Market Distortion and Efficiency of Index Numbers: Is There a “Price” to Pay for Cross-country Productivity Comparison

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Introduction

Agricultural productivity growth is at the heart of dealing with global food security

- Global agricultural total factor productivity grew at 1.0% a year between 1961 and 2010
- It accounted for a significant proportion of agricultural output growth and depressed global food price

However, agricultural productivity grows unevenly across countries

- No evidence of convergence in agricultural productivity between developed countries
- Significant gap in productivity levels and growth between developed and developing countries

It is essential to measure and compare agricultural productivity across countries.
Average annual growth rate of agriculture since 1990, by region (%)

Source: Fuglie et al. (2012)
Introduction

The growth accounting based index method is widely used a tool to measure agricultural TFP at the industry level.

- initially developed by Jorgenson and Nishimizu (1978) and others
- large amount of literature including Ball et al. (2001, 2010), Fuglie et al. (2012), Coelli and Rao (2005), Ludena et al. (2007) and Nin-Pratt and Yu (2009) etc.

Most of these studies can be categorised into two groups, depending on the index method that they have used

- the superlative index (i.e. Fisher or Törnqvist)
- the quantity-only based index approach (i.e. Malmquist)
Introduction

The superlative index

• Use data of both price and quantities for inputs and outputs
• Estimation process is simple and transparent
• Need to adjust for transitivity for level comparison

The quantity-only based index

• Apply distance function to data on input and output quantities
• Sensitive to the estimation methods (i.e. SFA, DEA, LP), pre-assumed functional form, and the data in use
• Circularity easy to adjust for and allows for efficiency analysis

Although the two methods should be equal theoretically (Caves et al. 1982; Färe and Grosskopf 1992; Färe et al. 2008), it is not known which one performs better from an empirical perspective.
Comparison of various agricultural productivity measures in the world

- Output
- TFP-DEA
- TFP-growth accounting
- Land productivity
- Labor productivity

Annual growth rate (%)

Year:
- 1970
- 1975
- 1980
- 1985
- 1990
- 1995
- 2000
- 2005
- 2010
Introduction

This paper aims to apply both of these index methods to cross-country consistent data between the United States, Canada and Australia

• measure and compare agricultural TFP across countries
• examine the relative performance of the two methods

There are two contributions to the literature

• provide a unique (national account based) dataset to compare agricultural production systems across countries at the commodity and industry levels.
• examine the role of price information in constructing reliable index measures for international comparison.

The findings are not restricted to the three-country case, and have important policy implications for statistical agencies.
Methodology: TFP Measure

Agricultural TFP is measured as the ratio of gross output to total input such that

\[ TFP_t = \frac{y_t}{x_t} \]  

(1)

\[ \frac{d \ln(TFP_t)}{dt} = \frac{d \ln(y_t)}{dt} - \frac{d \ln(x_t)}{dt} \]  

(2)

where \( Y^t = \sum_i y^t \) and \( X^t = \sum_j x^t \) and \( y^t \) and \( x^t \) are output and input vectors.

How we aggregate different outputs and inputs into the corresponding quantity/volume index matters for the final results

• Form of transformation function (i.e. parametric vs. non-parametric)
• Weights to be used (i.e. real price vs. implicit price)
Methodology: the superlative index

The superlative index (i.e. Törnqvist) uses revenue shares as weights for output aggregation and cost shares as weights for input aggregation.

\[ T_{TFP}^{t,t+1} = \frac{T_y^{t,t+1}(p^{t,t+1}, y^{t,t+1})}{T_x^{t,t+1}(w^{t,t+1}, x^{t,t+1})} \]  

with

\[ T_y^{t,t+1}(p^{t,t+1}, y^{t,t+1}) = \prod_{i=1}^{n} \left( \frac{v_i^{t+1}}{y_i^t} \right)^{1/2} [R_i^{t} + R_i^{t+1}] \]  

\[ T_x^{t,t+1}(w^{t,t+1}, x^{t,t+1}) = \prod_{j=1}^{m} \left( \frac{v_j^{t+1}}{x_j^t} \right)^{1/2} [S_j^{t} + S_j^{t+1}] \]

where \( R_i^t = p_i^t y_i^t / \sum_i p^t y^t \) is the revenue share of the \( i \)th output and \( S_j^t = w_j^t x_j^t / \sum_i w^t x^t \) is the cost share of the \( j \)th input at time \( t \). Implicit in the formula are the price vectors of output \( p^t \) and \( w^t \).
Methodology: the quantity-only based index

The quantity-only based index (i.e. Malmquist) uses implicit prices as weights for output and input aggregation.

\[ M^t_{TFP} = [M^t_0 * M^{t+1}_0]^{1/2} = \left[ \frac{D^t_0(x^{t+1},y^{t+1})}{D^t_0(x^t,y^t)} \right] \times \left[ \frac{D^{t+1}_0(x^{t+1},y^{t+1})}{D^{t+1}_0(x^t,y^t)} \right]^{1/2} \] (7)

A distance function has been employed in the estimation of changes in aggregate input and output quantity.

