Looking for Water in the Agricultural Productivity and Efficiency Literature

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The findings in this presentation are a first attempt to survey the agricultural productivity and efficiency literature with regard to the explicit inclusion of water aspects in productivity and efficiency measurements.

The aim is to contribute to the discussion on how to assess and possibly improve agricultural water productivity.

**Main methods surveyed:**

- Single-Factor Productivity Measures
- Total Factor Productivity (TFP) Indices
- Frontier Models
- Deductive Methods
0. Productivity: General Considerations

1. Single-Factor Productivity Measures
2. Total Factor Productivity Indices
3. Frontier Methods
4. Deductive Methods
5. Conclusions
0. Productivity: general considerations

- **Productivity** is generally defined as the ratio of the output(s) to the input(s) that a firm uses.
- It is widely used as a *performance measure* where larger values of the ratio are associated with better performance.
- **Potential productivity improvement** can be assessed when firms are compared to a benchmark:
  - with cross-sectional data, firms are compared with each other in the same period;
  - time-series data allow comparisons over time.
Sources of Improvements in Productivity

Source: Based on Coelli et al., 2005.
0. Productivity: General Considerations

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6. References
1 Single-Factor Productivity Measures

(i) Background

• Single-factor (also called partial) productivity ratios or indices, relate output to only one input, and are easy to calculate.
• Their use, especially variations of “crop per drop”, is dominant in productivity-related studies in the irrigation literature.
• Generally, water productivity in agriculture is understood as agricultural output per unit volume of water.
1 Single-Factor Productivity Measures

(ii) Review of Studies

• SFP studies use various methods to measure ‘water productivity’ across locations and time periods for comparison to other studies and/or to identify factors causing the differences.

• Enormous differences in spatial and temporal water productivity values are documented; variations are often attributed to the water input.

• Authors use these findings to explain the potential scope for improvement and to make policy recommendations, e.g. increase international food trade or upgrade irrigation technologies.
1 Single-Factor Productivity Measures (cont.)

(iii) Typical Features

- **Input Factors**: One input (water), one output (usually crop yield or revenue)
- **Scale**: Any scale, from field and basin level (and global)
- **Water Variable**: Water withdrawn, applied, consumed (as quantity)
- **Prices**: Sometimes considered for output, not for input; variable and fixed costs are not taken into account
- **Economic Approach**: Implicit water-crop production function (yet usually without consideration of other inputs); no underlying economic model
- **Focus**: Partial productivity
- **Aim**: Maximizing “crop per drop” ratios
(iv) Assessment

**Pros:**
- Simple approach
- Ratios easy to compute and compare

**Cons:**
- All variations in output attributed to one input
- Average, not marginal productivity
- No consideration of possible input or output substitution
- No prices or costs considered
- No insight into variables that cause differences
- Little value for policy analysis

**Further Development:**
Few studies so far combine SFP with regression analysis for analysis of influencing variables. Possibly lessons to be learned from partial productivity research on labor and capital.
0. Productivity: General Considerations

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2 Total Factor Productivity (TFP) Indices

(i) Background

- **TFP indices** compare a single output or an aggregate output index to an aggregate input index.
- Different ways of aggregation lead to different TFP indices, with Laspeyre, Paasche, Fisher, and Törnqvist indices being commonly used.
- These indices require both quantity and price information for the outputs and inputs included, and implicitly assume that all firms are efficient (which is unlikely to be true);
- Hence, TFP changes over time are attributed to technological change.


(ii) Review of Studies

Empirical studies using TFP indices measure changes in agricultural productivity over time or across countries.

• Review focused on a number of studies published in two recent books: Alston et al. (2010) and Fuglie et al. (2012).

Only a few studies account (indirectly) for water.

• A recent review of agricultural productivity studies concluded that future studies should make an effort to investigate the effects of irrigation and rainfall (Darku et al., 2013).
2 Total Factor Productivity (TFP) Indices (cont.)

(iii) Typical Features

- **Input Factors**: “All”/multiple inputs, “all”/multiple outputs
- **Scale**: Usually whole agricultural sector at the national level
- **Water Variable**: Water usually only indirectly taken into account (for example, by distinguishing between irrigated and non-irrigated cropland); irrigation fees are sometimes included
- **Prices**: Used for aggregation of inputs and outputs (though prices are not required for some indices); for water only irrigation fees included (if at all)
- **Economic Approach**: Growth theory
- **Focus**: Technological progress
- **Aim**: Gauging technological progress over time and/or across countries
(iv) Assessment

**Pros:**
- Analysis of overall performance of a country’s agricultural sector across

**Cons:**
- Difficulty of including water (data lacking at national level, both for quantity and price), and thus little insights into effect of water on productivity.
- Typical assumption of technically efficient firms may not be true.
  (Inefficiency can be tackled with Malmquist index.)

