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

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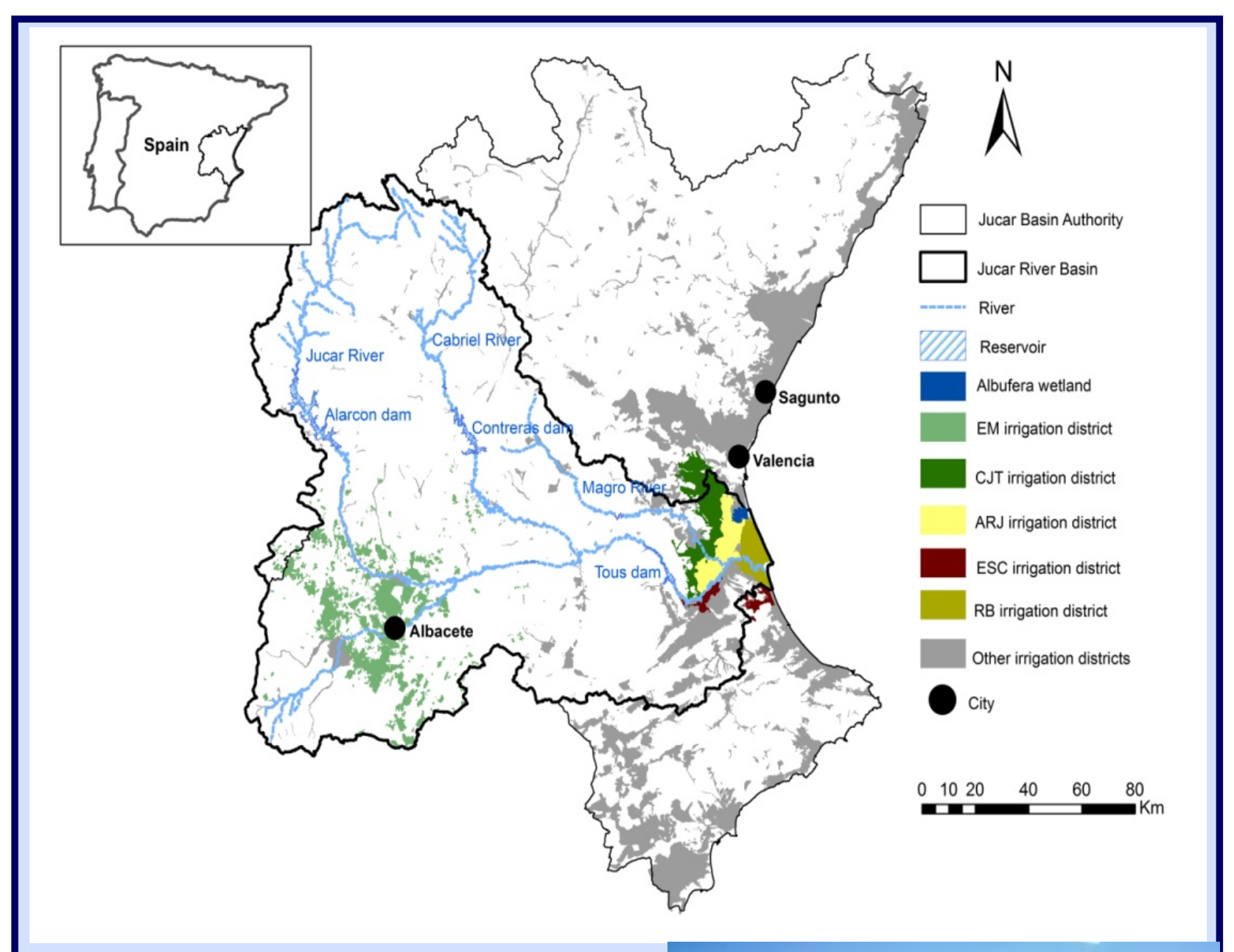
INTRODUCTION

- Climate change is a major challenge for sustainable agricultural production in the coming decades in arid and semiarid regions worldwide
- 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
- One important question whose answer can inform policy debates focuses on the identification of potential adaptation possibilities of irrigation to the impending effects of climate change
- This study presents a stochastic modeling framework to analyze the contribution to adaptation of two incentive-based policies, water markets and irrigation subsidies, together with several on-farm adaptation measures, and the economic and environmental tradeoffs between these policies

