

**PRODUCTIVITY ANALYSIS IN AGRICULTURE:  
CONCEPTS AND CHALLENGES**

**by**

**Jean-Paul Chavas**

**University of Wisconsin-Madison**

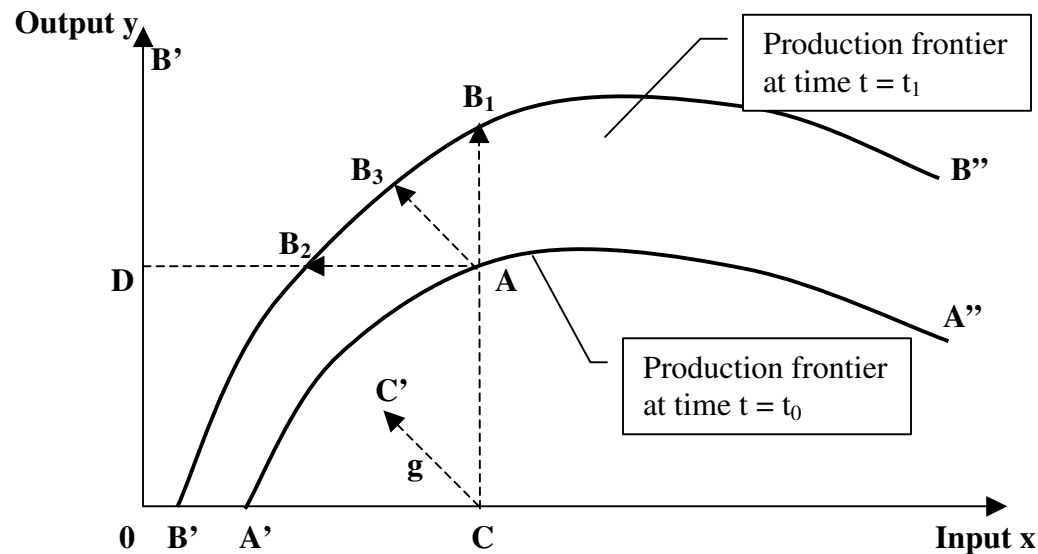
## **Motivations**

- **Agriculture is in the business of feeding a growing human population**
- **Agricultural Productivity has increased a lot over the centuries**
  - **Corn hybrid**
  - **Green revolution**
- **Two key questions:**
  - **Will agricultural productivity growth remain strong in the future?**
  - **Is agricultural productivity growth “sustainable”? Or are we “mining” current ecosystems in unsustainable ways?**

## Overview

- **Productivity Measurement: Input-Output Approach**
- **Productivity Measurement under Constant Returns to Scale**
- **Productivity Measurement: Multiple Output Approach**
- **The Effects of Diversification on Productivity**
- **The productive value of diversity: apple and bees**
- **Decomposition of the Productive Value of Diversity**
- **Risk and Agricultural Productivity**
- **Implications for Agricultural Productivity**

# Productivity Measurement: Input-Output Approach



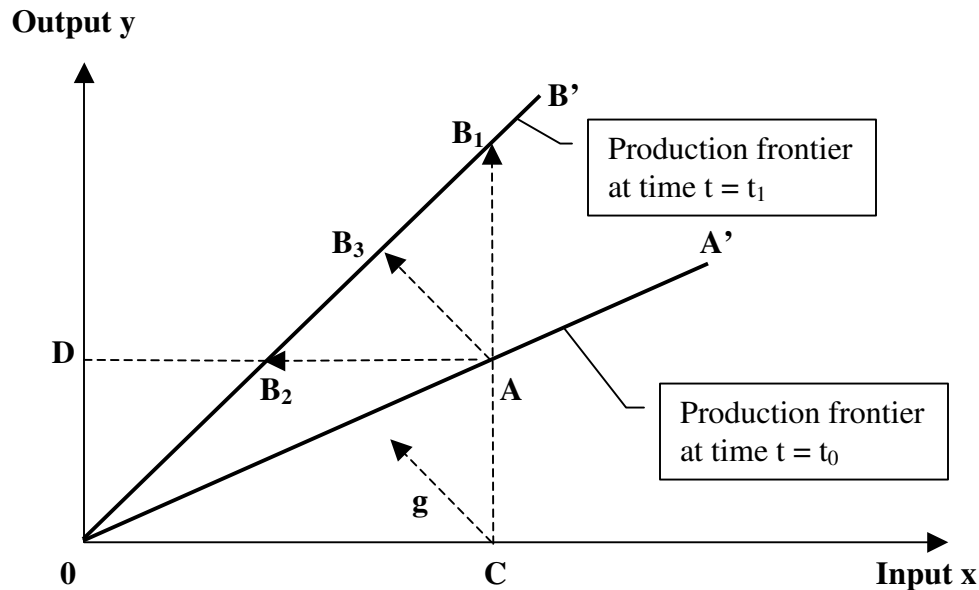
Measurement of technological progress (from  $t_0$  to  $t_1$ ):