**Further Development:**
Only few studies so far use TFP indices at subnational level (e.g. district), and include water (e.g. as dummy variable) to study the effect of water.
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(i) **Background**

- **Frontier models** measure efficiency as a potential input reduction or potential output expansion, relative to a reference “best practice” or efficient frontier.
- Techniques for defining the frontier can be classified into **parametric** and **non-parametric methods**.
  - **Parametric methods** rely on specifying a production frontier and estimating its parameters econometrically, either **deterministic** or **stochastic frontier analysis**.
  - **Non-parametric methods** use mathematical programming techniques to construct the frontier. The most popular method to do this is **data envelopment analysis (DEA)**.
3 Frontier Models

(ii) Review of Studies

Review built on a meta-analysis of frontier models with a focus on farm-level studies: 167 studies from 1979 to 2005 (Bravo-Ureta et al., 2007).

- Of these, 28 studies presented models that incorporated water. Yet most either included water as one of numerous inputs, or grouped water with other miscellaneous factors in a combined input, without explicitly analyzing water’s role in technical efficiency.
- Only six studies incorporated water in more details.

Review also included studies beyond the meta-analysis. Of these, McGuckin et al. (1992) and Karagiannis et al. (2003) have a specific focus on water.
3 Frontier Models (cont.)

(iii) Typical Features

- **Input Factors**: One (or more) outputs, multiple inputs
- **Scale**: Usually at farm level
- **Water Variable**: Water used/applied
- **Prices**: Usually not included
- **Economic Approach**: Underlying economic model with stochastic frontier
- **Focus**: Technical efficiency (seldom allocative efficiency and/or technological progress)
- **Aim**: Moving to production frontier
(iv) Assessment

**Pros:**
- Analysis of extent of inefficiency and factors influencing inefficiency
- Water-related policy recommendations possible

**Cons:**
- Aggregation beyond farm level difficult (thus return flows and basin level issues are not incorporated)
- Bias from omitted variables

**Further Development:**
Studies increasingly include water, but few have explicit conclusions with respect to water. Some studies move beyond the production frontier approach to the profit frontier approach.
Outline

0. Productivity: General Considerations
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(i) Background

- Following Young (2005), a last group of methods can be termed “deductive.”
- They are based on the specification of a **physical production function**, and implicitly **assume that firms operate on the frontier**.
- Deductive methods can:
  - be used to incorporate physical externalities related to return flow issues.
  - incorporate the various economic linkages created by agricultural production.
4 Deductive Methods

(ii) Review of Studies

- Deductive methods include various alternatives such as the residual imputation method, mathematical programming, hydroeconomic models, and computable general equilibrium (CGE) models.
- A review of approaches based on deductive methods which link hydroeconomic models to policy is provided by Booker et al. (2012).
- While not inherently equipped with a multi-factor, basin-level framework, deductive methods provide the flexibility to overcome many of the limitations of the other methods.
- Yet deductive methods are usually not mentioned in the productivity and efficiency literature (even though they can also examine technological change).
(iii) Typical Features

- **Input Factors**: Inclusion of wide range of outputs and inputs possible
- **Scale**: Variable from farm to irrigation scheme to basin level; computable general equilibrium (CGE) models at national level
- **Water Variable**: Water withdrawn, applied, consumed (except CGE models)
- **Prices**: Included for inputs and outputs
- **Economic Approach**: Normative (neoclassical) economics, welfare theory
- **Focus**: Economic efficiency; possibility of including exogenous technological progress
- **Aim**: Deriving producers’ net income
4 Deductive Methods (cont.)

(iv) Assessment

Pros:  
- Well suited for policy analysis
- Flexible for reflecting any desired future economic and technological conditions
- Economic model can be linked with biophysical models (more limited with CGE)

Cons:  
- Constructed empirical and behavioral models
- Firms are assumed to be at production frontier
- More realistic deductive methods may require extensive data collection and model-building proficiency

Further Development:  
Few studies so far include water consumption.
Conclusions

• When looking for water in the agricultural water productivity and efficiency literature, it becomes apparent that numerous studies have examined the question of agricultural water productivity—using a wide range of definitions and methods (and also advocating a wide range of interventions).

• A key finding is that
  - most studies either incorporate field- and basin-level aspects but focus only on a single input (water), or
  - they apply a multi-factor approach but do not tackle the basin level.

• It seems that no study on agricultural water productivity has yet presented an approach that accounts for multiple inputs and basin-level issues.
References


