Agricultural Productivity Growth and Water: Evidence from the Frontier

Boris E. Bravo-Ureta
U. of Connecticut & U. de Talca, Chile

Roberto Jara - U. de Talca, Chile
Michée Lachaud - U. of Connecticut
Victor Moreira - U. Austral de Chile

GOING BEYOND AGRICULTURAL WATER PRODUCTIVITY

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Outline

- Introduction and Objectives
- Frontier Methodologies: An Overview
- Generating the Meta Dataset
- Descriptive Analysis
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Introduction and Objectives

Across the globe, snow and ice melting along with changing precipitation patterns are modifying hydrological systems and **adversely affecting** the quantity and quality of **water resources** (Porter et al. 2013; IPCC 2014).

Population and **income growth** are expected to put increasing pressure on the agricultural sector to **intensify production** and the expansion of **irrigation water** to meet rising demands for food and fiber is a prominent option.

Demand for water resources will expand in **other sectors** of the economy. The combination of these factors is expected to generate a **growing water scarcity** around the globe.

Introduction and Objectives…..

Irrigation water worldwide accounts for approximately **70% of all freshwater withdrawals**. The increasing water scarcity will put added pressure on farming to reduce consumption so that water can be diverted elsewhere.

The overall pressure on water resources points to the importance of improving the **productivity** and **efficiency of water** use in agriculture.

Scheierling et al. (2014) argue that the literature that deals with the role of water on farm productivity provides **limited insights** on actions that could be taken to increase agricultural production.

Introduction and Objectives…..

General objective: Review the frontier function literature focusing on water productivity and efficiency building on Bravo-Ureta et al. (2007).

Specific objectives:

1. Update and expand the database available from our 2007 paper, with a **specific focus on water**.

2. Analyze specific water-related issues in frontier models.

3. Perform a meta-regression analysis for farm level studies focusing on the inclusion of water.

4. Operationalization of how **frontier models** could be used in project work related to irrigated agriculture with **water-related interventions** (e.g., irrig. infrastructure, systems and scheduling), including impact evaluation.

Introduction and Objectives….

Contributions

Up to date systematic and comprehensive analysis of the effects that different methodologies and study-specific attributes have on TE scores.

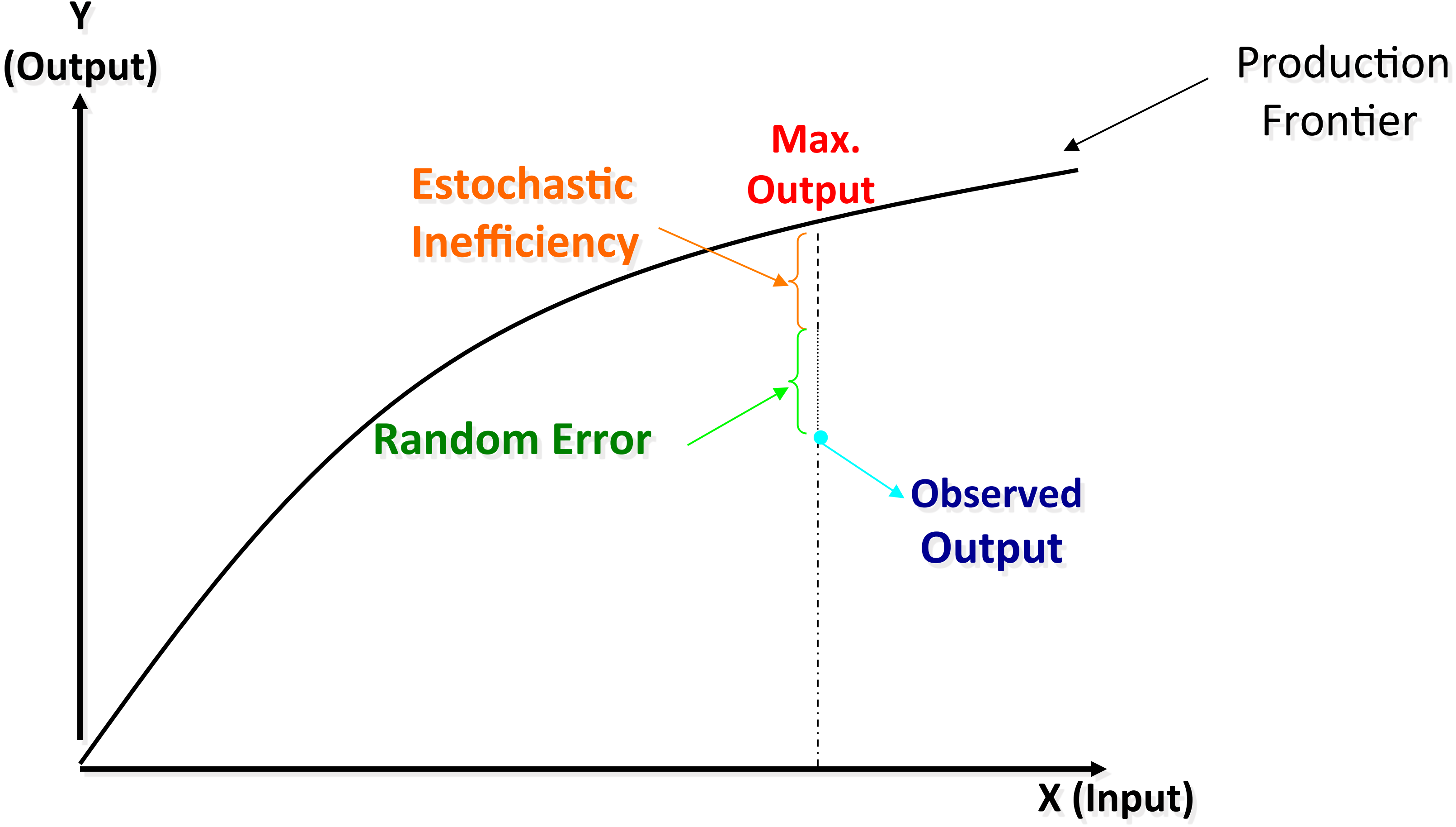
Focus on water related papers. To our knowledge the first comprehensive study to do so.

