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Income and irrigation water use efficiency under climate change: An application of spatial stochastic crop and water allocation model to Western Uzbekistan

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A B S T R A C T

A decline in water availability due to rising temperatures and growing water demand presents significant and unique challenges to agricultural producers in Uzbekistan. This study investigates the impact of climate change on farm revenues and water use efficiencies in Western Uzbekistan. A spatially explicit stochastic optimization model is used to analyze crop and water allocation decisions under conditions of uncertainty for irrigation water availability in the area for the first time.

Results show farmers' income could fall by as much as 25% with a 3.2 °C temperature increase and a 15% decline in irrigation. Farmers located in the tail end of the irrigation system could lose an even greater share of their revenues. A more conservative increase in temperature could increase farmer income by as much as 46% with a 2.2° temperature increase and only 8% decline in irrigation water since some crops benefit from extended vegetation periods. Under both pessimistic and optimistic scenarios, environmental challenges due to shallow groundwater tables may improve associated with enhanced water use efficiency.

1. Introduction

The gradual disappearance of the Aral Sea in Central Asia has been caused by unabated irrigation of water intensive crops. While this trend began during the Soviet Union, it has continued largely unchanged since the collapse of the USSR. The extent of the crisis has gained international attention. A wide range of studies have investigated how water management policies and practices impact the environment, the economy and the health and livelihoods of those in the region (Micklin, 1988; Glantz, 2005; Bucknall et al., 2003; Bekchanov et al., 2010). The many, multi-dimensional problems surrounding the agricultural sector are increasing during the recent years. Coping mechanisms related to market production and risk have been further complicated by unpredictable and sudden changes in the climate (Bobojonov and Aw-Hassan, 2014; Bobojonov and Lamers, 2008).

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In Uzbekistan, farmers do not own the land, instead it is leased from the government (Djanibekov et al., 2012). Decision-making regarding land allocation and water use is heavily influenced by government directive (Veldwisch and Spoor, 2008). For example, 60–70% of agricultural land must be allocated to the two main state crops: cotton and wheat. Farmers are responsible for ensuring quotas on state crops are met; therefore, they must make decisions around the timing of planting according to field location within the irrigation system.

In flood and furrow irrigated systems, such as those in Uzbekistan, unpredictable weather patterns increase farmers' risk depending on where they are located within the irrigation system. Assessing the risk level is complex as it depends not only on the location within the irrigation system, but also on farm specialization, levels of market risks, temperature fluctuations, soil parameters (e.g. texture, fertility) and other weather uncertainties. Consideration of these multiple aspects requires the use of a spatial crop and water allocation model. A number of spatial bio-economic models exist which analyze the impacts of climate change on agricultural production worldwide (e.g. Busch, 2006; van Meijl et al., 2006). Some spatial models that consider biological and economic fluctuations on irrigated agriculture were particularly developed in northwest Uzbekistan (e.g. Sommer et al., 2011; Djanibekov et al., 2013), but these models do not incorporate risk into the decision analysis. The inclusion of risk in spatially explicit models greatly improves the analysis of farmers' decision-making, especially under climate change scenarios.

Studies over the last two decades prioritized the investigation of water productivity and increased efficiency (e.g. Abdullaev et al., 2007; Bekchanov et al., 2010). These studies were largely motivated by environmental problems. However, in recent years, studies concentrate on the importance of finding options to cope with the negative consequences of climate change (e.g. Mirzabaev, 2013; Bobojonov and Aw-Hassan, 2014). Therefore, increasing water use efficiency as well as identifying risk management options to cope with climate risks is becoming an important issue in the region. Yet, there are no studies available which analyze the impacts of climate change on income and water use efficiency. Therefore, this study attempts to analyze changes in income and water use efficiency under climate change for the first time. The integration of bio-physical and socio-economic aspects in the modeling framework provides for an in-depth analysis of complex problems in the irrigated farming systems of Uzbekistan. Although the integration of geographical and economic data in the spatial optimization model is becoming important in many land allocation models used worldwide (e.g. Briner et al., 2012; Meiyappan et al., 2014; Chen et al, 2015), risk management aspects in crop and irrigation water allocation at farm level is rarely discussed.

The contribution of this study to the existing literature is twofold. First, we discuss the possibilities and challenges of incorporating stochastic production functions into a crop and water allocation model under conditions of data scarcity at the farm level. Secondly, the developed model is used to test fluctuations in farm income under varying climate change scenarios; this is done while considering the adaptive capacity of the decision makers and the impact of their activities on the environment of the irrigated system. Thus, the scenario simulations contribute to the discussions about climate change impacts on income and water use efficiency at regional level.

2. Theoretical framework and methodology

The approach used in this study has two main characteristics: first, it explicitly considers the risk associated with decisions on crop allocation and irrigation. Since the risk level depends on the actually implemented cropping pattern and irrigation strategy, the choice of optimal actions requires that the decision makers' attitudes towards risk are considered as well. To accomplish this, a risk programming framework is used. Second, this study integrates bio-physical and socio-economic relationships into a spatially explicit model. Both characteristics are described in the following sections.

2.1. Risk programming framework

The most common and still widely accepted approach for assessing the impacts of risky choices on a decision maker's wellbeing is by means of expected utility (Hardaker and Lien, 2005). This requires that all possible outcomes of the risky prospect be translated into utility measures to compute the expected utility. Faced with a choice amongst a set of risky prospects, the expected utility hypothesis states that the prospect with the highest utility is preferred. The expected utility (EU) can be retranslated into a monetary measure, i.e. the certainty equivalent (CE), through the inverse of the utility function. The CE represents the amount of money a decision maker with a given utility function would rate as equivalent to the uncertain outcome of the risky prospect (cf. Robison and Barry 1987, p. 23ff). Ranking prospects by CE is equivalent to ranking them by EU.

By definition the CE equals the expected return E(y) minus the risk premium π, i.e. CE = E(y)−π. For the latter, Pratt has derived the approximate relationship $\pi = 1/2R[E(y)]\,V(y)$, where R[E(y)] indicates the decision maker's absolute risk aversion measured at the expected value E(y) and V(y) denotes the variance (cf. Robison and Barry 1987, p. 34). The CE is expressed in Eq. (1):

$$CE = \mathrm{E}(y) - \frac{1}{2}\mathrm{R}[\mathrm{E}(y)]\,\mathrm{V}(y) \tag{1}$$

Eq. (1) is well-known as the value-variance (EV) approach. The conditions under which the EV approach yields results consistent with the more general EU model have been worked out by several authors (cf. Meyer, 1987; Robison and