- Output-based measure:  $AB_1$
- Input-based measure:  $AB_2$
- Directional-g measure:  $AB_3$

Productivity measures:

- Output-based productivity index:  $T_0 = 1 + AB_1/CA = CB_1/CA$   
 $T_0$  is Shephard's output distance function  
 $(T_0 - 1)$  = proportional increase in output due to technological progress
- Input-based productivity index:  $T_1 = 1 + AB_2/DB_2 = DA/DB_2$   
 $1/T_1$  is Shephard's input distance function  
 $(T_1 - 1)$  = proportional decrease in input due to technological progress
- Directional-g measure:  $T_g = AB_3/CC' =$  number of units of the reference bundle  $g$  due to technological progress  
 $T_g$  = directional distance function (= - Luenberger's shortage function)

## Productivity Measurement under Constant Returns to Scale



Measurement of technological progress (from  $t_0$  to  $t_1$ ):

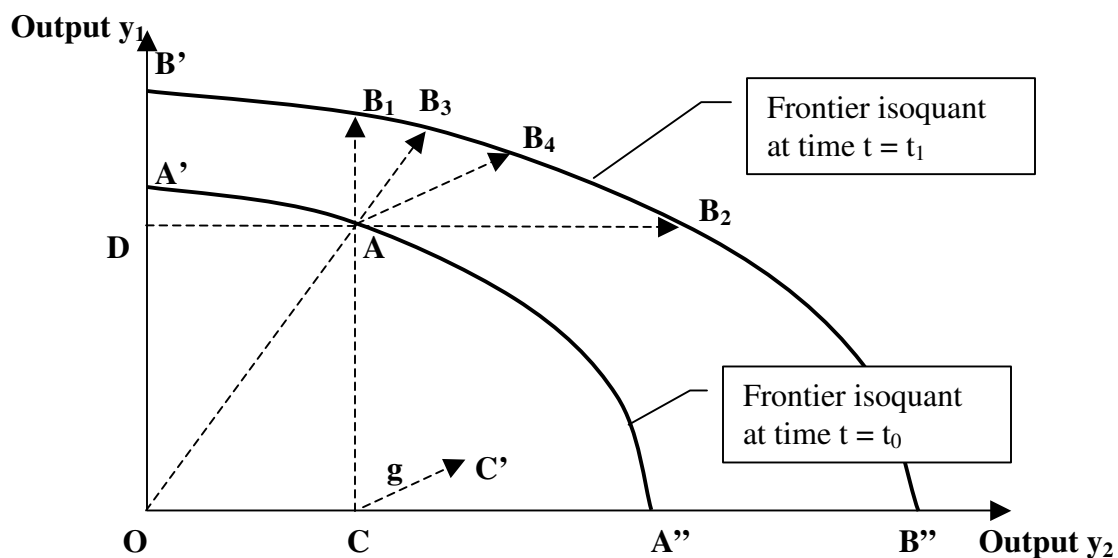
- Output-based measure:  $AB_1$
- Input-based measure:  $AB_2$
- Directional-g measure:  $AB_3$

Output-based productivity index ( $T_O$ ) = Input-based productivity index ( $T_I$ )

$$T_O = CB_1/CA = DA/DB_2 = T_I \\ = (\text{output index})/(\text{input index})$$

Do “scale effects” matter in productivity analysis?