Comprehensive literature search conducted yielding **408** studies, with **867 data points** containing Avg. TE (some studies report multiple results).

Of the total 408 papers, **107 have a water focus**.

Frontier Methodologies: An Overview

$$Y_i = \beta X_i + \delta Z_i + (v_i - u_i)$$



Frontier Methodologies: An Overview

Farrell (1957) (preceded by Debreu 1951 & Koopmans 1951), seminal paper propelling frontier function research (Fried, Lovell and Schmidt 2008; Greene 2008).

Farrell: efficient unit isoquant to define & measure **TE** and **AE**, and **EE= TE*AE**

Much of the literature has **focused on TE** and this is our focus as well.

TE is a measure of the distance a firm operates relative to its frontier, such distance can be measured with an **input** or an **output orientation**.

Frontier Methodologies: An Overview…

TE: index between 0% and 100%; proxy measure for **managerial performance**.

Frontier methodology: divided into **parametric** and **non-parametric** methods. Parametric models subdivided into **deterministic** and **stochastic frontiers.**

Major limitation of deterministic frontiers: measurement errors distort TE scores (Fried, Lovell and Schmidt, 2008).

Stochastic Frontier Analysis (SFA) (ALS 1977; Meeusen and van den Broeck 1977) copes with outliers through a **composed error** structure (2-sided symmetric and a one-sided component).

Frontier Methodologies: An Overview…

Frontier studies can also be separated into **primal and dual** approaches.

Non-parametric frontiers come directly from Farrell (1957). It took~20 years to get a footing in the literature (Charnes, Cooper and Rhodes 1978). Can **readily** accommodate **multi-input multi-output** technologies.

Early **multi-input multi-output parametric** models appealed to dual cost or profit frontiers. Data challenges at the micro-level and need for behavioral assumptions.

Recent developments in the stochastic literature enable the estimation of multi-input multi-output models with **input** & **output distance functions**. Further extension, **directional distance functions**, which have been used to examine the tradeoff between good and bad outputs.

Frontier Methodologies: An Overview…

Frontier functions can also be characterized in terms of the type of data used, as **cross-section or panel data**.

Panel data frontiers have made **considerable progress** in both the non-parametric and the parametric worlds.

Panel data enhances our ability to identify different components of **total factor productivity change**, (TC, TE change and SEC).

In the stochastic approach, recent work by Greene (2005) has opened up useful options to account for **time invariant firm heterogeneity** (TRE & TFE)

Frontier Methodologies: An Overview…

Explaining TE. Initially, 2-step approach, TE estimated first, using any of the models we have discussed, in the 2nd-step TE is regressed on an array of variables.

2-step procedure has **criticized** in both parametric and non-parametric models. Fried, Lovell and Schmidt (2008) state: **"We hope to see no more two-stage SFA models"** (p. 39).

2-step approach increasingly **replaced** by 1-step procedures in the SFA literature. The most common is by Battese and Coelli (1995). Progress has also been made in the explanation of TE in the no-parametric literature using bootstrapping techniques.

On Going: models that decompose TE into **persistent** and **transient** plus **unobserved time invariant heterogeneity** (Colombi, et al., 2014; Filippini & Greene 2014; Kumbhakar, Lien & Hardaker 2014; Tsionas & Kumbhakar 2014; Lachaud, Bravo-Ureta & Ludena 2014).

Frontier Methodologies: An Overview…

Another recent development in **SFA, correcting for selectivity bias** (Greene, 2010). Bravo-Ureta, Greene and Solís (2012) combine the Greene (2010) model with Propensity Score Matching (PSM) to account for **biases from observables and unobservables**. Then **decompose impact of a development project** into output growth (i.e., upwards shifts in the frontier) and management improvements (i.e., narrowing the gap from the frontier) for cross sectional data models

Also receiving attention is the possible **endogeneity** of inputs in stochastic frontiers. Zellner, Kmenta and Drèze (1966) provided the classical justification for valid econometric estimates of production functions.

