Technical and Water Use Efficiency in Italian Agricultural Farms

Missione 4
Istruzione e Ricerca

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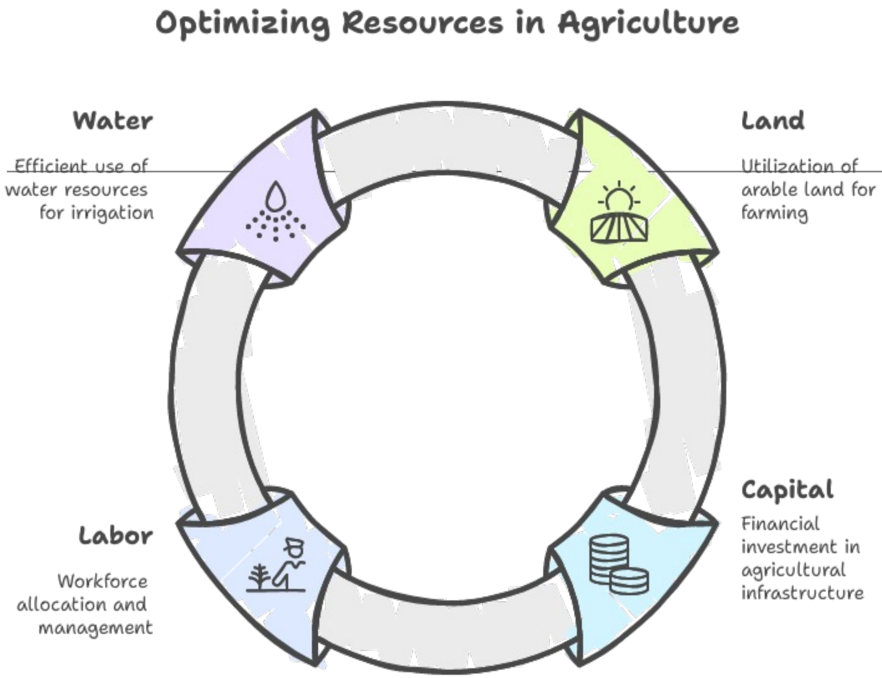
Efficiency Evaluation



Efficiency evaluation is a crucial component of program assessment, enabling decision-makers to optimize resource allocation (land, capital, employee, water use, …) for maximum economical impact in agricultural systems.

Efficiency Evaluation Approaches

Parametric approach

- ❑Needs a particular form of the objective function
- ❑ coefficients of the unknowns function are determined
- ❑Production units should either have a single output or, if they have multiple outputs, these must be convertible into one another.

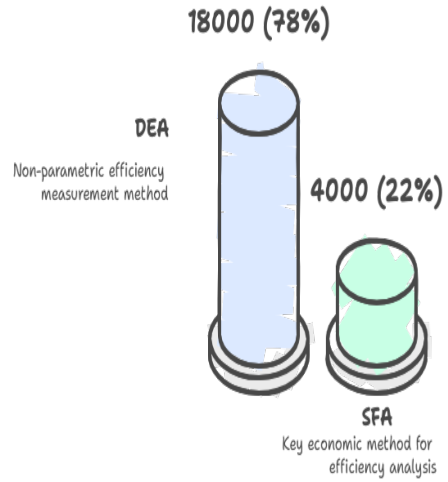
Stochastic Frontier Analysis (SFA)

non- parametric approach

- ✓Does not need to estimate the objectiv function
- ✓unit can have several outputs
- ✓(DMU) provides a virtual reference set a an optimum sample for inefficient units

Data Envelopment Analysis (DEA)

Trajectories of efficiency measurement: A bibliometric analysis of DEA and SFA



DEA models

$$\frac{\textbf{Output}}{\textbf{Input}} = \textbf{Measure of Efficiency}$$

→ **WUE =** *Crop yield (kg)* / *Water consumption (m^3)*

- Technical efficiency (input-oriented DEA models)

CCR model (global technical efficiency) --- Charnes et al. (1978)

$$\mathrm{Min}_{\theta,\lambda}\theta$$

With:

$$-q_i + Q\lambda \geq 0,$$

$$\theta x_i - X\lambda \geq 0,$$

$$\lambda \geq 0$$

where θ is a scalar and λ is a *Ix1* vector of constants. Hence, 0< θ <1, when a DMU (farm) is fully efficient , θ*=1

Constant Returns to Scale (CRS) assumption posits that all DMUs can proportionally increase their output corresponding to a proportional increase in their inputs, regardless of their scale of operation.

