Analysis of technical efficiency: Factors affecting efficiency of West Java rice farms

Data envelopment analysis

František Brázdik

frantisek.brazdik@cerge-ei.cz

CERGE-EI, Praha, Czech Republic
Presentation outline

• DEA methodology
  ◦ Literature review
  ◦ Example
  ◦ Methodology

• Application: Rice farming in Indonesia
  ◦ Stage 1: Efficiency computation
  ◦ Stage 2: Analysis of efficiency scores
  ◦ Tobit model for efficiency
  ◦ Assessment of farm size – productivity relation
  ◦ Other factors related to productivity
DEA methodology

- Farrell (1957) – concept of multiplicative efficiency: \( \text{OE} = \text{TE} \times \text{AE} \)
- E. Rhodes (1978) – evaluated the educational program for disadvantaged students
- Charnes, Cooper and Rhodes (1978) – first paper introducing DEA
- Banker, Charnes and Cooper (1984) – variable returns to scale in DEA
- Löthgren and Tambour (1996) – summary of returns to scale identification approaches
Efficiency concepts

\[ \text{OE} = \frac{0R}{0P}, \quad \text{TE} = \frac{0Q}{0P}, \quad \text{AE} = \frac{0R}{0Q} \]
DEA score - computation

[Diagram showing the DEA score computation with points A, B, C, and V, and the Efficiency Frontier line.]
DEA Methodology - summary

• $n$ homogenous DMUs: $m$ inputs and $s$ outputs

• $T \subset \mathbb{R}_{+}^{m+s}$ is general a production possibility set, where

$$T = \{(x, y) \mid \text{using inputs } x \text{ outputs } y \text{ are produced}\}$$

• Properties of production possibility set:
  ◦ Convexity
  ◦ Inefficiency property – free disposal
  ◦ Minimum extrapolation
  ◦ No free lunch

• Efficiency dominance: DMU is dominated when there exist a DMU that can produce the same levels of outputs with less intensive use of inputs
DEA problem

- Input oriented model:

\[
\begin{aligned}
\min_{\lambda_j, \theta_j, e_j, s_j} & \quad \theta_j \\
\text{s.t.} & \quad \theta_j x_{ij} - i x \lambda_j - e_{ij} = 0, \quad i = 1, \ldots, m; \\
& \quad r y \lambda_j - s_{rj} = y_{rj}, \quad r = 1, \ldots, k; \\
& \quad \varphi(1^T \lambda_j) = \varphi; \\
& \quad \lambda_j, e_j, s_j \geq 0,
\end{aligned}
\]

- \( \theta \) proportional reduction of inputs
- \( e_j, s_j \) non-proportional slacks
- \( \lambda \) intensity variable
- \( \varphi = 1 \) variable returns to scale
- \( \varphi = 0 \) constant returns to scale
Motivation:

- Success of “Green Revolution”
  - Growth of Indonesian rice production over 1950–1980 period

Goals:

- Test farm size–productivity relation

- Evaluate impact of intensification program and other factors on farm’s efficiency
  - Farm specific factors: labor, fertilizers, ...
  - Economic factors: prices of inputs
  - Environmental factors: location, wet-dry period, ...
Application: Methodology

• Stage 1 – DEA:
  ◦ Price distortions: Input oriented model
  ◦ Time invariant production frontier
  ◦ Time varying production frontier

• Stage 2 – Tobit:
  ◦ Efficiency scores – censored variable
  ◦ Efficiency model estimation
    • Random effect model
    • Mundlak’s correction used to control for correlation of individual characteristics and unobserved heterogeneity
Application: Results

- Stage 1:
  - High correlation of average DEA score ranking with SFA rankings: 0.7127 – 0.8214
  - Average technical efficiency scores range from 0.60 to 0.77
  - High average scale efficiency 0.90
  - Apx. 70% of farms are located in DRS region of production possibility set
  - Afficiency scores are consistent across models
  - No significant technological change over considered period – Malmquist index
  - Conjecture: Production growth was mainly driven by growth in area used for production
  - High degree of heterogeneity in scores
Application: Results