More recently, several authors (Tran and Tsionas 2013; Shee and Stefanou 2014) have proposed **alternative approaches** to tackle the **endogeneity** issue.

Frontier Methodologies: An Overview…

Dynamic Efficiency in DEA and SPF active area of work (Stefanou and colleagues).

In sum, **major methodological advances** have been made in both parametric and non-parametric frontier models.

SFA and DEA have important similarities as well as differences. Both are rigorous analytical tools to measure efficiency relative to a frontier.

Two key differences (Fried, Lovell & Schmidt (2008):

1. **Econometric approach** is stochastic: makes it possible to separate noise from inefficiency, provides basis for statistical inference.
2. **DEA** is nonparametric: avoids misspecification due to the choice of the functional form (of both technology and inefficiency).

Frontier Methodologies: An Overview…

Dynamic Efficiency in DEA and SPF another active area of work (Stefanou and colleagues).

O'Donnell (2014): the core assumptions of DEA "… are rarely, if ever true (e.g., output, input and environmental variables are almost always measured with error, if not unobserved). It follows that most, if not all, DEA estimators are inconsistent" (p. 22).

O'Donnell quotes Simar & Wilson (2000): "Consistency is an essential property of any estimator. …. If the data contains noise, DEA …. estimators will be inconsistent, and there seems little choice **but to rely on SFA** ."

Clearly the **SFA-DEA controversy** will go on for a few more rounds.

Generating the Meta Dataset

We started with our **2007 paper** but did new a comprehensive search for this study conducted using a number of databases (EBSCOhost, Econlit, Academic Search Premier, Agricola, Scopus and ISI Web of Knowledge which includes Agris International, Science Direct and Social Science Citation Index).

An additional search on specific journals that overtime have published a good number of TE studies and/or are major outlets of agricultural economics work.

Generating the Meta Dataset ...

Key words used: Irrigation, Technical Efficiency, Farming, Agriculture, Productivity and Frontier, water, water use, groundwater, water flows, return flows, water quality, and leaching which were combined in different ways to expand the search.

The two critical and necessary key words in all searches were **Technical Efficiency** and **Agriculture**. All searches were limited to papers written in English and ended this past July.

Combined searches yielded **408 papers for the Meta-Regression work**, including all papers (167) in Bravo-Ureta et al. (2007). All References are filed using the Mendeley Desktop Program.

Descriptive Analysis

107 of a total of 423 papers have a water focus.

But **15 of the water studies** considered only in selecting 26 papers reviewed and are excluded elsewhere. These are aggregate and **our main focus is on farm level**, or do not report TE required as the dependent variable in Meta-Regressions **leaving 408 papers** (Table 1 and 2).

Some papers present more than one MTE from alternative methods => number of MTEs, or cases, from the 408 studies is 816, **186 from water studies**.

Table 1: summary of Average MTE (AMTE) for various groupings for all 408 studies and separately for the 92 water studies.

Table 1. Overview of Empirical Studies of Technical Efficiency in Farming

Category	Water papers		Non-water papers		All papers	
	No. of Cases	AMTE*	No. of Cases	AMTE	No. of Cases	AMTE
Approach						
Parametric	113	**73.3**	470	**75.8**	583	**75.3**
Non-Parametric	73	**74.0**	211	**73.7**	284	**73.7**
Stochastic	112	**73.6**	399	**76.5** ●	511	**75.9**
Deterministic	74	**73.6**	282	**73.2** •	356	**73.3**
Data						
Panel	46	**76.5**	261	**77.6** ●	307	**77.4** ●
Cross Sectional	140	**72.7**	392	**73.6** •	532	**73.4** •
Functional Form**						
Cobb-Douglas	78	**73.6**	248	**73.3** •	326	**73.3** •
Translog	35	**72.9**	199	**78.9** ●	234	**78.0** ●
Others	0	**---**	24	**73.7** •	24	**73.7**
Technology Representation						
Primal	149	**73.8**	633	**75.1**	782	**74.8**
Dual	35	**73.3**	32	**73.8**	67	**73.5**
AMTE	***73.6***		***75.1***		***74.8***	
Number of Cases	***186***		***681***		***867***	
Number of Studies	***92***		***316***		***408***	

* Circle size denotes statistical differences in means.