DEA models

- Technical efficiency (input-oriented DEA models)

BCC model (local pure technical efficiency) --- Banker et al. (1984)

$\text{Min}_{\theta,\lambda}\theta$

With:

$-q_i + Q\lambda \geq 0,$

$\theta x_i - X\lambda \geq 0,$

$N1'\lambda = 1$

$\lambda \geq 0$

Convexity constraint (VRS): when two or more input–output combinations are known to be feasible, any weighted average of the input bundles can produce a similarly weighted average of the corresponding output bundles. Hence, in this model, each farm is compared against other studied farms within the same scale range.

- Scale Efficiency (SE)

$$SE = \frac{\theta^*_{CCR}}{\theta^*_{BCC}}$$

DEA models

- Water use efficiency
DEA-BCC input-oriented model

$\text{Min}_{\theta,\lambda}\theta^k$

With:

$$-q_i + Q\lambda \geq 0,$$

$$\theta^k x_i^k - X^k\lambda \geq 0,$$

where θ^k is the score of sub-vector technical efficiency related to the input k for the firm i, in which k is reduced while maintaining the other inputs and output constant. The terms x_i^{n-k} and X^{n-k} refer to x_i^v and X^v without introducing the input k. x_i^k and X^k include only the input k.

$$x_i^{n-k} - X^{n-k}\lambda \geq 0,$$

$$N1'\lambda = 1$$

$$\lambda \geq 0$$

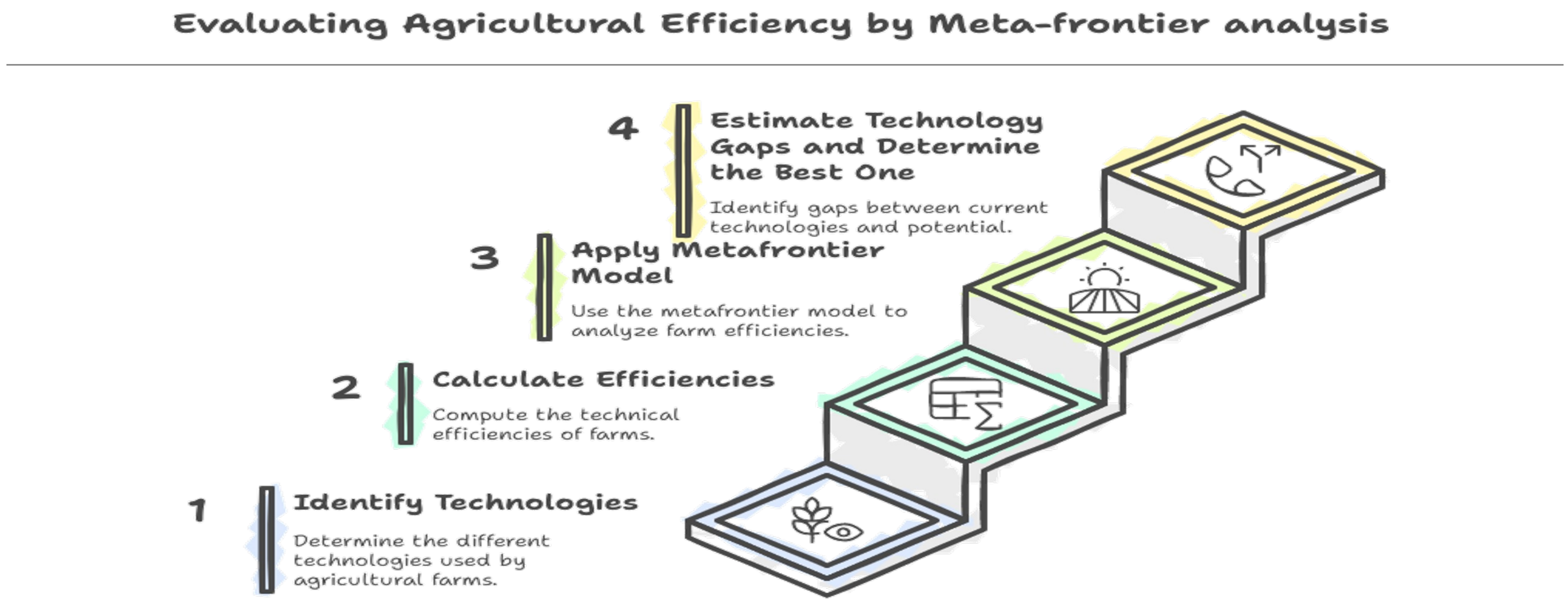
- Two-stage DEA approach
Tobit regression model

For determining the factors which affect WUE of farm's' efficiency in our sample, a Tobit model was chosen because efficiency is a bounded quantitative variable (bounded between zero and one)

$$\theta^{k*} = \sum_{r=1}^{R} \beta_r z_r + e$$

Meta-frontier analysis

How to address technical efficiency and technology gaps in regional agriculture with diverse farming technologies?