STUDY AREA: JUCAR BASIN



The map shows the area drained by the Jucar River with the main tributaries (Magro and Cabriel Rivers), reservoirs (Alarcon, Contreras, Tous), cities (Valencia, Sagunto, Albacete), Irrigation districts (EM, CJT, ARJ, ESC, RB), and ecosystem (Albufera wetland)

METHODOLOGY

- Farmers' decisions are modeled using a two-stage stochastic programming optimization
- First stage: long-run choices of capital investment in cropping and irrigation systems. This investment is the response to the expected climate change scenario made prior to the knowledge on annual water inflows, which is a stochastic variable
- Second stage: short-run (annual) choice of variable input levels, including irrigated and fallowed areas, and irrigation water applied to crops, which are determined after stochastic annual water inflows are known (states of nature). This short-run choice is conditional on the fixed capital investment level chosen in the first stage

Mathematical formulation

Objective function

$$Max\ \Pi_k = \left[-\sum_{i} fcc_{i,k} - \sum_{i,j} fic_{i,j,k} \right] \cdot A1_{i,j,k}$$

First stage irrigation and crop investment costs

$$+\sum_{s} pr_s \cdot \sum_{i,j} p_i \cdot Y_{i,j,k,s}\left(W_{i,j,k,s}\right) \cdot A2_{i,j,k,s}$$

Second stage Crop revenue

$$-\sum_{s} pr_s \cdot \sum_{i,j} pw_k \cdot IW_{i,j,k,s} \cdot A2_{i,j,k,s}$$

Second stage variable costs

$$-\sum_{s} pr_s \cdot \sum_{i,j} vc_{i,k} \cdot A2_{i,j,k,s}$$

Second stage irrigation water costs

$$-\sum_{s} pr_s \cdot \sum_{per,j} yp_{per,j,k} \cdot AF_{per,j,k,s}$$

Second stage perennial crops land fallowing penalty

The objective function is subject to the following constraints:

$$\sum_{i,j} A1_{i,j,k} \le landavail_k \quad \forall k$$

Land availability constraint in first stage

$$A2_{i,j,k,s} \le A1_{i,j,k} \quad \forall i,j,k,s$$

Land availability constraint in second stage

$$AF_{i,j,k,s} = A1_{i,j,k,s} - A2_{i,j,k,s} \quad \forall i,j,k,s$$

Land fallowing accounting equation

$$\sum_{i,j} IW_{i,j,k,s} \cdot A2_{i,j,k,s} \le wateralloc_{k,s} \quad \forall k,s$$

Water availability constraint in second stage

$$Y_{i,j,k,s}\left(W_{i,j,k,s}\right) = a_{i,j,k,s} + b_{i,j,k,s} \cdot W_{i,j,k,s} + c_{i,j,k,s} W_{i,j,k,s}^2$$

Yield-irrigation water response function

$$\Phi_{k,s} = \left[wateralloc_{k,s} - \sum_{i,j} IW_{i,j,k,s} \cdot A2_{i,j,k,s} \right] + \left[\sum_{i,j} IW_{i,j,k,s} \cdot A2_{i,j,k,s} \cdot \left(1 - ef_{j,k}\right) \right] \quad \forall k,s$$