- Stage 2:
  - HYV employment and sharecropping positively related with efficiency score
  - no significant efficiency benefit from intensification program participation
  - No significant effect of wet period
  - Positive effect of family labor share
  - Size–efficiency relation:
    - “U” shaped relation – quadratic
    - Threshold – apx. 1.41 ha and apx. 1.9 (using Mundlak’s correction)
    - Threshold coincides size of farm in other islands
Conclusions

- Adopt “best–practice” production mixes: 23%–42% proportional reduction of all inputs
- Positive returns of HYV employment
- Adjust farm size – pooling plots
- Reform of subsidies system to avoid overuse of inputs – pesticides prices
- Personalization of intensification program
Appendix: Input reduction

- Input orientation in DEA

![Graph showing input orientation in DEA with DMUs and various efficiency measures such as CRS, IRS, and DRS.](image-url)
Appendix: SDEA-SFA correlation

- Spearman rank correlation

<table>
<thead>
<tr>
<th>Model type</th>
<th>$CCR_N$</th>
<th>$BCC_N$</th>
<th>$CCR_{LN}$</th>
<th>$BCC_{LN}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFA-SDEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$FE$</td>
<td>0.2534***</td>
<td>0.2448***</td>
<td>-0.0224</td>
<td>-0.0292</td>
</tr>
<tr>
<td>$FE_{sp}$</td>
<td>0.2115***</td>
<td>0.2399***</td>
<td>-0.0835***</td>
<td>-0.0762**</td>
</tr>
<tr>
<td>SFA-DEA a.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$FE$</td>
<td>0.8214***</td>
<td>0.7127***</td>
<td>0.2949***</td>
<td>0.8539***</td>
</tr>
<tr>
<td>$FE_{sp}$</td>
<td>0.7988***</td>
<td>0.6297***</td>
<td>0.1130***</td>
<td>0.8263***</td>
</tr>
</tbody>
</table>
Appendix: Efficiency score summary

- **DEA scores:**

<table>
<thead>
<tr>
<th>Model</th>
<th>Obs.</th>
<th>Mean</th>
<th>Std.Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Two–outputs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\chi$–CCR</td>
<td>960</td>
<td>0.6199</td>
<td>0.2221</td>
<td>0.1612</td>
<td>1</td>
</tr>
<tr>
<td>$\theta$–CCR</td>
<td>960</td>
<td>0.7069</td>
<td>0.1942</td>
<td>0.2795</td>
<td>1</td>
</tr>
<tr>
<td>$\chi$–BCC</td>
<td>960</td>
<td>0.7016</td>
<td>0.2216</td>
<td>0.2065</td>
<td>1</td>
</tr>
<tr>
<td>$\theta$–BCC</td>
<td>960</td>
<td>0.7757</td>
<td>0.1884</td>
<td>0.3294</td>
<td>1</td>
</tr>
<tr>
<td>Scale efficiency</td>
<td>960</td>
<td>0.9126</td>
<td>0.1123</td>
<td>0.4493</td>
<td>1</td>
</tr>
<tr>
<td><strong>Pooled DEA two–outputs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\chi$–CCR</td>
<td>960</td>
<td>0.5155</td>
<td>0.2024</td>
<td>0.1647</td>
<td>1</td>
</tr>
<tr>
<td>$\theta$–CCR</td>
<td>960</td>
<td>0.5866</td>
<td>0.1948</td>
<td>0.2116</td>
<td>1</td>
</tr>
<tr>
<td>$\chi$–BCC</td>
<td>960</td>
<td>0.5913</td>
<td>0.2012</td>
<td>0.2309</td>
<td>1</td>
</tr>
<tr>
<td>$\theta$–BCC</td>
<td>960</td>
<td>0.6533</td>
<td>0.1988</td>
<td>0.2591</td>
<td>1</td>
</tr>
<tr>
<td>Scale efficiency</td>
<td>960</td>
<td>0.9003</td>
<td>0.1183</td>
<td>0.3618</td>
<td>1</td>
</tr>
</tbody>
</table>
Appendix: Analysis of scores