Meta-frontier analysis

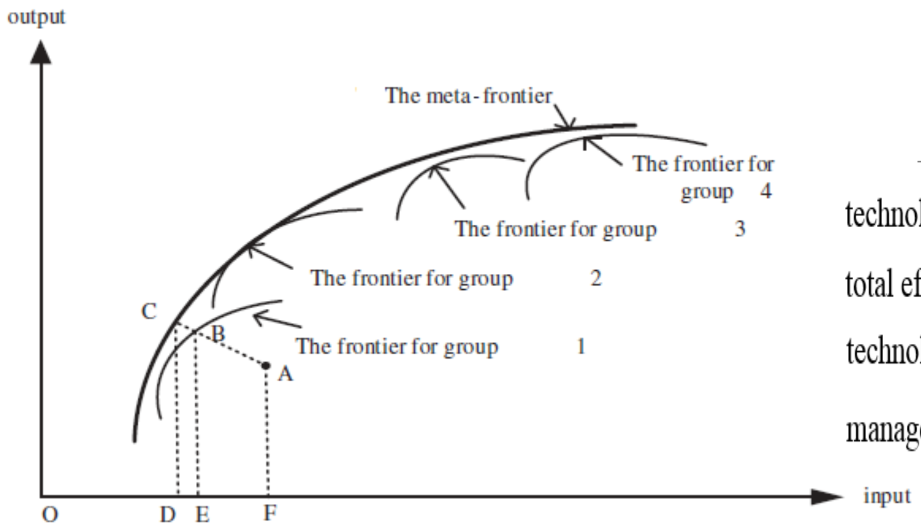


Figure. Illustration of meta-frontier, group frontier, and technology gap ratio (TGR)

Equations

technology gap ratio	$TGR_j^h = MFE_j / GFE_j^h$
total efficiency loss under the meta-frontier	$MTI_n^h = TGI_n^h + MI_n^h = \rho_n^{meta}$
technological gap inefficiency	$TGI_n^k = GFE_n^k(1 - TGR_n^k) = \rho_n^{meta} - \rho_n^k$
managerial inefficiency	$MI_n^k = 1 - GFE_n^k = \rho_n^k$

Input-output optimization approach

❑ Rectangular Choice-of-Technology (RCOT) model

A linear programming framework designed to select optimal technologies that minimize factor costs while satisfying final demand and resource constraints. It is formulated as:

$$\min Z = p' F^* x^*$$

Subject to:

$$(I^* - A^*)x^* \geq y$$

$$F^* x^* \leq f$$

$$x^* \geq 0$$

Where:

- A^* $(n \times t)$: Intermediate input coefficients per unit output for t technologies across n sectors.
- F^* $(k \times t)$: Factor input coefficients (e.g., labor, land) for k factors.
- I^* $(n \times t)$: Allocation matrix linking technologies to sectors (1s indicate availability).
- x^* $(t \times 1)$: Activity levels of selected technologies.
- y $(n \times 1)$: Final demand.
- f $(k \times 1)$: Resource endowments.
- p $(k \times 1)$: Factor prices.

Identifying New Efficient Technologies

Objective: Determine best-practice technologies to inform subsequent modeling.

- Meta-Frontier Technologies: DMUs with $MFE_j = 1$ are on the Meta-Frontier and represent the most technically efficient technologies nationwide.
- Group Frontier Technologies: Within each region h, DMUs with $GFE_{hj} = 1$ are efficient relative to their regional technology.

Input-output optimization approach

❑ **How to Adjust the A and B Matrices Using the New Optimal Technology**

Step 1: Regional Technologies (GFE < 1)

Scaling Rule:

Multiply all entries in both A and F by $1/GFE_h$.

Example:

If $GFE_h = 0.8$, scale A and F by 1.25.

- Original A entry 0.5 units of water (m3) per dollar of crops.

  Adjusted A entry: $0.5 \times 1.25 = 0.625$

Step 2: if GFE = 1

No Scaling: technologies are included in the A and F matrices without adjustment.

These represent the best practices and do not require penalization for inefficiency.