** Valid for Parametric approach studies

Table 2. Overview of Empirical Studies of TE in Farming

Category	Water papers		Non-water		All papers		
	No.	AMTE*	No.	AMTE	No.	AMTE	
Geographical Region							
Africa	39	**65.6**	64	**69.9**	103	**68.3**	
Asia	113	**74.0**	141	**75.2**	254	**74.7**	
L. America	2	**61.0**	35	**63.0**	37	**62.9**	
N. America**	8	**81.0**	126	**78.7**	134	**78.8**	
E. Europe	1	**69.0**	29	**72.9**	30	**72.7**	
W. Europe & Oceania	23	**83.9**	286	**76.4**	309	**77.0**	
Country Income							
LIC***	50	**69.8**	47	**78.7**	97	**74.1**	●
LMIC	64	**74.7**	132	**72.5**	196	**73.2**	●
UMIC	32	**74.1**	98	**66.6**	130	**68.5**	●
HIC	40	**76.2**	404	**77.6**	444	**77.5**	⬤
Product							
Rice	63	**76.1**	57	**73.3**	120	**74.7**	●
Maize	2	**74.5**	28	**76.1**	30	**76.0**	●
Wheat	18	**74.3**	15	**73.7**	33	**74.0**	●
Mixed Grains	0	---	38	**73.7**	38	**73.7**	●
Crops and Livestock	89	**70.1**	261	**71.0**	350	**70.8**	●
Dairy	13	**84.0**	188	**80.8**	201	**81.0**	⬤
Other Animals	1	**81.0**	72	**78.3**	73	**78.3**	●
Whole Farm	0	---	22	**72.5**	22	**72.5**	●
AMTE	***73.6***		***75.1***		***74.8***		
Number of Cases	***186***		***681***		***867***		
Number of Studies	***92***		***316***		***408***		

* Circle size denotes statistical differences in means.

** North America includes the United States and Canada.

*** LICs: Lower Income Countries, LMICs: Lower Middle Income Countries, UMICs: Upper Middle Income Countries, and HICs: Higher Income Countries (World Bank, 2014).

Descriptive Analysis…

Equal Variance: one-way analysis-of-variance (ANOVA), multiple-comparison tests. Unequal Variance: Kruskal Wallis non parametric test to tests the hypothesis that several samples are from the same population.

Water Papers: No significant differences found

Non-Water Papers

AMTE Stochastic is higher than Deterministic

*AMTE Panel is higher than Cross Sectional

#AMTE Translog is higher than Cobb Douglas and Other

All Papers

*AMTE Panel is higher than Cross Sectional

#AMTE Translog is higher than Cobb Douglas

AMTE **Dairy is higher** than all other categories

Overview of 'Selected' Water Papers

I. **Irrigation:** **73** studies subdivided in **A, B, C**.

   A. **Quantity** 53 studies subdivided into 5 classes:

      i) Quantity of Water used = 18;

      ii) Hours of Irrigation = 5;

      iii) No. Irrigations, Index, or Irrig. Expenses = 20;

      iv) Percent of Irrigated Land = 7; and

      v) Land Area Irrigated= 3.

   B. **Dummy: 9** studies dummy Yes/No Irrig.

   C. **Mixed:** 11 papers combines **A & B**.

II. **Rainfall/Precipitation: 6** papers, quantity or dummy

III. **Combines I & II.** **13** irrigation and precipitation.

IV. **Distance Functions:** **5** articles.

V. **Aggregate: 9** papers.

Classification of Water Papers

I- Irrigation		
A) Quantity	Paper Number	Total
i) Water	9, 20, **25**, 26, **27**, 32, **35**, 37, 57, 58, 68, 74, **76**, 94, **97**, 98, 99, **100**, 107	19
ii) Hours of irrigation	**1**, 61, 67, 86, 103	5
iii) Number of irrigations/ Index/Expenses	8, **12**, **14**, 15, 40, 42, 43, 45, 50, 56, 62, 64, 70, **78**, 80, 84, 85, 87, 96, 101, 102	21
iv) Percent of Irrigated Land	17, 18, 22, 46, **51, 55**, 60	7
v) Land Area Irrigated	**13**, 21, 34	3
B) Dummy	10, 16, 31, 48, 59, **72**, 82, 83, **105**	9
C) Mixed (quantity & dummy)	3, 6, 7, **11,** 39, **54,** 79, 89, 95, 106	10
Total I		**74**
II- Rainfall/Precipitation		
	2, 36, 49, **75**, 77, **90**	**6**
III- Combines I & II		
Irrigated Land, Rainfall	19, 23, 24, 28, 29, **38,** 47, 52, **63, 66, 69,**71,73	**13**
IV- Distance Function		
	4, 41, 81, 91, **93**	**5**
V- Aggregate Data		
	5, 30, 33, 44, **53,** 65, 88, 92, 104	**9**
OVERALL TOTAL		**107**

Water Additional Characteristics

Category	Water Papers
Irrigation	74
Quantity	29
Others	45
Rainfall/Precipitation	6
Combined both	13
Distance Function	5
Aggregate Data	9
Total	107
Paper Main Characteristics	No of Cases
Specific Irrigation Technologies	9
MetaFrontier	**6**
Panel Data	47
Cross Sectional	139
Rice	64
Wheat	17
Daity and Cattle	7
Others	98
Model Specification	
Production Function	122
Inefficiency Equation	29
Both	13
Neither (Irrigated vs non-irrigated)	22

Overview of ‘Selected’ Water Papers

In the report we have a summary of **26 papers.**

We selected what we consider the **“best” papers** in each of the five groups (I-V): depth of treatment of water; overall quality, methodological approach, favored more recent papers, good representation of alternative approaches).

Here we focus on just a **hand full of papers**, which we consider the most informative.

