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Modeling the economic benefits and distributional impacts of supplemental irrigation

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ABSTRACT

Standard hydroeconomic policy models are usually applied to areas in the world where precipitation is very low and crops are fully irrigated. As such, these models pool the annual stored precipitation plus other water supplies and assume that this total water supply can be allocated by time and place. This water pooling approach treats precipitation and irrigation water as fully substitutable. In many irrigated areas, however, a significant amount of water used by crops comes from precipitation. In fact the majority of the global irrigation systems are supplemental to rainfall and, in this context, precipitation and water stored in reservoirs are not fully substitutable. By using primary data from a watershed in Brazil, where precipitation and supplemental water use occur, this paper shows that standard models under-estimate the predicted drought impacts. The paper investigates this issue by setting up two model specifications of regional net-revenue maximization based on a calibrated economic programming model integrated with a mass balance hydrologic model. In one model the substitution between precipitation and irrigation water is explicitly formalized and in the other precipitation and irrigation water are aggregated together in a single water supply. The models are used to estimate and predict the short-run impacts of precipitation cuts on irrigation reservoir levels and the impacts of lower irrigation water supply on farmers' agricultural income. In comparing the results, we find that the standard aggregated hydroeconomic model under-estimates losses in expected returns to farmers and also results in less variability of returns under stochastic rainfall.

1. Introduction

Farmers are the dominant water users worldwide and compete for water resources which are heterogeneously distributed across time and space. Changes in water availability may affect agricultural income, productivity and cropping strategies and have potential environmental effects for the hydrologic system as a whole. Therefore, an accurate evaluation of how farmers may react to different water resource policies or environmental scenarios (e.g.: temperature, water supply, precipitation regimes etc.) is important for policy makers and can help to shed light on ways to increase farmers' income and to alleviate poverty in many parts of the rural world. This paper questions whether the simpler hydroeconomic models that treat seasonal precipitation as part of the total irrigation water supply are sufficiently accurate for policy analysis in

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regions where irrigation is supplemental to seasonal precipitation.

Empirical modeling of the effects of alternative water allocation regimes on agricultural communities and farmers' reactions is complex and by definition interdisciplinary. Several surveys of studies that develop models involving economics, hydrology, ecology and agronomy have been published [13,1]. Although all the studies attempt to integrate different disciplines, each one focuses on a particular issue. For example, Pulido-Velazquez [28] deals with water scarcity values estimation, Rosegrant et al. and Cai et al. [30,3] focus on salinity and water availability for irrigation; Cai and Wang and Cai [4,5] on the optimal strategies for water allocation among competing sectors and Harou [12] on water pricing, irrigation and institutional constraints; Loucks [23] focuses on the integration of economics and ecology and Guan [10] on the relationship between economic activity and water quality; and finally Krol et al., Medellín-Azuara et al., and Harou et al. [20,25,11] focus on the estimation of drought and climate change impacts on water availability for agriculture.

One of the aspects these studies have in common is that their models are mostly applied to arid or semi-arid regions of the world where rainfall during the growing season is minimal or absent. Water available for irrigation in an arid or semi-arid region predominantly comes from out-of-season precipitation, or is imported from regions where precipitation occurs through a system of man-made channels, rivers, groundwater aquifers. For example, water from Northern California and the Sierras is used to irrigate the Central Valley and Southern California regions. Similar transfers are found in Spain, Chile, Israel and Australia. As a consequence, in their modeling approaches precipitation and irrigation water from water bodies, reservoirs and aquifers are not treated separately in the production modeling process.

In many areas of the world, however, precipitation occurs during the growing season, and a significant amount of water used for crop production comes from precipitation that falls directly onto the crops. Rost et al. [31] show regions of the world where there is a significant increase in net primary productivity due to irrigation. The largest areas under irrigation are located in monsoon climates and Central American regions where irrigation systems are supplemental to seasonal rainfall. During the rainy season in these areas, it is common for farmers to experience several days without rainfall. Water storage in surface reservoirs or underground aquifers provides a supply of irrigation water in the event of a drought. When precipitation is lower than expected, farmers will, *ceteris-paribus*, react by taking more water from surface or groundwater sources to irrigate their crops. That is, precipitation and surface (or groundwater) water are substitute agricultural inputs.

Our point is that the predicted drought impacts from models that ignore the restrictions implicit in precipitation and the surface (or groundwater) substitution relationship for seasonal rainfall are likely to under estimate the severity of drought. For instance, if the impacts of a reduction in precipitation on farmers' income are estimated considering only the changes in the volume of the reservoirs or other water bodies, the impacts may appear to be minimal if the amount of water in the reservoir is not a binding constraint on deliveries. If however, the model allows for the fact that a reduction in precipitation may induce farmers to replace rainfall with water from reservoirs, the impacts of drought on income may be significant even if the reservoir's volume is not binding, since access to irrigation water from the reservoirs is costly due to water fees, pumping costs, and system maintenance costs.

One way to deal with this issue is to include precipitation as an explicit input in the production system as in [24,34]. Although these two studies have made important contributions to the literature, gaps remain. In particular, the integration of uncertain rainfall with irrigation supplies in a formal production function. The models used in this study build and improve on these earlier models in that the calibration of water use is now exact, and the stochastic nature of precipitation and its effect on income risk is explicitly modeled. In this context, this paper measures the importance of correctly specifying precipitation by setting up two alternative simulation models of regional agricultural production. One where the substitution between precipitation and surface water is explicitly formalized and another where precipitation and irrigation water are aggregated together in a single water supply quantity, as is generally done in the models applied to arid and semi-arid regions cited above.

Both models are integrated with a hydrological model which estimates the amount of water available for irrigation and precipitation in time and space. The agricultural production models and the hydrological model are externally coupled and the resulting hydroeconomic models are used to estimate and predict the short-run impacts of precipitation cuts on irrigation reservoir levels and the impacts of lower irrigation water supply on farmers' agricultural income. As in [24], the focus is on the Buriti Vermelho river sub-basin, situated in the Federal District, near Brasília. The database is based on primary data collected from interviews performed during the dry and wet seasons of the 2007/2008 agricultural year. More details are provided throughout the paper sections below.

2. Methodology

In this paper, we develop an agricultural production model (hereinafter termed the economic model) using a mathematical programming approach and apply it, using primary data from the farm community of Buriti Vermelho located in a watershed in the São Francisco River Basin in Brazil. The model is calibrated to reflect the coexistence of irrigated and rainfed agriculture in the region. Moreover, it takes into account seasonal precipitation levels as one of the arguments of the crop specific multi-input, multi-output production functions. In this model, water is introduced through two sources: from the surface water storage system which is allocated by the farmer, and from seasonal precipitation that falls directly onto the crops. The model is specified so that farmers adjust their product