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Analysis

Efficient water management policies for irrigation adaptation to climate change in Southern Europe

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ABSTRACT

This paper evaluates economic and environmental effects of two incentive-based water management policies to address climate change impacts on irrigated agriculture: water markets and irrigation subsidies. A Southern European case study assesses farmers' long and short-run adaptation responses under climate change and policy interventions with a discrete stochastic programming model. Results indicate that climate change will likely have negative impacts on irrigation activities and water-dependent ecosystems in Southern Europe. However, the severity of impacts depends on government policy settings and farmers' adaptation responses. The comparison between water market and irrigation subsidy policies shows the advantages of water markets over irrigation subsidies in terms of both private and social benefits. These findings could guide policymakers on the design of efficient water institutions and policies to address climate change in the irrigated agriculture of Southern Europe.

1. Introduction

Climate change is a major challenge for sustainable agricultural production in the coming decades in arid and semiarid regions worldwide. In those regions, climate change will likely increase temperature and evapotranspiration, reduce precipitation and snowmelt, and modify precipitation patterns, impacting negatively on water resources, irrigated and dryland agriculture, and water-dependent ecosystems (IPCC, 2014). This challenge will be difficult to manage in a context of rising world food demand and growing competition between consumptive and environmental water uses (Elliot et al., 2014).

The South of Europe is one of the arid and semiarid regions where the vulnerability of irrigated agriculture to climate change is expected to be especially strong (IPCC, 2014). Climate change projections for this region suggest significant reductions in freshwater supplies from surface and groundwater resources, and increases of the frequency and longevity of extreme drought events (Lehner et al., 2006). The reductions of water availability and reliability in Southern Europe will be combined with increases of irrigation demand (Jimenez et al., 2014), leading mostly to reduced crop yields and shifts of some cultivation activities northward (EEA, 2012).

Irrigation adaptation to climate change in Southern Europe has become one of the main objectives of the European water and agricultural regulations, such as the Water Framework Directive and the 2014–2020 Rural Development policy (EC, 2009, 2013). The evaluation of the effectiveness of existing adaptation policies and whether additional adaptation policies are needed is of particular interest for policymakers and stakeholders in the region. The response to these issues requires the development of studies that provide a better understanding of the economic and environmental impacts of climate change on irrigation, the adaptation policy alternatives, and the cost implications.

Many studies in the literature have addressed the issue of irrigated agriculture adaptation to the foreseeable climate change impacts. A wide variety of adaptation options has been proposed. Farm-level adaptation options such as improving irrigation scheduling, crop mix change, use of new crop varieties, and improving irrigation efficiency seem to contribute significantly to adaptation (Howden et al., 2007; Reidsma et al., 2010; Leclere et al., 2013). However, a string of the literature calls for a reconsideration of water institutions and policies used at present, and the implementation of incentive-based policies for more effective uptake of adaptation (Zilberman et al., 2002; Booker et al., 2005). Two popular incentive-based policies to address irrigation adaptation to climate change which are widely considered in the literature are water markets and public subsidies for investments in efficient irrigation systems.

Water markets seem to be a good option to smooth the economic impacts of climate change (Calatrava and Garrido, 2005; Gomez-Limon and Martinez, 2006; Gohar and Ward, 2010). Estimations of

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water market benefits during the last drought in the Murray–Darling basin of Australia, which is at present the most active water market in the world, are close to 1 billion US dollars per year (Connor and Kaczan, 2013).[1] A challenge to water markets is the third party effects such as the environmental impacts. Water markets reduce streamflows because previously unused water allocations are traded, and also because gains in irrigation efficiency at parcel level reduce return flows to the environment (Howe et al., 1986; Qureshi et al., 2010). Another worrying effect is the large surge in groundwater extractions, as shown in the last drought in the Murray–Darling basin.[2] These environmental impacts reduce the benefits of trading and increase adaptation costs. For instance, water authorities in Australia are implementing very expensive public programs on infrastructure upgrading investments and environmental water buyback, in order to recover water for the environment in the Murray–Darling basin (Wheeler et al., 2014).

Public policies that provide subsidies for investments in efficient irrigation systems (irrigation modernization) are considered also important options for climate change adaptation (Cazcarro et al., 2011, Graveline et al., 2014; Varela et al., 2014). The reason is that modernization reduces land abandonment, facilitates the adoption of diversified and high-value cropping patterns, and improves crop yields, leading to an increase in the value of agricultural production (Perry et al., 2014). In addition, modernization supports rural development and improves water quality (Playan et al., 2013). However, contrary to widespread expectations, modernization increases water depletion through enhanced crop evapotranspiration and reduction of return flows. These flows contribute to in-stream flows and groundwater replenishment that could be essential for downstream consumptive and environmental uses (Huffaker, 2008; Perry et al., 2014).

The above-mentioned studies analyze the advantages and limitations of water markets and irrigation subsidies in detail. However, there are no studies in the European context that provide a comparative analysis of the effectiveness of these two incentive-based policies for irrigation adaptation to climate change, and the extent to which farmers could realize potential adaptation opportunities. To address this gap in the literature, this paper presents a stochastic modeling framework to analyze the contribution of these two incentive-based policies to adaptation, and the economic and environmental tradeoffs between these policies.

