

# **A META ANALYSIS OF THE AGRICULTURAL FRONTIER LITERATURE WITH A FOCUS ON WATER STUDIES**

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The scientific community has progressively developed solid evidence concerning the impact of climate change on natural and human systems. The melting of snow and ice along with changing precipitation patterns are altering hydrological systems and adversely affecting the quantity and quality of water resources (Porter et al. 2013; IPCC 2014). Furthermore, income and population growth are projected to exert escalating pressure on the farming sector to increase productivity growth and the expansion of irrigation water use is often cited as an important avenue to follow. In parallel fashion, the demand for water resources will rise in other sectors of the economy and the confluence of these factors is anticipated to create increasing water scarcity in many parts of the globe.

Worldwide, irrigation accounts for about 70% of freshwater withdrawals; hence, there is little doubt that as water becomes more constraining the pressure on farming to diminish consumption to release water for other uses will grow. It is evident then that improving the productivity of water use in agriculture is a central policy objective. Therefore, it is important to synthesize the available literature that focuses on the connection between water and farm productivity to generate a better understanding on actions that could be taken to increase agricultural production while using water in a way that avoids adding to the scarcity of this essential resource (Scheierling et. al. 2014, World Bank).

Thus, the general objective of this study was to undertake a meta-analysis of the frontier function literature focusing on the technical efficiency (TE) component of water productivity. Water papers are defined here as those that explicitly include irrigation and/or precipitation in the analysis of TE. The point of departure was the previous meta-analysis for agriculture by Bravo-Ureta et al. (2007).

The specific objectives of the study were: 1) to generate a comprehensive data set of TE studies published in English in refereed journals with a special focus on water; 2) to analyze specific water-related issues in frontier models; 3) to perform a meta-regression analysis for farm level studies focusing on the inclusion of water; and 4) to discuss how frontier models could be used in project work related to irrigated agriculture including impact evaluation.

This paper contributes to the existing frontier function literature by providing an up to date systematic and comprehensive analysis of the effects that different methodologies and study-specific attributes have on Mean Technical Efficiency (MTE) scores. Moreover, the focus on water related papers appears to be the first of its kind.

A comprehensive literature search was conducted using a variety of search engines as well as a more pointed search in some specific journals. The search yielded a total of 415 studies published between 1980 and mid 2014. Of this total, 108 are water studies and the remaining 307 are farm level non-water studies. The 108 water studies include 9, which use aggregate data (e.g., country, provincial, municipal) and another 6 that have incomplete

data for the meta-regression analysis; thus, for the latter analysis we retained 93 water studies for a total of 400 (93 plus 307). These 400 studies yield 862 observations or cases given that some studies use alternative frontier models and report more than one MTE.

We first conducted a descriptive analysis based on all 400 farm level studies followed by a more detailed analysis that included all 108 water studies. We then performed a meta-regression analysis with the 400 studies controlling for the presence of water and then we repeated the meta-regression estimation focusing only on the 93 farm level water studies.

The descriptive analysis showed that of the 862 total cases, 581 come from parametric and 281 from non-parametric models, 509 observations come from stochastic and 353 from deterministic frontiers. The descriptive statistics for the 192 farm level water cases show that 119 come from parametric and 73 from non-parametric models, while 118 are from stochastic and 74 from deterministic frontiers.

The Average Mean Technical Efficiency reported (AMTE) is 74.8% for all studies, 75.2% for non-water and slightly lower at 73.4% for water studies. The difference between water and non-water studies is not statistically significant. Statistical tests for the null hypothesis that AMTE for non-water and water studies are the same across various methodological dimensions (e.g., type of frontier model, type of data, functional form, technology representation) revealed only a few statistically significant differences.

We also conducted statistical tests of AMTE for various groupings according to geographical region, income category and product type and again found few statistically significant mean differences between water and non-water papers. The data shows that AMTE for water papers is significantly higher than for non-water in W. Europe and Oceania (83.9% vs. 76.4%). A similar pattern is observed for UMICs where AMTE for water papers is 73.2% compared to 66.7% for non-water papers. Another statistically significant mean difference is for LICs where the AMTE is almost nine percentage points higher for non-water at 78.7% compared to 69.8% for water papers. Overall however, simple tests of means show only a few statistically significant mean differences when comparing water with non-water papers.

We then classified the 108 water papers into five groups (I-V), and in some cases into additional subgroups, depending on how water is introduced in the models. **Group I** is irrigation containing the largest number of studies at 75 and is further subdivided into three sub-groups (A, B and C) depending on how the water variable used to capture irrigation is measured. Group IA studies use quantity (56 studies) further subdivided into five classes: 1-Quantity of Water used; 2-Hours of Irrigation; 3-Number of Irrigations, Index, or Irrigation Expenses; 4-Percent of Land Irrigated; and 5- Land Area Irrigated. Group IB (9 studies) uses a binary Yes/No irrigation indicator; and Group IC (10 papers) combines a continuous measure and a dummy. **Group II** includes 6 papers that use precipitation as a continuous or dummy variable. **Group III** combines measures of both irrigation and precipitation (13 papers); **Group IV** relies on stochastic distance functions (5 articles); and **Group V** consists of 9 papers that use data at a level of aggregation higher than a farm. The focus of this paper is on farm level studies so Group V was considered

only in the descriptive analysis of water papers but not in the meta-regressions.