## Productivity Measurement: Multiple Output Approach



Measurement of technological progress (from  $t_0$  to  $t_1$ ):

- $y_1$ -based measure:  $AB_1$
- $y_2$ -based measure:  $AB_2$
- Output-based measure:  $AB_3$
- Directional-g measure:  $AB_4$

Productivity measures:

- $y_1$ -based measure:  $T_1 = 1 + AB_1/CA = CB_1/CA$   
 $(T_1 - 1)$  = proportional increase in output  $y_1$  due to technological progress
- $y_2$ -based measure:  $T_2 = 1 + AB_2/DB_2 = DA/DB_2$   
 $(T_2 - 1)$  = proportional decrease in output  $y_2$  due to technological progress
- Output-based measure:  $T_O = 1 + AB_3/OA = OA/OB_3$   
 $(T_O - 1)$  = proportional decrease in outputs  $y_1$  and  $y_2$  due to technological progress
- Directional-g measure:  $T_g = AB_4/CC' =$  number of units of the reference bundle  $g$  due to technological progress  
 $T_g$  = directional distance function (= - Luenberger's shortage function)

## The Effects of Diversity on Productivity

For a given technology  $Z$  and a reference bundle  $g$ , the shortage function  $S(z, g)$  evaluated at point  $z = (-x, y)$  is

$$S(z, g) = \min_{\alpha} \{ \alpha : (z - \alpha g) \in Z \},$$

where  $S(z, g)$  is the number of units of the reference bundle  $g$  reflecting the distance between point  $z$  and the frontier technology.

Consider producing  $z$  under  $K$  separate sub-systems, where  $z^k$  is produced by the  $k$ -th sub-system. A measure of the productive value of diversity is

$$D(z, g) = \sum_{k=1}^K S(z^k, g) - S(z, g),$$

where  $z = \sum_{k=1}^K z^k$ .

$D(z, g)$  measures the number of units of the reference bundle  $g$  that can be obtained by producing  $z$  in an integrated system compared to producing  $z$  from  $K$  separate (and less diverse) sub-systems.

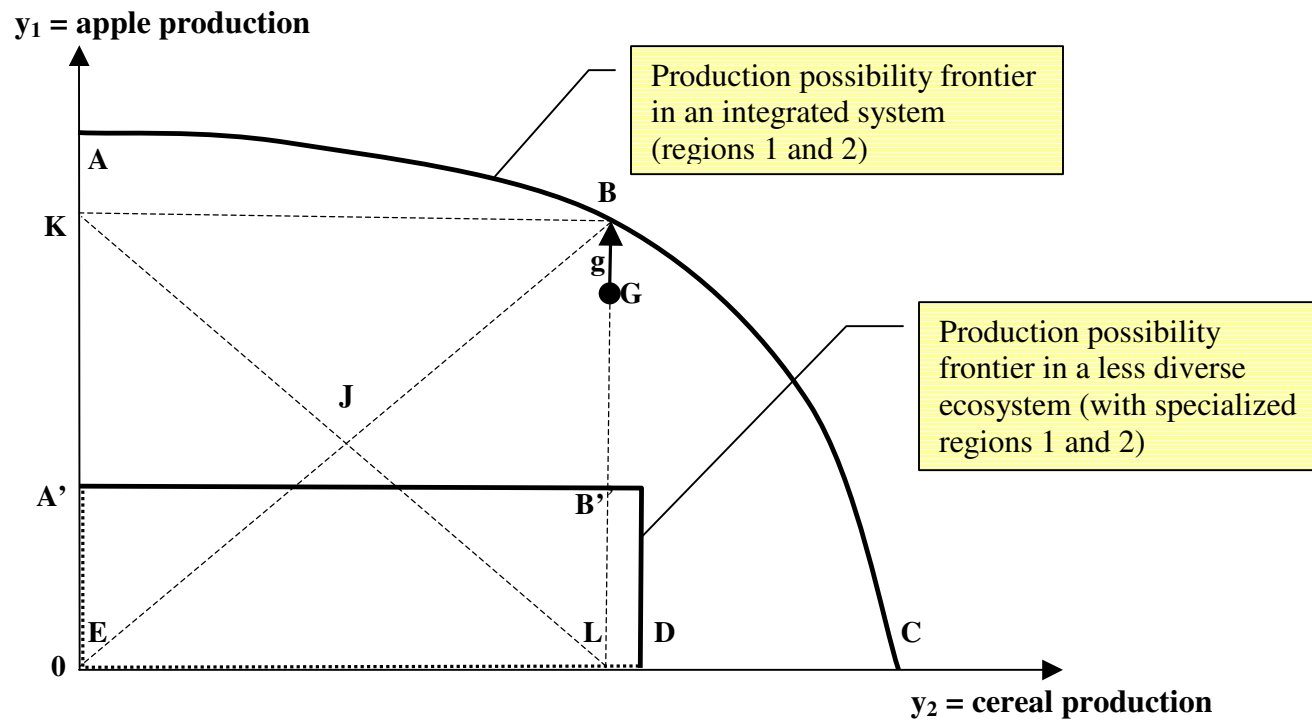
When  $g$  involves market goods (with unit price  $p$ ), a monetary value of diversity is given by

