ENVIRONMENTAL EFFICIENCY & PRODUCTIVITY: MATERIALS BALANCE APPROACH

Viet-Ngu (Vincent) Hoang
QUT’s School of Economics and Finance, Australia
Contents

• Background
• Methodology
• An empirical study
• Drawbacks
BACKGROUND
Efficiency and productivity measures (indicators)

- Several approaches to measuring efficiency levels & productivity change
  - The index approach uses efficiency measures to construct productivity index
- Environmental pollution should be included into these conventional measures.
- The use of frontier framework has become more popular.
3 general modelling approaches

- Pollution is an INPUT as pollution is costly or an undesirable output as we want to reduce it (CONVENTIONAL environmental efficiency measures)
- Pollution is an environmental pressure and one seeks to reduce this pressure while increasing/remaining economic values of outputs (ECO-EFFICENCY measures) (Callens and Tyteca, 1999, Tyteca, 1999)
- Instead of using economic/resource input units, Coelli et al. (2007) uses the balance of nutrients in the context of animal farming
Actual Pollution vs Potential to pollute

• Agricultural production has undesirable outputs (by-products):
  – e.g. emissions of nutrients or greenhouse gases
  – Here they are called materials (or compounds of elements such as nitrogen, phosphorous, carbon, etc.)

• It is better but harder to measure/quantify “actual” pollution than to measure “potential to pollute”
  – Emission of nutrient compounds of N and P can cause eutrophication
  – It is hard to quantify the actual impacts
  – Measuring the amount of nutrients emitted to the water systems is easier.
METHODOLOGY
Technical efficiency

- Efficiency improves if we can reduce input consumption holding outputs constant

- A: an observed farm
- B: technical efficient farm
- A → B: improved efficiency
- Ratio OB / OA = Efficiency level
Malmquist productivity index

• Caves et al. (1982) proposed to use TE measures to construct Malmquist TFP index

\[
M^s_{\text{TFP}} = \frac{\text{ITE}^{s,t}}{\text{ITE}^{s,s}} \\
M^t_{\text{TFP}} = \frac{\text{ITE}^{t,t}}{\text{ITE}^{t,s}}
\]

using year \( s \) as reference technology

\[
\text{TFPC} = \frac{\text{ITE}^{t,t}}{\text{ITE}^{s,s}} \left[ \frac{\text{ITE}^{s,s}}{\text{ITE}^{t,s}} \times \frac{\text{ITE}^{s,t}}{\text{ITE}^{t,t}} \right]^{1/2} = \text{TEC} \times \text{TC}
\]
Environmental Efficiency

- Traditionally, emission modelled as either an input or output (in addition to other conventional inputs or outputs)
- The MBP: emission = balance of materials
- The MBP-based EE model
  - Does not consider emission as either inputs or outputs
  - Minimizes the balance of materials
    - Less amount of materials going to the environment, less power to pollute the environment
MBP-based EE

• $u = a'x - b'q$
  
  - $x$: inputs, $q$: outputs
  - $a$: material contents of $x$
  - $b$: material contents of $q$

• To minimize $u$
  
  - Fixed $q$, $u$ minimized when $a'x$ minimized
  - Fixed $x$, $u$ minimized when $b'q$ maximized
  - or maximize ($-u = b'q - a'x$) using directional /hyperbolic distance functions
Input-orientated optimization

\[ MC(q, a) = \min_x \{ a'x \mid \langle x, q \rangle \in T \} \]

\[ T = \{(q, x) : x \text{ can produce } q\} \]

- \( x_{ME} \) is a solution \( \rightarrow a'x_{ME} \): smallest material amount
- \( EE = a'x_{ME} / a'x \)
- \( NE = a'x_{TE} / a'x * a'x_{ME} / a'x_{TE} = TE * MAE \)
  - \( TE \): proportional reductions of inputs
  - \( MAE \): changes in input combinations that gives smaller total amount of materials in the input set.
Input-orientated optimization

- A: an observed farm
- B: technical efficient
- C: minimum total nutrient amount

AB: technical inefficiency
BN: allocative inefficiency

- TE = OB / OA
- ME = ON’ / OA
- MAE = ON’ / OB
Cost & environmental efficiency linkage

(i) $\text{TE} = \frac{\text{OB}}{\text{OA}}$

(ii) Cost Allocative Efficiency  
    $(\text{CAE} = \frac{\text{OC}}{\text{OB}})$