The lower Jucar basin in Spain is chosen as a representative basin for Southern Europe. This basin is a good experimental field for studying irrigation adaptation possibilities to the impending climate change. The Jucar River is under severe stress with acute water scarcity and near zero mouth outflows, and severe ecosystem degradation.

Possibilities for water markets and irrigation subsidies as potential policy instruments for irrigation adaptation to water scarcity are accommodated in Spanish policies. Formal water trading was instituted in Spain in 1999 by the Law 46/1999. However, there have been very few transactions of water trading in the last decade. Many barriers should be overcome in the future to improve the performance of water markets in Spain (Calatrava, 2006). Irrigation subsidies were introduced by the Spanish National Irrigation Plan in 2002. The plan promoted the modernization of irrigation infrastructure in order to increase the competitiveness of the agricultural sector and to reduce water use. The objective was to modernize 2 million ha in a period of 10 years (MARM, 2002). Total investments have been around 7 billion €, financed by private and public funds.

The paper is organized as follows. First, the lower Jucar basin is described in Section 2, followed by the explanation of the modeling framework in Section 3. Climate change and adaptation scenarios are presented in Section 4, and the simulation results in Section 5. Finally, Section 6 concludes with the summary and policy implications.

[1] Potential water market benefits in California during drought have been also estimated at 1 billion US dollars per year (Medellin et al., 2013).

[2] Blewett (2012) indicates that groundwater extractions between 2002 and 2007 were seven times above the allowed limits placed on groundwater users.

2. Case Study Area: The Lower Jucar Basin

The lower Jucar basin is located in the region of Valencia in Spain (Fig. 1). This basin has an irregular hydrology, characterized by recurrent drought spells and normal years with dry summers. The irrigated area in this basin expands over 102,000 ha, with water extractions for irrigation close to 980 Mm^3 per year (CHJ, 2014).

The analysis undertaken in this paper focuses on irrigation activities in the four major irrigation districts in the basin: Acequia Real del Jucar (ARJ), Escalona–Carcagente (ESC), Ribera Baja (RB), and Canal Jucar–Turia (CJT). These districts use almost 80% of total extractions in the basin. The ARJ, ESC and RB districts use only surface water resources, while the CJT district uses both surface and subsurface water resources. The major crop grown in the four districts is citrus, representing between 40 and 90% of the irrigated area. Rice is an important crop in the ARJ and RB districts, covering 20 and 60% of the irrigated area, respectively. Other crops grown in the four districts include corn, tomato, watermelon and peach. The most important irrigation systems used in the districts are flood and drip systems.

The lower Jucar basin includes the Albufera wetland, which is one of the most important aquatic ecosystems in Southern Europe. The Albufera is cataloged in the RAMSAR list, and declared a special protected area for birds. It receives water mainly from the return flows of the ARJ and RB districts. Other flows originate from the neighboring Turia basin, and from the discharge of untreated and treated urban and industrial wastewaters in the adjacent municipalities.

The growth of water extractions in the upper Jucar and the severe drought spells in recent decades have triggered considerable negative environmental and economic impacts in the basin. For instance, water available to the ARJ district has been reduced substantially in the last 40 years. Consequently, the dwindling irrigation return flows have caused serious problems to the Albufera wetland. In addition, the outflows of the Jucar River to the Mediterranean Sea are mostly below 1 m^3/s, which is very low compared with other major rivers in the region (Garcia-Molla et al., 2013).

3. Modeling Framework

There is a growing body of economic literature that analyses irrigation adaptation to climate change. Two major approaches are widely used. One approach is mathematical programming models (both partial and general equilibrium models) that link biophysical (hydrologic, agronomic, and environmental) and economic components to simulate farmers' choices of crop mix, technologies, and resources for different climate scenarios, allocation rules, institutional arrangements, and policy interventions (Connor et al., 2012; Medellin et al., 2013; Calzadilla et al., 2014). The alternative approach is econometric models that represent observed responses of farmers to past climate conditions under existing policies and institutions. These models are then used to estimate the effects of changes in climatic and policy variables (Zilberman et al., 2002; Mendelsohn and Dinar, 2003; Wheeler et al., 2013). Generally, mathematical programming models are computationally intensive, while econometric models are data intensive.

The modeling approach used in this paper is discrete stochastic programming (DSP). The advantage of using DSP models compared to other modeling techniques is their ability to capture sources of risk that influence the objective function and the constraint set, and also allowing for a multi-stage decision process in which the decision makers' knowledge about random events changes through time as economic choices are made (Rae, 1971). DSP has been previously used in many studies in the literature to analyze different water management problems. Some examples are the measurement of forgone irrigation benefits derived from rural to urban water transfers under uncertain water supplies (Taylor and Young, 1995), the impacts of reducing pumping in the Edwards aquifer in Texas (McCarl et al., 1999), and the assessment of water market outcomes under uncertain water