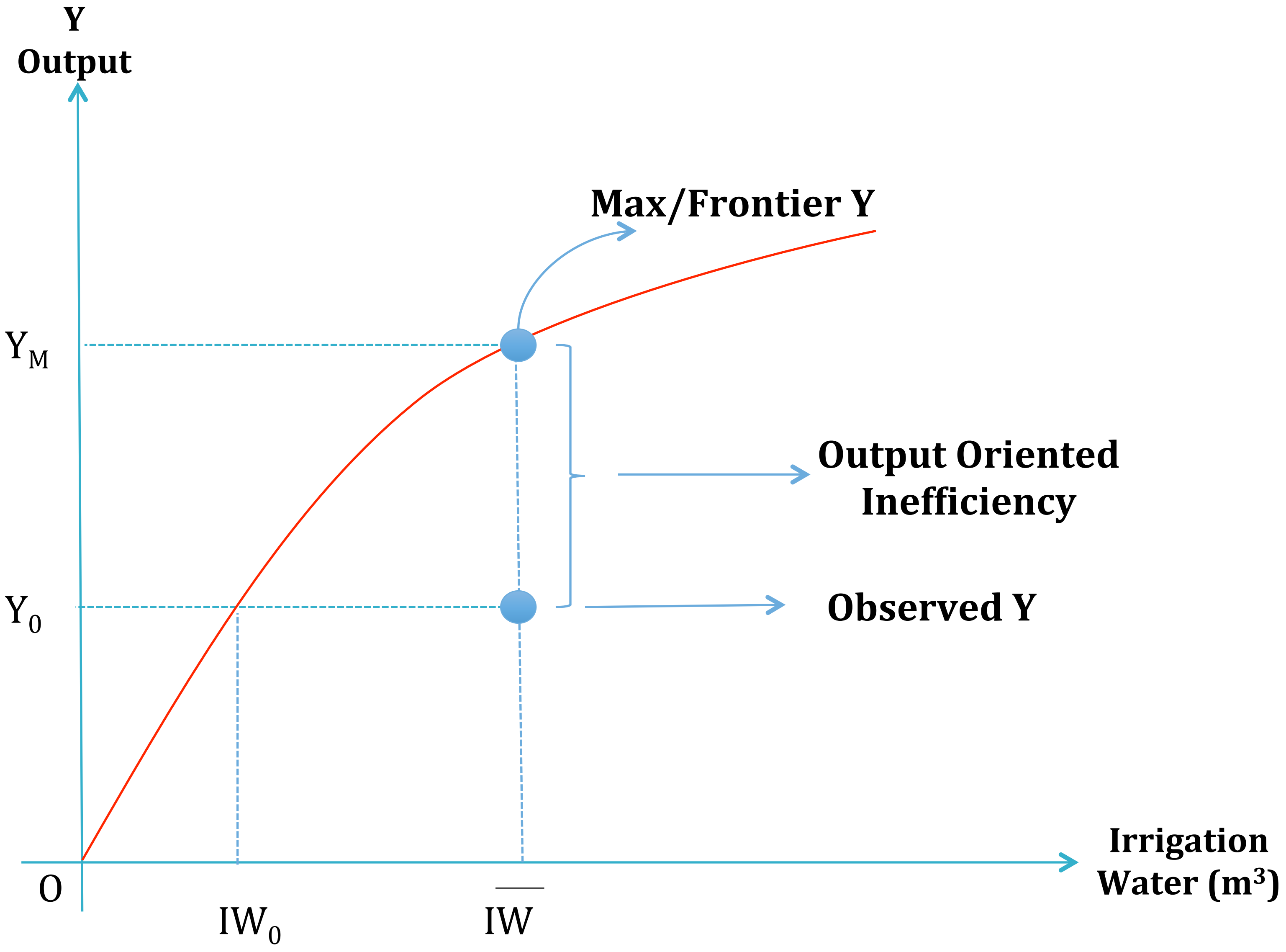
Overview of 'Selected' Water Papers

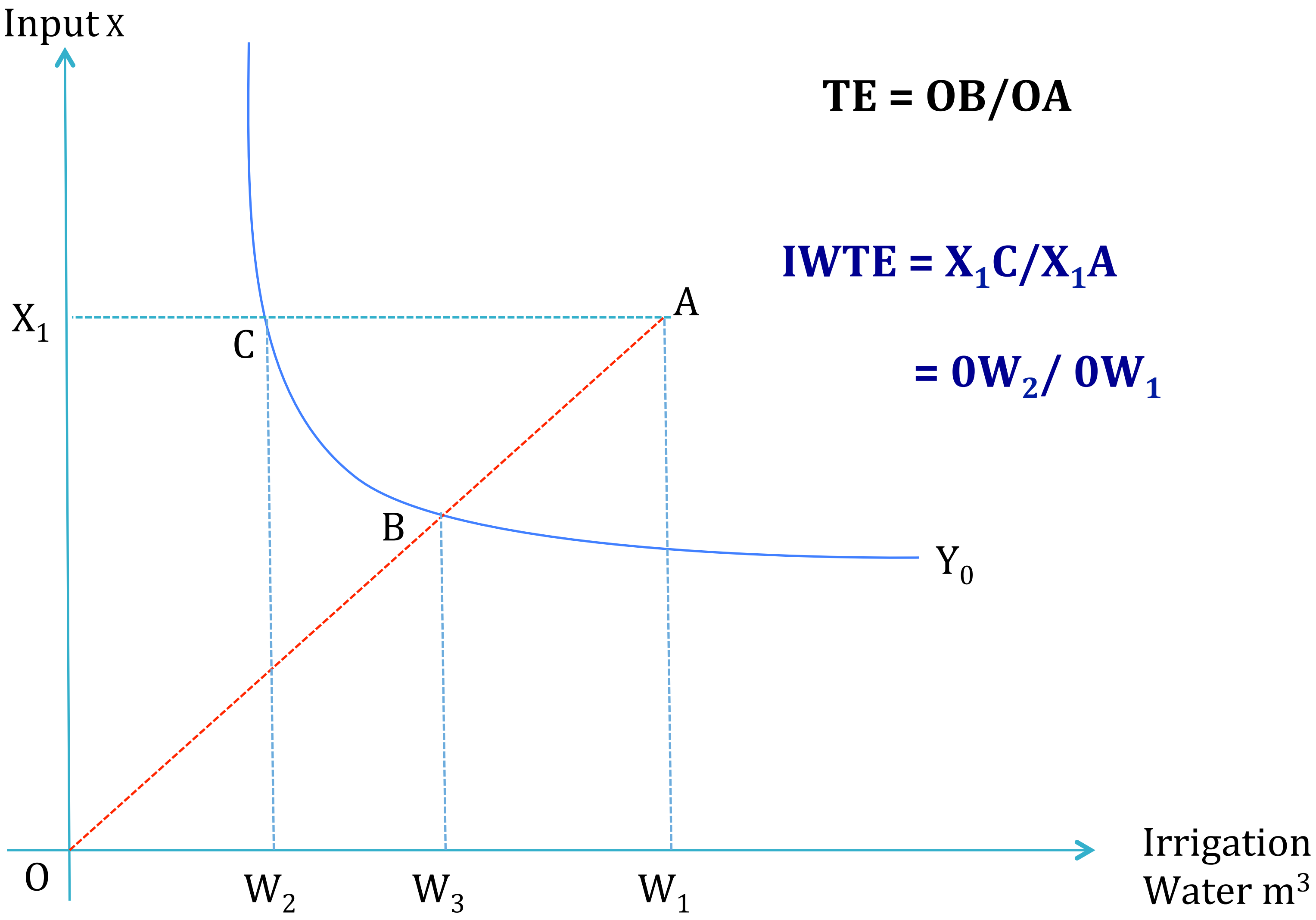
Karagiannis et al. (2003), first to present a measure of **irrigation water TE (IWTE)**, using an SPF model based on previous work by Reinhardt and colleagues (1999 and 2002).

IWTE is a non-radial input oriented measure and has an economic instead of an engineering interpretation.

IWTE = ratio of the minimum amount of water required to the observed water used to produce a given level of output conditional on the technology and the quantity of other inputs.

IWTE = amount of water that could be saved while keeping output and other inputs constant.


Y
Output
Max/Frontier Y
Y_M
Output Oriented Inefficiency
Observed Y
Y_0
O
IW_0
$\overline{IW}$
Irrigation Water (m^3)



$TE = OB/OA$

$IWTE = X_1C/X_1A$

$= 0W_2/\ 0W_1$

Input Oriented TE & IWTE (Karagiannis, Tzouvelekas & Xepapadeas, 2003)

Overview of ‘Selected’ Water Papers…

50 out-of season vegetable farms, 4 regions in Crete, Greece, 1998-1999. TL SPF is fitted using B&C1995. Total value of vegetables produced regressed on conventional inputs and irrigation water (m^3). 2-step to explain IWTE.

Results: water positive & significant partial elasticity =0.053; but lowest of all partial elasticities reported. IRTS 1.13.

Shadow price of water significantly higher than market price. The former an upper bound given all other inputs are constant.

Avg. TE=70.2% (36.3%-89.1%) **Avg. IWTE=47.2%** (23.1%-98.6%) => output could be achieved using 52.8% less water holding other inputs at observed levels.

COST savings by reducing irrigation water to its efficient level small since water costs are a minor share of total cost.

Overview of 'Selected' Water Papers….

Coelli & Sanders (2012) TE wine grape production, unbalanced panel data, 135 growers (N=214), Eastern Australia, 2006-07 / 2009-10. TL SPF and B&C1992.

Tons of wine grapes harvested regressed on conventional inputs and irrigation water applied (megaliters).

Avg. TE=79% (30%-100%). IRTS (Mean=1.07) suggest further farm consolidations.

Irrigation water statistically **positive and significant** mean partial elasticity=0.30.