Environmental flows accounting equation

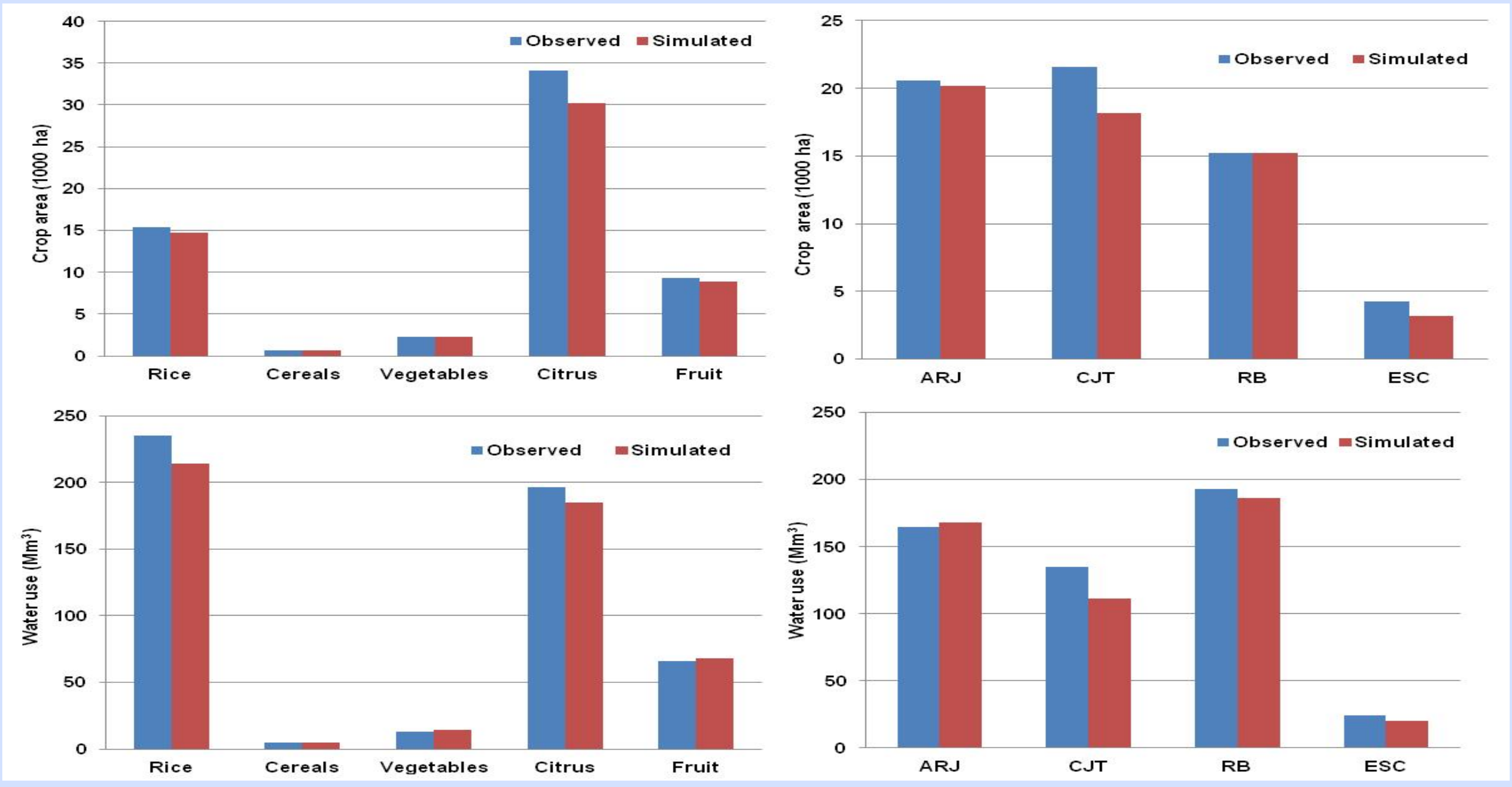
$$\Psi_s = \alpha \cdot \Phi_{ARJ,s} + \beta \cdot \Phi_{RB,s} \quad \forall s$$

Inflows to Albufera wetland accounting equation

MODEL CALIBRATION AND SCENARIOS

The model is calibrated to observed conditions using the Positive Mathematical Programming (PMP) method (Howitt 1995, Röhm and Dabbert 2003).