A comparison of the AMTE for each of the groups and sub-groups clearly shows a great deal of variability in the AMTEs which suggests that the way water is defined in the various studies has a considerable effect on the resulting TE scores. The lowest AMTE is 51.0% for Group 5. By contrast, the highest AMTE is 91.4% for Group I-A2, which corresponds to the 5 studies that use hours of irrigation followed, by 81.1% for Group IA-5 with 3 studies where the relevant variable is land area irrigated. These last two groups contain very few studies. The next value is 79.9% for the 21 studies in Group IA-3 that includes number of irrigations, index measures or irrigation expenses. The AMTE for all of Group I, i.e. for all 75 studies that incorporate quantity of water in the models, is 76.3%, and is the highest number compared to the other four groups.

The data shows the countries most frequently studied in terms of TE and water are India with 14 studies, followed by China and Pakistan with 9, Bangladesh with 7 each, and Australia, Ethiopia and The Philippines with 6. An aggregation according to the main focus pursued by water studies shows that the dominant focus is irrigation water use efficiency (IWUE), along with TE, AE, EE and Scale Economies both with 17 studies, followed by Productivity with 11. Another interesting feature has to do with how water is included in the model and here we have four options: only in the frontier; only in the inefficiency effects; in both the frontier and the inefficiency part of the model; and the fourth includes primarily studies where separate models that compare different models, with/without water are estimated and examined. A typical example of this last option is to estimate separate models for irrigated and rainfed farms. The respective number of cases for these four options is: 128; 30; 13; and 21.

A few studies present Irrigation Water Use Efficiency (IWUE) with an overall mean value equal to 46.4%. This means that on average, farms could produce the same level of output with roughly half of the water actually applied. This is an important indicator but is only reported in 9 studies so it is difficult to generalize; but, this suggests an important area for future work. Another set of informative measures provided by several studies are farm output response measures with respect to different variables including partial elasticity of production with respect to: the volume of water use for irrigation, irrigation expenditures, irrigation hours, number of times a field is irrigated, irrigated land, and some other indicators expressed as percentage and in a couple cases as the difference in the marginal value product of irrigated and rain-fed land. The evidence presented for all these response indicators reveals clearly that irrigation has a positive and significant effect on output.

Surprisingly, only two studies report shadow values for water, which is a measure that has important economic meaning. The computation is straightforward particularly when volumetric measures of water are incorporated in the specification and estimation is done with a parametric model. Again, this suggests an important area for future work and something that could be done easily along with IWUE provided the appropriate data is available.

Fractional Regression Models (FRM) were then used to estimate MTE as a function of a number of methodological attributes of the papers for all studies and then separately for water studies. These attributes include methodological variables, data characteristics, location, product type and how water is incorporated into the water studies. FRM was chosen because it is an approach well suited for cases where the dependent variable consists of fractional data, i.e., defined on the unit interval.

A few alternative specifications were tested for all studies and the water studies data sets and the preferred alternative for both data sets includes regional effects (unrestricted model). The methodological approaches (stochastic production frontier versus other; parametric versus no parametric) and type of data (cross sectional versus panel data) significantly affect AMTE in the same direction for both the all data and for water studies. Parametric models and cross sectional data on average yielded lower levels of MTEs while SPF approaches showed higher ones.

Finally, a dummy variable for Water was included in the FRM for all data and the results show no statistically significant association between Water and MTE. However, in the FRM model for water papers the way the water variable enters in the model affects significantly the results.

A critical aspect in evaluating the contributions of the papers reviewed has to do with how water is treated in the analysis. There is a large degree of variability going from papers that barely mention water and do not focus the analysis on it to those whose specific objective is to examine the role of irrigation in farm efficiency and productivity. There is also considerable variability in the methodologies used going from DEA models to stochastic directional distance functions.

Another important source of variability in the studies reviewed concerns the definition of the water variable and here there are several options such as: area of irrigated land; percent of total land irrigated; quantity of water used ( $m^3$ , ml); distance from the farm to the source of water; use of irrigation (yes/no dummy); rainfed vs. irrigated agricultural production; type of irrigation system (e.g., improved versus traditional; sprinklers; well type); and irrigation related expenses.

The papers reviewed reveal that there is very little comparative evidence across irrigation systems and no benefit cost analysis based on actual farm level data. In addition, little attention has been paid to the interaction between climatic variability, especially precipitation, and irrigation. It would certainly be useful to have an understanding of the substitutability between irrigation and precipitation.

Finally, econometric models generally and efficiency analysis in particular make it possible to go only so far in identifying specific components of irrigation in farming while mathematical and economic engineering models are not able to provide estimates of actual farm responses. The merging of these approaches is something we did not find in the literature reviewed and integrated modeling approaches merit consideration.