Avg. **shadow price for water=$489**/megaliter compares to Avg. **spot price~$300**/megaliter => underuse of water.

Overview of 'Selected' Water Papers…

Njiraini & Guthiga (2013), TE and IWTE, and 2nd-step for the latter.

Cross sectional data, March-April 2010, 201 small-scale irrigators, lake Naivasha basin. Input oriented Variable RTS DEA. Single output, several inputs including the quantity of water used for irrigation (m^3).

Results: farm profits positive & significant effect on IWTE, land fragmentation negative effect.

Sprinkler **technology** negative effect on IWTE while drip technology positive effect relative to bucket technology.

Implications: land fragmentation results suggest that irrigation might be better managed on larger plots.

Overview of ‘Selected’ Water Papers…

Athukorala & Wilson (2012), TE onion production, sample of 276 farmers in Sri Lanka.

Onion yields (kg/ha), CD SPF including water used (m^3/ha) in the frontier and several irrigation related variables in inefficiency component.

Results: low Avg. TE (53.6% & 57.1%), negative elasticities for water used.

Free water leads to overuse, and farmers are not aware of negative long-term consequences.

Overview of 'Selected' Water Papers…

Lilienfeld & Asmild (2007): effect of irrigation system type on IWTE, sample from western Kansas. **Sub-vector variation of DEA**, data for the 8-year period 1992-1999, 43 farms (N=339). All crops under irrigation relied on water pumped from the Ogallala aquifer.

In 1992, just over **50% used flood irrigation** systems; by 1999, **85% relied on center pivots**. Model: output for 6 crops, non-irrigated and irrigated area for each crop, irrig. water (m^3), available water supply (AWS) in the soil, Avg. annual precipitation, and other conventional inputs.

Results: Avg. **excess water**/ year 349 to 1,216 m^3 => roughly half of the water applied was excess. **No single irrig. System** associated with high IWTE, or zero excess water use. Moving to center pivots may not be warranted. Assigning public funds to improve management a desirable option.

Overview of ‘Selected’ Water Papers….

Gebregziabher, Namara & Holden (2012): analyze TE and productivity for irrigated and rain-fed small-scale producers in Tigray, Ethiopia. Random sample (2004-05), 331 with access to irrigation, 282 only rain-fed. 2,194 plots, 426 irrigated and 1,768 rain-fed. **PSM to match plots**.

CD SPF, B&C1995. The results confirm that irrigation does shift the frontier out. Total as well as average production considerably higher for irrigated compared to rain-fed plots.

Avg. TE=45% for irrigated plots & 82% for rain-fed plots => great potential to increase output by improving TE in irrigated farms (**Schultz type result**). Key: training to enhance agronomic and water management skills.

By contrast, **rain-fed farmers** very close to their frontier. A critical action for this group is to improve soil moisture and to enhance yields associated with improved seeds and fertilizers.

Overview of 'Selected' Water Papers…

Adhikari & Bjorndal (2012) Nepalese Living Standards Measurement Surveys collected in collaboration with the World Bank in 2003. Detailed data for 2,585 households. TL **stochastic output distance function (SODF)** and a DEA model for comparison.

TL model is B&C1995. DEA TE analyzed in a 2-Step regression. Models: 4 outputs and 6 inputs including separate measures for irrigated and rain-fed land measured in hectares.

SODF: Irrigated land highest Avg. elasticity of all inputs=0.20, that for rain-fed land is a bit lower=0.16 (both highly significant). SODF model reveals DRTS and overall ATE=73%.

Group ATE: 72%-small; 77%-medium; 75%-large farms.

Efforts to **promote medium size farms** by encouraging the consolidation of the smaller operations and breaking up the larger farms. **Irrigation** primary factor to get higher yields.

Meta –Regression Framework

A suitable framework to deal with dependent variables defined on the unit interval is the **Fractional Regression Model (FRM)** proposed by Papke and Wooldridge (1996). The FRM is a Quasi Maximum Likelihood Estimator (QMLE).

Recent efficiency studies by McDonald (2009), Ramalho (2010) and Ogundari (2014) have relied on the FRM and we follow their lead in our Meta Regression Analyses (MRA).

The empirical regression model to be estimated below can be written as:

$$MTE_i = \alpha_0 + X_i'\beta + \varepsilon_i, \quad i=1,\ldots\ldots N;\ \varepsilon_i \sim N(0, \sigma_\varepsilon)$$