This measure could be further used to split the efficiency change component from technical change component, allowing for off-frontier possibilities.
Methodology: comparison of the two indexes

Define the input-oriented distance function

\[ D_1^t(x^t, y^t) = \sup \{ \theta > 0 : (\theta x^t, y^t) \in L^t \} \]

F. O. C. leads to

\[
\nabla_x D_1^t(x^t, y^t) = q^t(x^t, y^t) \\
p^t(x^t, y^t)[\frac{\partial p^t(x^t, y^t)}{\partial x^t} \frac{x^t}{p^t(x^t, y^t)} + 1] = \frac{1}{\lambda(x^t, y^t)} * \nabla_x D_1^t(x^t, y^t)
\]

At equilibrium, the market input price vector \( p^t(x^t, y^t) \) is equal to the shadow price of input vector \( q^t(x^t, y^t) \), if there is perfect competition and no friction in all factor and product markets.

\[
p^t(x^*, y^*) = \frac{\rho(x^*, y^*)}{\lambda(x^*, y^*)} q^t(x^*, y^*)
\]

However, if producers face differing degrees of market distortions, the derived shadow price vector will deviate from the market price vector.
Methodology: comparison of the two indexes

Empirically, a Fisher index equals a Malmquist index (or the two index methods) under certain conditions (Caves et al. 1982, Fare and Grosskf 1992, Kousmanen et al. 2004)

\[
\max_{\rho,\omega} \frac{\sum_{i=1}^{m} p_i y_{oi}}{\sum_{j=1}^{n} w_j x_{0j}}
\]

s.t.

\[
\sum_{i=1}^{m} p_i y_{ki} / \sum_{j=1}^{n} w_j x_{kj} \leq 1 \quad \text{with} \ k = 1, \ldots, r
\]

\[
p_i, w_j \geq 0 \quad \text{with} \ i = 1, \ldots, m; j = 1, \ldots, n
\] (11).

As in Coelli and Rao (2001), we need to impose the unit condition \( \sum (w_j x_{kj})=1 \) to solve Equation (11). This leads to a condition that equalize Equation (3) and to Equation (7), such that

\[
D_x^t(x^t, y^t) = \max_{\rho,\omega} \left\{ \frac{\rho y^t}{\omega x^t} : \frac{\rho y^t}{\omega x^t} \leq 1 \forall (y^t, x^t) \in L^t \right\}
\] (12)

In particular, the retrieved implicit prices should be the same as market prices and all observations are located at the production frontier.
Data Source

Agricultural input and output data are compiled based on the production accounts

• The United States and Canada: ERS-USDA
• Australia: ABARES

Data are compiled at the commodity level

• there are 70 Outputs and 28 inputs between 1960 and 2006
• both quantity and price variables are collected
• quality adjustment for land, labour and some intermediate inputs
Empirical Results

The results are summarised in three areas

• Compare agricultural TFP estimates between the United States, Canada and Australia

• Examine the difference in the results obtained from using the two methods and explore potential reasons for differences.
  
  • In particular, we need to compare the value shares used as weights for outputs and inputs in aggregation
  
  • This means we need to compare real prices to implicit prices, since the quantities are the same.

• Explore the relative performance of the two methods at different aggregation levels

  • 2 outputs x 4 inputs
  
  • 6 outputs x 10 inputs
  
  • 16 outputs x 10 inputs
Figure 1 Cross-country consistent estimation of levels of agricultural TFP

(A) The United States

(B) Canada

(C) Australia

Note: The three figures display levels of agricultural TFP for the three countries. “USA”, “CAN”, and “AUS” denote the United States, Canada and Australia respectively. The last letter of each indicator, “_T” and “_M” stand for results from the Törnqvist and Malmquist index approaches respectively. Note that the level of agricultural TFP in the US in 2005 is set to one (as base country-year).
Compare Agricultural TFP between the United States, Canada and Australia

Agricultural TFP has been increasing in all the three countries over time

• The finding is consistent with our previous study
• It is not directly comparable to country-specific study (Diewert and Fox 2015)

The two index methods will generate different agricultural TFP estimates across countries.

