expenditures allocated by Region
5. Results: Formal technical, efficiency, and TFP change

Table 3. Regional per-annum rates of agricultural formal technical change, efficiency change, and total factor productivity growth, India, 1980-2008

<table>
<thead>
<tr>
<th>Region</th>
<th>Formal Technical Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>0.263%</td>
</tr>
<tr>
<td>Central</td>
<td>0.152%</td>
</tr>
<tr>
<td>East</td>
<td>0.085%</td>
</tr>
<tr>
<td>South</td>
<td>0.208%</td>
</tr>
<tr>
<td>West</td>
<td>0.263%</td>
</tr>
</tbody>
</table>

Note: The West regional slope parameter estimate in Table A.1 is not statistically different from the North’s (omitted region) and thus assumes the North’s value here. Mean TE Change is estimated by an exponential trend function which includes an error term.
5. Results: Comparison to literature

- Summing regional technical change, weighted by regional revenue shares gives 0.21%/year.

- Similarly aggregating efficiency change gives 0.24%/year.

- Thus TFP in 1980-2008 was only 0.45%/year.
  - Much lower than Rada’s (2016) 1.9%/year rate
  - Closer to Chand et al.’s (2014) 0.28%/year rate in 1980-2008
5. Results: Comparison to literature

• However, if we replace \( ARE \) with \( t \) a different picture emerges --- TFP grew by 1.93%/year

• This suggests the difference between the research-induced TFP and the time trend-induced TFP growth rates reflects non-public R&D effects and other unmeasurables, such as private R&D and learning-by-doing.
5. Results: Explaining efficiency gains

Table 5. Irrigation and education effects on technical efficiency (TE), variance and mean, 1980-2008, annual averages

<table>
<thead>
<tr>
<th>Policy Variable</th>
<th>TE Variance</th>
<th>TE Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well Irrigation</td>
<td>-0.723%</td>
<td>0.055%</td>
</tr>
<tr>
<td>Canal Irrigation</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>North Schooling</td>
<td>-1.693%</td>
<td>0.129%</td>
</tr>
<tr>
<td>Central Schooling</td>
<td>-1.693%</td>
<td>0.129%</td>
</tr>
<tr>
<td>East Schooling</td>
<td>-0.669%</td>
<td>0.051%</td>
</tr>
<tr>
<td>West Schooling</td>
<td>-0.569%</td>
<td>0.043%</td>
</tr>
<tr>
<td>South Schooling</td>
<td>-0.109%</td>
<td>0.008%</td>
</tr>
</tbody>
</table>

*Effect of a 1% increase in the indicated factor on TE variance and mean respectively.

Note: Canal irrigation’s parameter estimate in Table A.1 was not statistically significant and is thus omitted. Central region’s school slope parameter was not statistically different from the North’s (omitted region) and thus assumes the North’s value here.
6. Conclusions

- The greatest return would be achieved by redistributing research effort toward the Northern Region, less if toward the West or South, and least of all if toward the Center or East.
- Research success in the North is likely explained by high technology adoption rates throughout its grain-fertilizer-irrigation production system.
- In the East poor integration between research priorities and producer output mix, and marketing opportunities, seem to have discouraged technology uptake.
6. Conclusions

• Southern farmers, who have benefitted from research investment nearly as much as their northern and central counterparts, have also enjoyed the highest factor productivity growth rate in the nation.
  – This has come from a shift not so much in the technical frontier but in the average farmer’s performance relative to it,
  – policy makers may wish to take a closer look at these sorts of efficiency effects in their research planning.
6. Conclusions

• Overall, the technical progress and productivity growth easily attributable to government-supported research and university education has been rather low.

• The bulk of growth has come instead from non-research, non-university factors like irrigation, primary education, learning-by-doing, and new farm output mixes.
Questions?
4. Returns to Agricultural Research

- The regional $ARE$ parameter values are elasticities reflecting the increase in formal technical change given a 1% increase in the stock of a respective region’s long-term public agricultural research and higher-education spending.

- The associated internal rate of return ($irr$) is derived by considering the effect of a marginal increase in research spending on subsequent output.

- Thus the $irr$, and therefore the $ARE$ elasticities, depend in part on the time-lagged distribution of the research spending stock.
6. Conclusions

• Weighting regional TFP growth rates by 1980-2008 farm revenue shares to account for regional scale differences:
  – South accounted for 33% of India’s factor productivity growth,
  – followed by the North’s 30% share,
  – the West’s 16%,
  – East’s 13%, and
  – Center’s 9%.

• The southern and northern states, that is, have had the greatest regional influence on national productivity growth.

