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Economic calibrated models for water allocation in agricultural production: A review

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ABSTRACT

There is a growing need to assess the effects of policies and global changes on both water resources and agriculture. Agricultural programming models are adequate to study this topic as their functional forms and calibration capacities make them suitable to represent real agricultural production systems and explicit the link between water and production. We present a review of the research on agricultural economic programming models that represent water demand and allocation among farming activities for different problem settings. The different types of models are discussed and particularly the integration of water into the production function so as to reflect the agronomic response of yields to varying levels of water. Uncertainty and risk integration as well as spatial and temporal scale issues are reviewed as they are determining to model results in a science support to policy perspective. A research agenda for future research in this field is provided.

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Contents

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1. Introduction

There is a growing need to assess the effects of policies and global changes on both agriculture and water resources. The challenge for economists is to adequately understand and represent the behaviour of farmers with respect to water use and allocation among crops in order to assess the economic impacts and the adaptations that might be implemented by farmers in reaction to policies and or changes in water availability such as those induced by climatic change.

Agricultural economics has developed various approaches based on production economics to model the allocation of inputs, and the derived demand for inputs, including water and nitrogen by representing the agricultural production process and thereby the observed allocation of scarce resources. There are various empirical economic methods available for representing agricultural water allocation and demand: programming models, econometrics (Moore et al., 1994; Hendricks and Peterson, 2012), field experiments (Bouarfa et al., 2011), and also Data Envelopment Analysis (Frija et al., 2011), hedonic pricing (Faux and Perry, 1999) and contingent valuation (Storm et al., 2011). The most commonly implemented approaches are econometrics and programming models. This paper reviews the literature on economic calibrated programming models (PM) for water allocation in agricultural production with a water management and policy perspective, which we will call WPM (Water – Programming Models). In addition to providing a detailed and critical analysis of published work, its aim is to provide a comprehensive guide for developers as well as discuss the important modeling choices and challenges relative to water use by farming in the context of global changes.

The objective of the modeler here is to represent the water use and allocation by farming either to analyse it or be able to simulate the effect of particular conditions in an explorative or forecasting perspective. Programming models can be defined as a system of equations including an objective function and a set of constraints including resource constraints as a minimum. The explicit objective function accounts for revenues and costs. Revenues are calculated as quantities per prices, and quantities are calculated with a given explicit production function. A crop-specific production function ensures that the inputs e.g. water are allocated to one activity in particular, which is interesting for the environmental or externality analysis of farming systems; and this might not be the case with econometric models. The normalized structure of PM models should ensure the relevance of out-of-sample simulations which is a major advantage when addressing the adaptation of farming to changing constraints. This is not the case with econometric models that are estimated based on observed data but with little or no constraint on the functional form (pure *positive* approach) which might not be valid when simulating policies that are out of the range of previously observed situations (so called "out of sample" issues) (Lichtenberg et al., 2010). However both PM and econometrics are and could be used in complements for studies on water use and allocation by farming. Chavas et al. (2010) contextualise these approaches in production economics of the farm. An historical perspective of programming models is given in Appendix 1.

WPM are used in various problem settings that can be classified in three types (i) adaptation of farming to policy including instruments such as irrigation water pricing or water markets, (ii) impact assessment of water scarcity, drought and climate- or global change on agriculture, (iii) on-farm technology adoption. These applications are detailed in Appendix 2. They offer new challenges in terms of model calibration in order to have realistic model responses. The calibration challenge is to correctly represent shifts of the supply curves due to changes (i) in resource use constraints or costs induced e.g. by a change in policy or in the natural resources availability, (ii) in the production function (link between resource use and output) due e.g. by climate change, whereas, classically, programming models have been used to represent movements along the supply curve (changing prices & quantities). These relative new applications induce new needs for calibration and require mobilizing data such as yield responses to water to calibrate adequate production functions. This also demands interdisciplinary work in particular with agronomics. As such developing programming models in the perspective of water use by farming require several choices that are of outmost importance in terms of impact on the results and on consequent policy recommendations. It still offers research questions that will be developed in this review.

WPM are sometimes associated with hydro (geo)logical, reservoir operation or crop growth models to better represent biophysical processes that influence economics or to assess the externalities of farming on water resources (water quality or flow/quantity) and to form hydro-economic models (see e.g. Harou et al. (2009)). This is why such a review will be of use to economists and none economists involved in the broader field of research of agricultural water management. WPM can also be implemented within a larger modelling framework with partial or general equilibrium models (e.g. Dudu and Chumi (2008)). From a practical point of view, programming models are now often developed in the *Generic Algebraic Modeling System (GAMS)* (Brooke et al., 1996) which is a powerful optimization software that operates non-linear solvers (e.g. CONOPT) necessary for latest developments of WPM. GAMS is used for calibration as well as simulation and can interact with

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