• There are difference in agricultural TFP estimates for all countries
• The estimates obtained from the two approaches are in opposite in directions for particular country

Reasons need to be provided to explain the difference in findings obtained from the two index methods as the data for quantities used are identical

• It should be price/implicit prices (used for weights for aggregation) causing the differences
Table 1 Output/input share and real prices in the Törnqvist index: average between 1960-2006

<table>
<thead>
<tr>
<th></th>
<th>USA</th>
<th>CAN</th>
<th>AUS</th>
<th>Real Price</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Output Share in Total Revenue</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crops Share (%)</td>
<td>55.2</td>
<td>52.0</td>
<td>49.5</td>
<td>1.022</td>
</tr>
<tr>
<td>Livestock Share (%)</td>
<td>44.8</td>
<td>48.0</td>
<td>50.5</td>
<td>0.724</td>
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<tr>
<td><strong>Input Share in Total Expenditure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land Share (%)</td>
<td>8.6</td>
<td>8.8</td>
<td>10.2</td>
<td>0.432</td>
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<tr>
<td>Capital Share (%)</td>
<td>11.3</td>
<td>17.0</td>
<td>31.5</td>
<td>0.715</td>
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<tr>
<td>Labor Share (%)</td>
<td>24.8</td>
<td>18.3</td>
<td>19.9</td>
<td>0.298</td>
</tr>
<tr>
<td>Intermediate Inputs Share (%)</td>
<td>55.2</td>
<td>55.9</td>
<td>38.3</td>
<td>0.7</td>
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</tbody>
</table>
Table 2 Output/input share and real prices in the Malmquist index: average between 1960-2006

<table>
<thead>
<tr>
<th></th>
<th>USA</th>
<th>CAN</th>
<th>AUS</th>
<th>Implicit Price</th>
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<tr>
<td><strong>Output Share in Total Revenue</strong></td>
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<tr>
<td>Crops Share (%)</td>
<td>32.5</td>
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<td>Livestock Share (%)</td>
<td>67.5</td>
<td>59.6</td>
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<tr>
<td><strong>Input Share in Total Expenditure</strong></td>
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<tr>
<td>Land Share (%)</td>
<td>59.1</td>
<td>48.0</td>
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<tr>
<td>Capital Share (%)</td>
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<td>18.3</td>
<td>20.8</td>
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<tr>
<td>Labor Share (%)</td>
<td>12.6</td>
<td>19.3</td>
<td>15.8</td>
<td>0.312</td>
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<tr>
<td>Intermediate Inputs Share (%)</td>
<td>8.4</td>
<td>14.4</td>
<td>18.3</td>
<td>0.741</td>
</tr>
</tbody>
</table>
Figure 2 Comparison of estimated Törnqvist TFP growth: 2x4 model vs. 6x10 model

(A) The United States
(B) Canada
(C) Australia

Note: The three figures display levels of agricultural TFP for the three countries. “USA”, “CAN”, and “AUS” denote the United States, Canada and Australia respectively. The last letter of each indicator, “_T”, stands for the Törnqvist index. The number of each indicator, “_2x4” and “_6x10”, denote results from 2-output and 4-input model and 6-output and 10-input model respectively. Note that the level of agricultural TFP in the US in 2005 is set to one (as base country-year). Source: Authors' own estimation.
Figure 3 Comparison of estimated Malmquist TFP growth: 2x4 model vs. 6x10 model

(A) The United States  
(B) Canada  
(C) Australia

Note: The three figures display levels of agricultural TFP for the three countries. “USA”, “CAN”, and “AUS” denote the United States, Canada and Australia respectively. The last letter of each indicator, “_M”, stands for the Malmquist index. The number of each indicator, “_2x4” and “_6x10”, denote results from 2-output and 4-input model and 6-output and 10-input model respectively. Note that the level of agricultural TFP in the US in 2005 is set to one (as base country-year). Source: Authors' own estimation.
Conclusions

- There are challenging issues both in the construction of cross-country consistent data as well as the choice of measurement methods.
- Agricultural productivity has generally been increasing but has been uneven across countries.
- In terms of method comparison, agricultural TFP estimates obtained using the superlative index outperform those obtained using the quantity-only based index.
- Our findings point to the importance of price data collection work for cross-country consistent agricultural productivity comparison.
Conclusions

Notes

- the distance-function based index has many constraints in application
  - theoretically, the shadow price may not reflect the market price
  - empirically, the estimates may be sensitive to the assumed functional forms and outlier in sample
  - estimation technique could also be improved.
- at the aggregate level, it is hard to use the method efficiently for
  - agricultural TFP estimates
  - cross-country/ cross-region/cross-sector comparison.
- It is still a good tool to examine the farm-level productivity.
Questions and Comments
The Malmquist output-oriented index
The Malmquist input-oriented index
Duality and productivity