• Irrigation and education were most effective at lifting productivity in the northern and central states.
1. Motivation

• We test how three public agricultural ‘returns-to-research’ measures (internal rate of return, modified internal rate of return, and benefit-cost ratio) have varied by region.

• Internal rates of return are, for both aggregate output and individual commodities, available in India only at the national level (Evenson et al., 1999; Pal and Byerlee, 2003; Chand et al., 2011; Rada and Schimmelpfennig, 2015).

• We further decompose total farm factor productivity (TFP) growth into formal-technical and efficiency change, and test for:
  – transportation infrastructure effects on farm output, and
  – canal and well irrigation and primary education influences on farm technical efficiency.
5. Results: Research returns in the literature

• Pal and Byerlee (2006) – review the literature and find an average *irr* of 75.4%.
• Evenson et al. (1999) using 1956-1987 Indian data estimate an aggregate agricultural *irr* of 58%.
• Chand et al. (2011) estimate 46% in 1985-2006.
• Rada and Schimmelpfennig (2014) estimate an 85% *irr* and 18.34 *bc* in 1980-2008.
• Fan et al. (2008) develop Indian benefit-cost ratios: 8.65 in the 1960s and 1970s, 7.93 in the 1980s, and 9.50 in the 1990s.
4. Data: Output and Inputs

• The 63 output commodities are aggregated into a Chain-linked Tornqvist-Theil quantity growth index.
• All outputs are specified in metric tons, and all prices are normalized to 2004 basis prices using the World Bank’s India GDP price deflator (WDI, 2012).
• Recorded input volumes:
  – labor days,
  – quality-adjusted rainfed-equivalent hectares of land,
  – Fertilizer (N,P,K) quantities in active ingredients,
  – energy proxied by kilo-watt hours (kwh) of electricity to agriculture
  – machinery capital proxied by tractors-in-use,
  – animal capital measured as cattle-equivalent stocks of cattle, buffalo, sheep, goats, pigs, and poultry.
4. Data: Precipitation and Policy

- Annual average state rainfall controls for India’s predominately rainfed agricultural system

- Public agricultural research and higher education stocks
  - ICAR (Central) spending is added to each SAU spending stream

- Years of education

- Well and canal irrigation infrastructure (area equipped)

- Rural road density (km of rural roads/km\(^2\) of state area)
4. Returns to Agricultural Research

• Because the research stock affects the return rate, we estimate the research stock’s lagged distribution rather than assume Evenson et al.’s (1999) 27-year trapezoid stock structure.

• We test three lag structures: PDL, geometric, trapezoid, and gamma
4. Returns to Agricultural Research

\[
ARE_{it} = 0.000(\text{RE}_{it}) + 0.000(\text{RE}_{i,t-1}) + 0.016(\text{RE}_{i,t-2}) + 0.032(\text{RE}_{i,t-3}) \\
+ 0.048(\text{RE}_{i,t-4}) + 0.063(\text{RE}_{i,t-5}) + 0.079(\text{RE}_{i,t-6}) + 0.095(\text{RE}_{i,t-7}) \\
+ \ldots + 0.095(\text{RE}_{i,t-10}) + 0.085(\text{RE}_{i,t-11}) + 0.074(\text{RE}_{i,t-12}) + 0.063(\text{RE}_{i,t-13}) \\
+ 0.053(\text{RE}_{i,t-14}) + 0.042(\text{RE}_{i,t-15}) + 0.032(\text{RE}_{i,t-16}) + 0.021(\text{RE}_{i,t-17}) \\
+ 0.016(\text{RE}_{i,t-18})
\]

\[
= \sum_{d=0}^{18} \gamma_d \text{RE}_{i,t-d}
\]
4. Returns to Agricultural Research

• Measures of returns to research – the MIRR:

\[
1 = \left( \frac{\bar{Y}_r}{O_r} \right) \beta_{ARE} \sum_{d=0}^{18} \frac{\gamma_d}{(1 - \text{irr})^d} \\
MIRR = \sqrt[18]{\left( \frac{\bar{Y}_r}{O_r} \right) \beta_{ARE, r} \sum_{d=1}^{18} \lambda_d (1 + b)^{18-d}}
\]

Common standard for estimating returns to investment in agricultural economics literature. But assumes all benefits reinvested at the same rate as the IRR for the life of the project. Oehmke (2016) and Fuglie et al. (forthcoming) argue the MIRR assumes a sub-optimal reinvestment response and is sensitive to project horizon.

Alston et al. (2011) and Hurley et al. (2014) suggest the MIRR, which allows an alternative reinvestment rate.

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