Results of calibration:



The model is used to analyze the following scenarios:

Two climate scenarios:
1) Current climate situation/baseline scenario
2) Climate change scenario: reduction of inflows by 32% and increase of crop irrigation requirements by 15%

Four adaptation scenarios of several on-farm and institutional adaptation measures:
1) Adaptation measures at farm-level are crop mix and irrigation system change, land fallowing, and deficit irrigation
2) Adaptation measures at institutional-level are public subsidies for investments in efficient irrigation systems on-farm (sprinkler and drip systems), and introduction of water trading

RESULTS FROM SCENARIOS

Adaptation scenarios

Adaptation possibilities	No-policy (NP)	Irrigation subsidy (IS)	Water market (WM)	Full adaptation (FA)
On-farm adaptation				
Crop mix change	Yes	Yes	Yes	Yes
Irrigation system change	Yes	Yes	Yes	Yes
Land fallowing	Yes	Yes	Yes	Yes
Deficit irrigation	Yes	Yes	Yes	Yes
Institutional adaptation				
Irrigation subsidy	No	Yes	No	Yes
Water trading	No	No	Yes	Yes

Economic outcomes of the climate and adaptation scenarios (M€)

Economic indicators	Baseline	Climate change			
		NP	IS	WM	FA
Long-run fixed costs	120.1	87.9	96.9	100.7	108.7
Short-run variable costs*	93.2	65.8	73.3	82.9	87.8
Fallow penalty	1.6	0.5	0.5	0.0	0.0
Crop revenues	278.2	197.7	219.6	238.4	256.8
Public subsidy	0.0	0.0	4.6	0.0	4.9
Farmers' profits	63.3	43.4	48.8	54.8	60.2
Environmental costs	-	8.0	10.7	11.5	12.5

- Results indicate that climate change will likely have negative effects on irrigation activities in the Jucar basin for all scenarios considered
- The extent of climate change impacts on irrigation will depend on government policy settings and farmers' adaptation responses
- Environmental costs to replace water inflows losses to the Albufera wetland increase considerably under climate change for all scenarios considered

Long-run choices by climate and adaptation scenario (ha)

Land use indicators	Baseline	Climate change			
		NP	IS	WM	FA
Irrigated land	56710	36660	43030	43035	48430
Land abandonment	0	20050	13680	13675	8280
Crop mix					
Rice	14740	6890	10085	5090	8260
Cereals	600	440	485	400	580
Vegetables	2310	2270	2290	2275	2265
Citrus	30170	18510	22170	26900	28260
Other fruit trees	8890	8550	8000	8370	9065
Irrigation system					
Flood	31980	24110	16975	32245	22770
Sprinkler	150	115	145	65	210
Drip	24580	12435	25910	10725	25450

- Irrigated land is reduced between 15 and 35% compared to the baseline scenario
- Decline in the area of rice (water-intensive and low-value crop)
- Reduce long-run capital investment in citrus to minimize both current and future yield losses
- Farmers can adopt deficit irrigation and/or purchasing water in dry years, instead of investing in efficient irrigation systems with high sunk costs

Water outcomes by climate and adaptation scenarios (Mm^3)

Water indicators	Baseline	Climate change			
		NP	IS	WM	FA
Water use	449	347	367	358	373
Unused water	94	78	58	67	53
Environmental flows	217	174	146	164	136
Inflows to Albufera	45	33	29	28	27

- Water use under climate change decreases compared to the baseline scenario, although water use increases progressively as more adaptation options are included
- Water Market and Irrigation Subsidies provide incentive to use water allocations that are left in-stream in wet years under the non-policy intervention
- Reduction of environmental flows and inflows to Albufera wetland

CONCLUSIONS

- Results indicate that climate change will likely substantially reduce farmers' profits in the absence of any policy intervention
- Losses can be reduced through the implementation of water markets and irrigation subsidy policies
- These policies provide incentives to farmers for investing in cropping and irrigation systems, reducing land abandonment, shifting towards high-value cultivation activities, and increasing water use, although farmers' behavior is different under each policy
- A deficit irrigation strategy proves to be an important response to climate change, reducing significantly farmers' losses
- Environmental flows will be reduced under climate change for all scenarios considered, generating considerable environmental costs for society
- Water market and irrigation subsidy policies further reduce environmental flows compared to a climate change scenario without any policy intervention, with larger flow reductions from irrigation subsidies than water markets
- Results suggest that the benefits of the irrigation subsidy policy are very small, especially when public subsidies and social costs of replacing lost environmental flows are accounted for. In contrast, the benefits of introducing water markets seem to be quite large, even though well-functioning water markets involve sizeable monitoring and transaction costs that are not considered in this study but require evaluation

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