$$(p \cdot g) D(z, g)$$

(Note that the analysis still holds when some of the goods involve non-market environmental services).

## The productive value of diversity: apples and bees

- $z = (y_1, y_2, \text{bees}, \cdot)$ , where  $y_1 = \text{apple}$ ,  $y_2 = \text{cereal}$
- Start with an integrated agro-ecosystem in a region where apple orchards and bees are together.
- Consider  $K = 2$ : two specialized sub-systems (sub-regions 1 and 2) where  $z = z^1 + z^2$ ,
  - apples are only in region 1
  - bees and cereals are only in region 2



- Choosing  $g = 1$  lb. apple, the distance  $BB'$  measures the productivity loss when bees no longer perform pollination services.
- $D(z, g) = \text{distance } BB' = \text{quantity of apples that can no longer be produced under diversity loss.}$

## Decomposition of the productive value of diversity

The productive value of diversity  $D(z, g)$  can be decomposed as follows (Chavas 2009):

$$D(z, g) = D_C + D_R + D_V + D_A,$$

where

- $D_C$  = complementarity effect (when a process has a positive effect on the productivity of another)
- $D_R$  = scale effect (under increasing returns to scale, being “too small” reduces productivity)
- $D_V$  = convexity effect (under diminishing marginal productivity)
- $D_A$  = catalytic effect (when productivity is enhanced by the presence of “catalysts”).

In agriculture, the empirical evidence suggests that:

- Complementarity effects are important (contributing to “economies of scope” and farm diversification)
- Scale effects may not be very important...
- Non-convexity seems important, especially on larger farms (contributing to specialization)
- Complementarity effects and non-convexity effects work against each other.

## **Risk and Agricultural Productivity**

- **Agriculture faces a lot of risk (from weather effects, diseases, and pest damages)**
- **Risk is subject to management**
  - **By farmers**
    - **Diversification**
  - **By improved technology**
    - **Irrigation**
    - **Drought/flood resistance**
    - **Pest/weed control**
      - **Natural pest/weed control**
      - **Using pesticides/herbicides**
      - **Biotechnology (e.g., BT seeds)**
  - **Improved resilience of plants to adverse shocks**
- **Most agricultural productivity measures neglect risk (unfortunately)**
- **How to incorporate risk in productivity analysis?**
  - **Using a “state-contingent” approach**
    - **The most general case**
    - **But empirically challenging (Chavas 2008)**
  - **Estimating distribution function (e.g., applied to yield)**
  - **Using a moment-based approach (mean, variance, skewness)**

## **Implications for agricultural productivity**

- **Agriculture has been evolving toward greater specialization**
- **The productivity benefits of specialization are large**
  - **For farmers**
  - **For scientists**
- **The productivity benefit of complementarity are also large (that is why agriculture did not “industrialize” earlier)**
- **The productivity tradeoffs between specialization and diversity remain poorly understood.**
- **Can we capture the productivity gains of specialization without losing the benefits of complementarity?**
  - **Yes, but this will require a better identification and understanding of these productivity effects.**
- **There is a need to consider more explicitly the role of risk in productivity analysis**