Description of Variables

MTE	MTE for each observation obtained from the meta-dataset or the water dataset (Dependent Variable)
SPF	1 if the model is a stochastic production frontier and 0 otherwise, the omitted category is deterministic frontier
PAR	1 if it is a parametric model and 0 otherwise, the omitted category is non-parametric;
CS	1 for cross sectional data and 0 otherwise, the omitted category is cross sectional data;
VSZ	Ratio between the number of explanatory variables and the number of observations included in the study
RICE	1 if rice is the product analyzed and 0 otherwise;
WHEAT	1 if wheat is the product analyzed and 0 otherwise;
DAIRY	1 if dairy is the product analyzed and 0 otherwise;
SIO	1 if a single output is used and 0 otherwise, the omitted category is farm with two or more outputs;
AFRICA	1 if the region of the study is Africa and 0 otherwise;
ASIA	1 if the region of the study is Asia and 0 otherwise;
EEurope	1 if the region of the study is East Europe and 0 otherwise;
LAC	1 if the region of the study is Latin America and the Caribbean and 0 otherwise;
NAMERICA	1 if the region of the study is North America and zero otherwise, the omitted geographical category is West Europe and Oceania;
WATER	1 if a water study and 0 otherwise.
W_PROD	1 if water enters only in the production frontier;
W_INEFF	1 if water enters only in the inefficiency term;
W_BOTH	1 if water is in both parts of the model (production and inefficiency)

Fractional Meta-Regressions of MTE for all papers

N=822	**Model 1**		**Model 2**		**Model 3**		**Marginal Effects Model 3**	
Variables	**Coeff**		**Coeff**		**Coeff**		**Coeff**	
Constant	0.965	***	1.036	***	1.039	***		
SPF	0.315	***	0.401	***	0.405	***	0.077	**
PAR	-0.263	***	-0.290	***	-0.297	***	-0.054	***
CS	-0.161	***	-0.138	**	-0.137	**	-0.025	***
VSZ	1.134	***	1.099	***	1.108	***	0.207	*
Rice	0.062		0.005		0.011		0.002	***
Wheat	0.044		-0.003		0.005		0.001	***
Dairy	0.480	***	0.361	***	0.363	***	0.064	**
SIO	0.053		0.035		0.032		0.006	***
Africa			-0.315	***	-0.308	***	-0.061	***
Asia			-0.02		-0.012		-0.002	***
EEurope			-0.333	**	-0.333	**	-0.067	***
LAC			-0.556	***	-0.556	***	-0.116	***
North America			0.119		0.119		0.022	***
Water					**-0.026**		**-0.005**	***
QMLE	-327.0		-324.9		-324.9			
Deviance	90.5		86.3		86.3			

Note: * 10%, ** 5% and *** 1% level of significance.

Fractional Meta-regressions of MTE for Water Papers

N=185	Model 1		Model 2		Model 3		Marginal Effects of Model 3	
Variables	Coeff	Sign.	Coeff	Sign.	Coeff	Sign.	Coeff	Sign.
Constant	0.947	***	1.48	***	0.514			
SPF	1.258	***	1.32	***	1.718	***	0.314	***
DEA	-1.472	***	-1.53	***	-2.007	***	-0.438	***
CS	-0.443	***	-0.35	**	-0.466	***	-0.074	***
CD	0.229		0.21		0.369	*	0.051	**
VSZ	2.612	*	2.31	*	2.79	**	0 .428	***
Rice	-0.022		-0.02		0.028		0.004	
Wheat	0.005		0.083		0.004		0.001	
Dairy	0.657	***	0.2		0.357		0.050	
SIO	0.371	*	0.23		0.191		0.031	
Africa			-0.72	*	-0.516		-0.094	
Asia			-0.44		-0.319		-0.050	
Europe			-0.9	**	-0.952	**	-0.177	***
LAC			-0.88	*	-0.609		-0.102	
North America			-0.19		0.608		0.071	
W_prod					0.916	***	0.145	***
W_Ineff					1.141	***	0.186	***
W_both					1.053	***	0.182	***
QMLE	-75.02		-74.6		-72.7		-72.4	
Deviance	22.5		21.6		18.58		16.95	

Note: * 10%, ** 5% and *** 1% level of significance.

Concluding Remarks

The studies show high level of **TE compared to IWTE.**

Also, **partial elasticities** of production for water generally positive.

High Heterogeneity in how water is incorporated. Some papers only mention water while others have as the specific objective to examine the role of irrigation in farm efficiency and productivity.

Considerable variability in the methodologies as well as the data used.

Given the **growing importance** of this topic, one would expect an increasing focus from multilaterals, bilateral, foundations, NARS…..

There is a **role for Frontier Function Studies. At the farm level Benchmarking.**

Concluding Remarks…

Methodologically, Reinhard approach as adapted by Karagiannis et al. (2003) to irrigation, seems as the most informative but requires volumetric measures of water. This is challenging particularly in Lesser DCs.

Is it possible to **approximate** this kind of measure when the 'precision' gauges are not there?????

Calculating volume of water used in **gravity irrigation systems** a challenge. Very useful in evaluating the economics of promoting and adopting "modern" irrigation systems.

Having a direct measure of the quantity of water with **parametric** model makes it possible to **calculate shadow values** which would be useful for project evaluation.

Very little evidence **across systems** and of B/C analysis based on actual farm level data. TFP and Water??? More work needed.

Agricultural Productivity Growth and Water: Evidence from the Frontier

Boris E. Bravo-Ureta
U. of Connecticut & U. de Talca, Chile

Roberto Jara - U. de Talca, Chile
Michée Lachaud - U. of Connecticut
Victor Moreira - U. Austral de Chile

MUCHAS GRACIAS