(i) $\text{MAE} = \frac{\text{ON}}{\text{OB}}$

Fig. 2. Minimization of cost and nutrient in inputs.
Environmental productivity

• Using Malmquist TFP index with reference technologies are data observed in reference years t & s
• Each ME measures can be decomposed into TE and Allocative (MAE) terms, hence we will get

\[ M_{ETFP}^s = \frac{ME^{s,t}}{ME^{s,s}} \quad M_{ETFP}^t = \frac{ME^{t,t}}{ME^{t,s}} \quad MTFPC^{t} = \left[ M_{ETFP}^{s} \times M_{ETFP}^{t} \right]^{1/2} = \left[ \frac{ME^{s,t}}{ME^{s,s}} \times \frac{ME^{t,t}}{ME^{t,s}} \right]^{1/2} \]

\[ ME^{s,s} = \frac{a'x^{s,s}_{ME}}{a'x^{s,s}_{s}} = \frac{a'x^{s,s}_{ITE}}{a'x^{s,s}_{ITE}} = ITE^{s,s} \times MAE^{s,s} \]

\[ MTFPC = TFPC \times \left[ \frac{MAE^{s,t}}{MAE^{s,s}} \times \frac{MAE^{t,t}}{MAE^{t,s}} \right]^{1/2} \]
Environmental productivity

MTFPC = TC × TEC × \left[ \frac{MAE^{s,t}}{MAE^{s,s}} \times \frac{MAE^{t,t}}{MAE^{t,s}} \right]^{1/2} = TC × TEC × MAEC

- Technical change (TC) refers to the shift of the production frontier.
- Technical efficiency change (TEC) refers to changes in ITE levels.
- Materials-based allocative efficiency change (MAEC) measures changes in the levels of MAE.
- TC and TEC capture the effects of technical and efficiency changes, while MAEC accounts for changes in combination of inputs in terms of materials.
Data of 32 OECD agricultural economies from 1992 to 2008

- Eutrophication caused by N and P balances
- Greenhouse gases of N & C

Variable

Output (price-weighted Fisher Index)

Feed and Seed

Price Weighted Fertiliser (’000 tonnes)

Live cattle (weighted for relative sizes, ‘000 heads)

Energy consumption (’000 tonnes oil-equivalent)

Labour (’000 active labour) (NO MATERIALS)

Land (’000 hectare)
Results – environmental efficiency

<table>
<thead>
<tr>
<th>Efficiency measures</th>
<th>Geometric Mean</th>
<th>Arithmetic Mean</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Efficiency (ITE)</td>
<td>0.7694</td>
<td>0.8082</td>
<td>0.1370</td>
<td>1.00</td>
</tr>
<tr>
<td>Allocative Efficiency (AE)</td>
<td>0.4743</td>
<td>0.5343</td>
<td>0.1150</td>
<td>1.00</td>
</tr>
<tr>
<td>Material Efficiency (ITE x AE at Geometric Mean)</td>
<td>0.3649</td>
<td>0.4163</td>
<td>0.0940</td>
<td>1.00</td>
</tr>
</tbody>
</table>

- The mean ITE score of 0.7694 suggests that, on average, OECD agriculture should be able to produce their current output with 23.04% fewer inputs.

- In terms of N, P, and C balances, the mean MAE score of 0.4743 interprets that these economies could reduce the total material balance by 52.57% if they were to adjust the combination of materials-containing inputs (cattle, fertilizers, feed and seed, and energy).

- The overall ME score of 0.3649 indicates OECD agriculture should be able to produce the same output levels with inputs containing 63.51% less materials of N, P, and C.
## Results – Malmquist productivity

<table>
<thead>
<tr>
<th>TFP change measures</th>
<th>Geometric Mean</th>
<th>Arithmetic Mean</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Efficiency Change (TEC)</td>
<td>1.0097</td>
<td>1.0160</td>
<td>0.4386</td>
<td>2.1702</td>
</tr>
<tr>
<td>Technical Change (TC)</td>
<td>1.0036</td>
<td>1.0138</td>
<td>0.4766</td>
<td>1.8063</td>
</tr>
<tr>
<td>TFP Change (TFPC = TEC x TC for Geometric Mean)</td>
<td>1.0133</td>
<td>1.0226</td>
<td>0.4902</td>
<td>1.5131</td>
</tr>
</tbody>
</table>

![Graph showing Technical Efficiency Change, Technical Change, and TFP Change over time from 1992 to 2008.](image)
Technological progress – TC = 1.0036, around .36% per year
Improvement in technical efficiency over time – TEC = 1.0097
Material Allocative Efficiency Change is negative

Hypothesis of slow technological transfer? It is of speculative nature.
Malmquist environmental productivity
Methodological & data issues

• We cannot track actual pollution but rather just track the potential to pollute.
  • Various surrounding physical environment determines actual pollution
  • Varying impacts of different N, P, C compounds
  • Aggregate data of inputs and materials balance
  • Consequences: hard to link efficiency/productivity scores with actual performance

• Constant returns to scale
• Malmquist index issues
Key references


Thank You
Email: vincent.hoang@qut.edu.au