- Returns to scale

<table>
<thead>
<tr>
<th>Model</th>
<th>DRS</th>
<th>CRS</th>
<th>IRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>One–output</td>
<td>66%</td>
<td>12%</td>
<td>22%</td>
</tr>
<tr>
<td>Two–outputs</td>
<td>62%</td>
<td>16%</td>
<td>22%</td>
</tr>
<tr>
<td>Pooled two–outputs</td>
<td>77%</td>
<td>5%</td>
<td>18%</td>
</tr>
<tr>
<td>Thailand*</td>
<td>19%</td>
<td>32%</td>
<td>49%</td>
</tr>
<tr>
<td>Bangladesh**</td>
<td>63%</td>
<td>16%</td>
<td>21%</td>
</tr>
</tbody>
</table>

* From Krasachat (2004), ** From Wadud and White (2000)
Appendix: Productivity factors

- Intensification program participation

![Efficiency score boxplot](chart.png)

<table>
<thead>
<tr>
<th>Type of farm</th>
<th>Efficiency score</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-BIMAS</td>
<td>0.4</td>
</tr>
<tr>
<td>Mix</td>
<td>0.8</td>
</tr>
<tr>
<td>BIMAS</td>
<td>1.0</td>
</tr>
</tbody>
</table>

BCC-2 outputs | CCR-2 outputs
Appendix: Productivity factors

- Modern variety employment
Appendix: Technical and efficiency change

- Malmquist Index Summary Of Annual Means

<table>
<thead>
<tr>
<th>Year</th>
<th>Eff.ch.</th>
<th>Tech.eff.ch.</th>
<th>Prod.ch.</th>
<th>Sc.eff.ch.</th>
<th>TFP Ch.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.947</td>
<td>1.036</td>
<td>0.980</td>
<td>0.967</td>
<td>0.981</td>
</tr>
<tr>
<td>3</td>
<td>1.148</td>
<td>0.758</td>
<td>1.042</td>
<td>1.101</td>
<td>0.870</td>
</tr>
<tr>
<td>4</td>
<td>0.851</td>
<td>1.063</td>
<td>0.894</td>
<td>0.952</td>
<td>0.905</td>
</tr>
<tr>
<td>5</td>
<td>1.066</td>
<td>1.147</td>
<td>1.030</td>
<td>1.035</td>
<td>1.223</td>
</tr>
<tr>
<td>6</td>
<td>1.045</td>
<td>0.960</td>
<td>1.046</td>
<td>0.999</td>
<td>1.004</td>
</tr>
<tr>
<td>Mean</td>
<td>1.006</td>
<td>0.983</td>
<td>0.997</td>
<td>1.010</td>
<td>0.989</td>
</tr>
</tbody>
</table>
Appendix: Estimation details

- **Tobit:**
  - $\chi_{ij}^* = \beta^T x + \nu_i + \epsilon_{ij}$, where $\chi_{it}$ is censored variable
  - random effects, $\nu_i$, are iid $N(0, \sigma^2_{\nu})$ and $\epsilon_{it}$ are iid $N(0, \sigma^2_{\epsilon})$ independently of $\nu_i$

- **Unobserved heterogeneity modelling:**
  - Mundlak (1978): unobserved heterogeneity can be modelled as a function of means of included regressors
  - $\nu_i = \bar{\beta} \bar{x}_i + \alpha_i$
    - $\alpha_i$ is a part of farm’s unobserved heterogeneity and uncorrelated with regressors
    - $\bar{x}_i$ is vector of farm $i$ means for individual regressors $x_i$ over the observed period
Appendix: Parametric methods

• Kumbhakar and Lovell’s (2000) review

• COLS:
  ◦ Estimate: \( \ln(y_j) = \beta_0 + \sum_{k=1}^{m} \ln(x_{jk}) \beta_j - u_j \)
  ◦ Correct OLS residuals: \( -\hat{u}_j^* = \hat{u}_j - \max_j \{ \hat{u}_j \} \)
  ◦ Calculate efficiency: \( TE(COLS)_j = \exp(-\hat{u}_j^*) \)

• SFA:
  ◦ Estimate: \( \ln(y_j) = \beta_0 + \sum_{i=1}^{m} \beta_i \ln(x_{ij}) + v_j - u_j \)
  ◦ \( u_j \) represents non-negative technical inefficiency
  ◦ \( v_j \) is the symmetric two sided random shock component.